Texas Instruments

Webinar

System solutions for In-Vitro Diagnostics applications

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IVD System engineer

Agenda

- IVD introduction and subsystems
- Key subsystems in IVD applications
  - Optical signal chain
    - Precision optical signal chain
    - High-speed optical signal chain (Flow cytometry)
  - Motor automation & control
  - Thermo-Electric Cooling (TEC)
  - LED and laser driving
  - Liquid level sensing
  - Electro-chemical sensing
- Q&A

Design smarter, high-performance medical systems

Imaging

Handheld imaging with highest density, multi-modal AFEs.

In-vitro diagnostics

Retail healthcare with user-accessible diagnostics technology for newer diseases & variants.

Hospital patient monitoring

IEC60601-1 compliant systems enabling patient safety, product robustness and reliability.

Home healthcare

Personalized healthcare with at-home continuous monitoring of vital signs.

Introduction for IVD applications

	END EQUIPMENT	CLINICAL USE	KEY TECHNOLOGY BLOCKS
Blood/Cell/ Fluid Analysis	Chemistry/ Gas Analyzer	-Diabetes -Lipid Panel -Lung Function	-Electrochemical Sensing Front End -Precision Optical Signal Path
	Hematology Analyzer/ Flow Cytometer	-Complete Blood Count (3/5 part) - Cell Analysis	-Precision Optical Signal Path -High Speed Signal Path -Impedance Method (Coulter) -Motor Automation
	Immunoassay	-Antibody/Virus -Pregnancy -Drug/Doping -Bacteria -Cardiac -Hormone	-Motor Automation -Precision Optical Signal Path
Molecular/ Genetic Identification	Molecular Analyzer	-Virus/Bacteria Identification	-Precision Optical Signal Path -TEC Controller -Motor Automation
	DNA Sequencer	-Genetic Sequencing -Cancer Genetics -Prenatal	-TEC Controller -Motor Automation

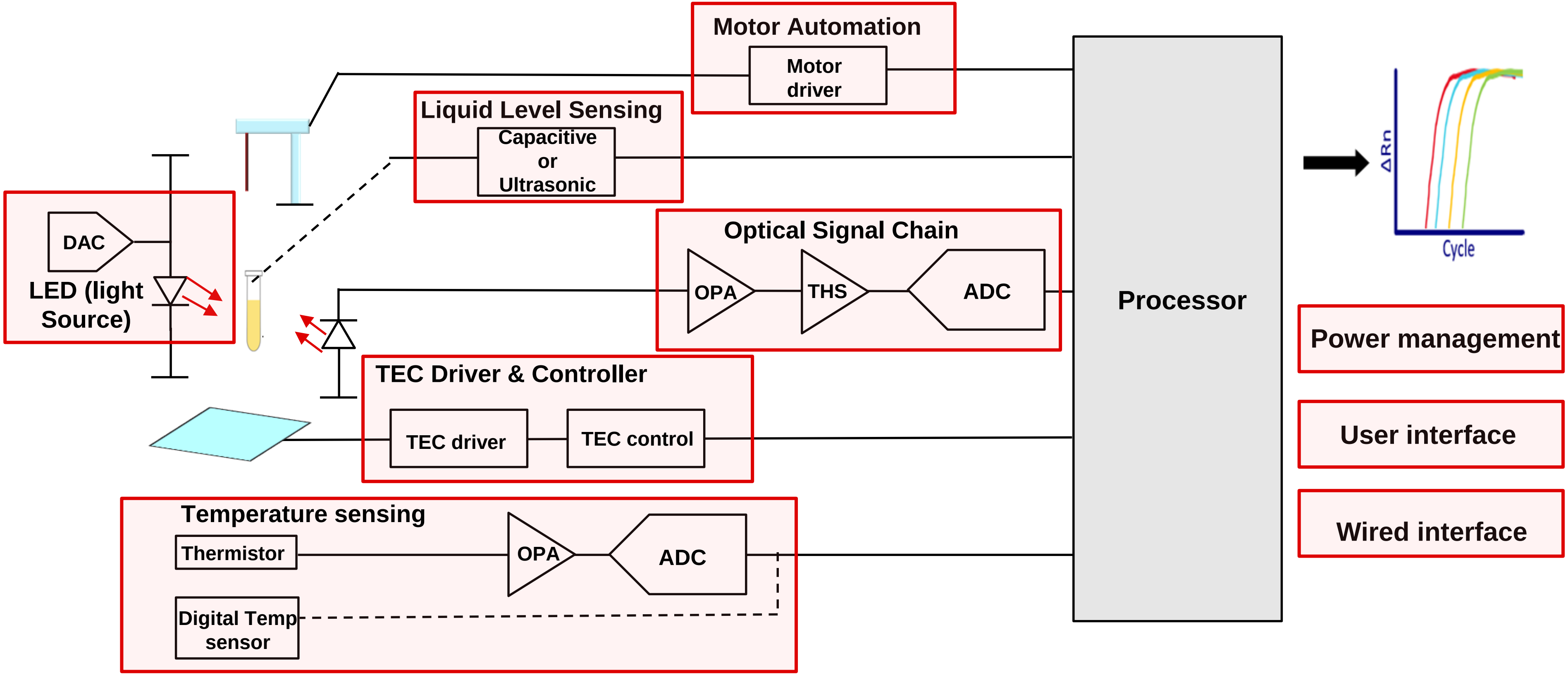
Applications

- Infectious disease detection
- Diabetes
- Tumor markers
- heart disease
- Autoimmune disease
- Renal function

Main sub-system

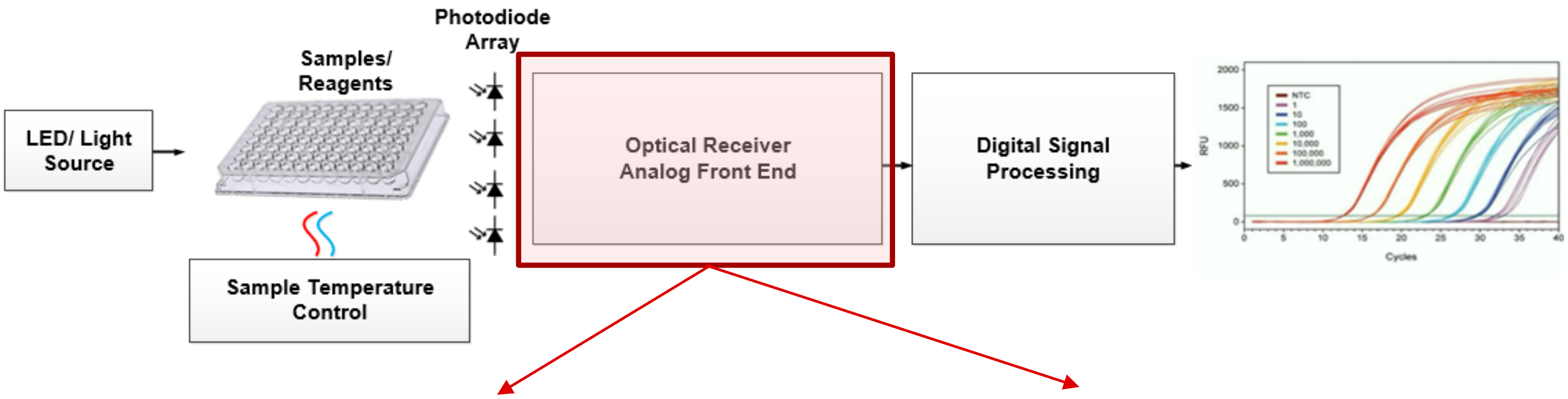
- Optical signal chain
- Thermoelectric cooling
- Liquid level sensing
- Temperature sensing
- Motor automation
- LED/LASER driver

Block diagram & sub-system



Optical signal chain

Optical signal chain | Overview



LED/ Light Source

Samples/ Reagents

Sample Temperature Control

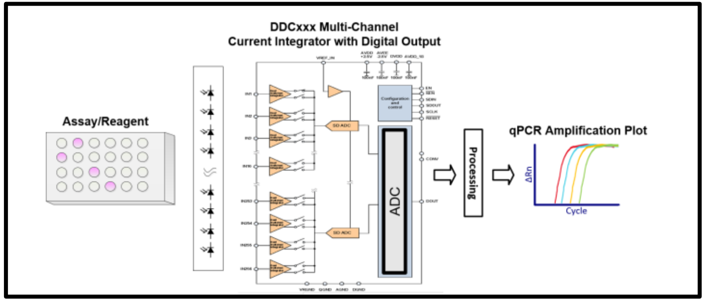
Photodiode Array

Optical Receiver Analog Front End

Digital Signal Processing

Integrated solution

DDC family



DDCxxx Multi-Channel Current Integrator with Digital Output

Assay/Reagent

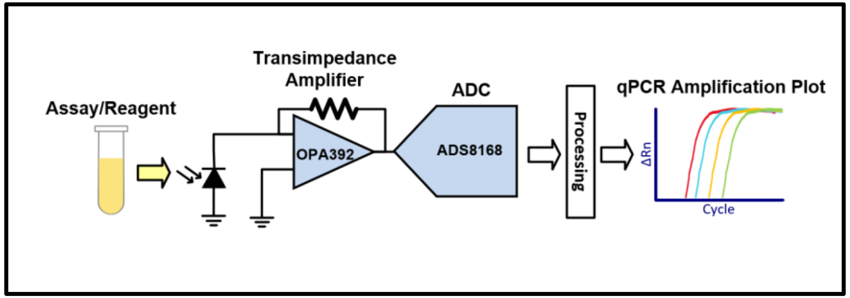
ADC

Processing

qPCR Amplification Plot

Discrete solution

TIA + filter/buffer + ADC



Assay/Reagent

Transimpedance Amplifier

OPA392

ADC

ADS8168

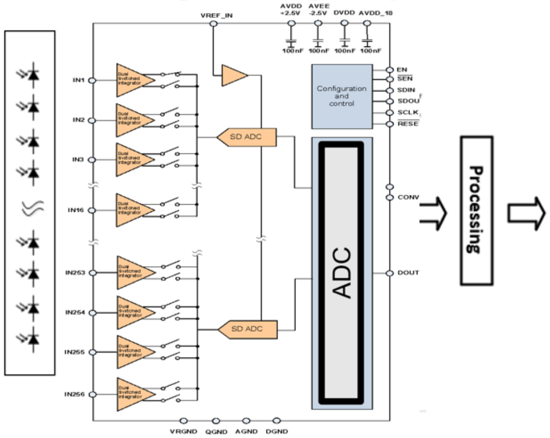
Processing

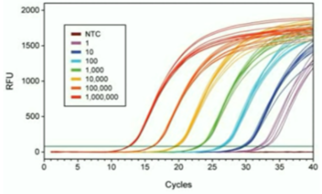
qPCR Amplification Plot

Precision Optical Receive | Integrated solution for high sensitivity and throughput

- Integrated simultaneous amplification and sampling of **1 to 256 photodiode currents with one device**
- Up to **24bit ADC**
- Adjustable input gain for **full scale range from 6.25pA to 3uA**
- **Low noise: 0.37fArms at 1SPS and 6.25pA full-scale setting**

DDCxxx Multi-Channel
Current Integrator with Digital Output

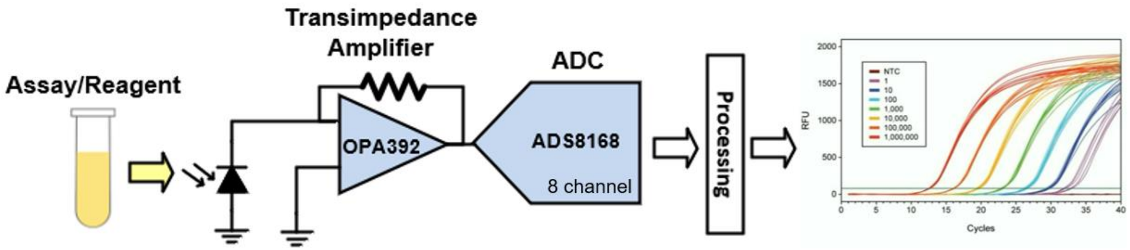




DDC/#ch	mW/ch @ KSPS	DDC/#ch	mW/ch @ KSPS
11**2**	85 @ 3	2**32**	10 @ 6
11**4**	18 @ 3	2**64**	5.5 @ 6
11**8**	18 @ 3	1**128**/9	5.5 @ 6/12
3**16**	31 @ 50	2**256**A	2.1 @ 12

Precision Optical Receive | Op-amp based discrete solution

- Discrete solution customizable for different full-scale-range and timing requirements
- OPA392: Ultra-low bias current **0.8pA(25℃)**
- OPA928: Ultra-low input bias current **20 fA** (tested max) at 25ºC and 85ºC
- ADS9110 18-bit, 2-MSPS, one-channel SAR ADC with enhanced serial peripheral interface (SPI)



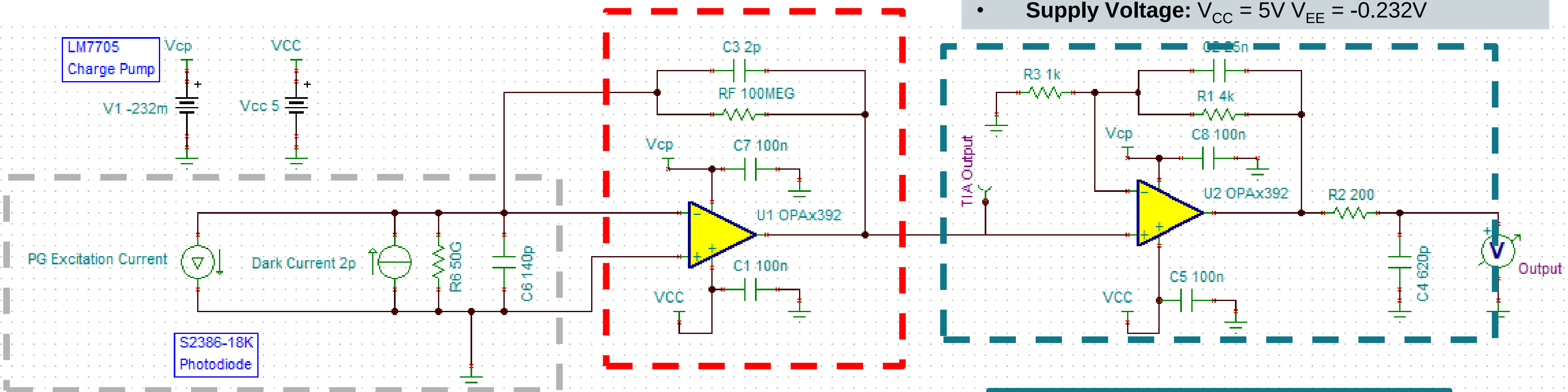
Parameter	Transimpedance Amplifier	Precision ADC Optical Signal Chain	Precision ADC Temperature Sensing
GPN	OPAx392 OPA928 THS4551	ADS9110 ADS127L11 ADS7066	ADS124S06 ADS124S08
Description	• Precision, Low Vos, noise, Ibias current, Amplifiers • Femtoampere Input Bias, Precision Amplifiers • Low-Noise, Precision, FDA	• 18 bit, 2-MSPS, SAR • 24 bit, 400-kSPS, Δ-Σ • 8-Ch, 16-Bit, 250-kSPS SAR ADC	• 24-bit, 4-kSPS, 6-ch Δ-Σ ADC • 24-bit, 4-kSPS, 12-ch delta-sigma ADC with PGA

Discrete Optical Receiver | Simulation

The below simulation emphasizes the sensitivity achievable through a discrete analog front end. The circuit is optimized to given specifications. Passives can be tailored to different current level and timing requirements as shown here.

Specifications

- **Excitation Pulse:** 10ms pulse, 32Hz
- **Total TIA Gain:** 500MV/A
- **Full scale current range:** 9.9nA
- **Lowest distinguishable current:** ~0.476pA_{pk}
- **Resolution:** 14.27bits
- **Supply Voltage:** V_{CC} = 5V V_{EE} = -0.232V



Photodiode Model

S2386-18K Photodiode

- Low Noise Eq. Power (6.8×10-16 W/rtHz)
- Low dark current (2pA),
- Good sensitivity (0.3A/W at 500nm)

TIA

OPA2392 Precision Op Amp

- **Low I_n (4.0 nV/√Hz),**
- **Low I_b (Typical 10fA)**

Non-Inverting Amplifier

OPA2392 Precision Op Amp

- Smaller BOM using 2nd channel

Simulation on TI.com for Download

Simulation results | Sensitivity

Low optical sensitivity allows for a low Limit of Detection and high reproducibility in qPCR measurements. Sensitivity is increased through averaging of samples as well as tightening the bandwidth.

$$\mathrm{I}_{\mathrm{max}} = \frac{\mathrm{V}_{\mathrm{max\_swing}}}{R_F \times G_{NIA}} = \frac{4.95\mathrm{V}}{500M} = 9.9\mathrm{nA}$$

$$Optical\ Sensitivity = \frac{\mathrm{V}_{\mathrm{n-out}}}{G_{NIA}}(rms) = \frac{257.6\mathrm{uVrms}}{500\mathrm{M}} \times 6$$
$$= 3.09\mathrm{pAk}(\mathbf{0.476pApk})\ [\text{with 50 sample averaging}]$$

G_{NIA} = Gain of Non-inverting amp

$$Dynamic\ Range = \frac{9.9nA}{3.09pA} = 3.2k$$
$$= 11.6bits$$
$$(\mathbf{14.47}\boldsymbol{bits})\ [with\ 50\ sample\ averaging]$$

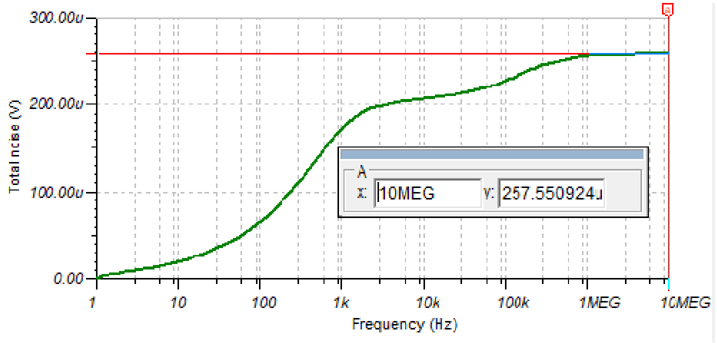


Figure 1. Total Noise vs. Frequency

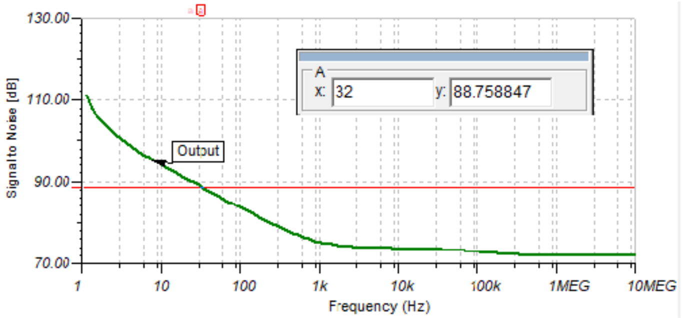


Figure 2. SNR

Simulation results | AC performance

$$Settling\ Time(to\ 16\ bits) \cong 12 \times \sqrt{\tau_{TIA}{}^{2}+\tau_{NIA}{}^{2}} = \mathbf{2.68ms}$$

$$\mathrm{F}_{-3\mathrm{dB}} = 670Hz$$

$$Phase\ Margin = \ \ 88.7°$$

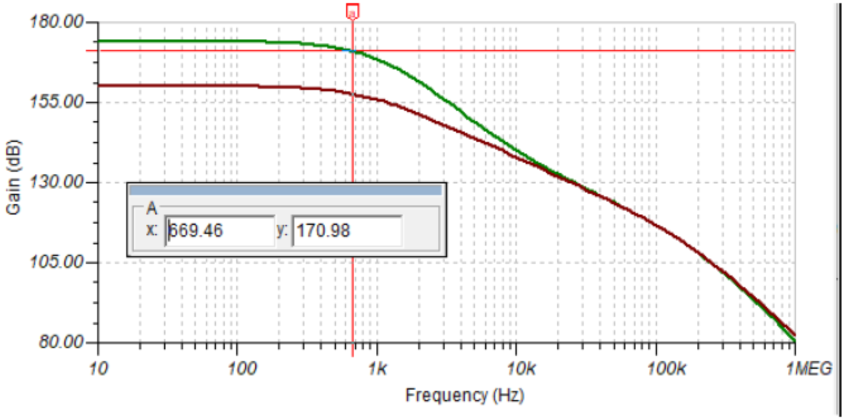
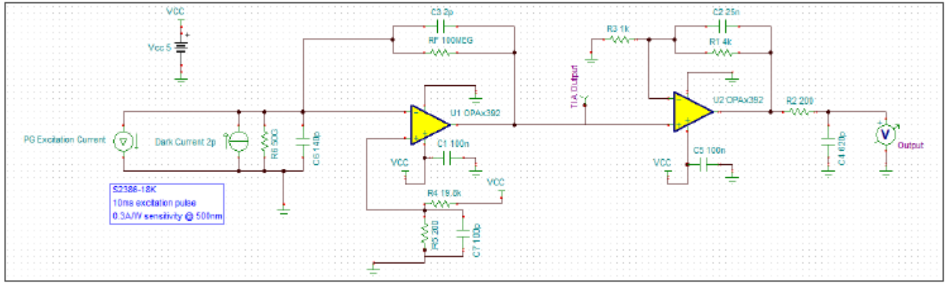


Figure 1. AC Transfer Characteristic

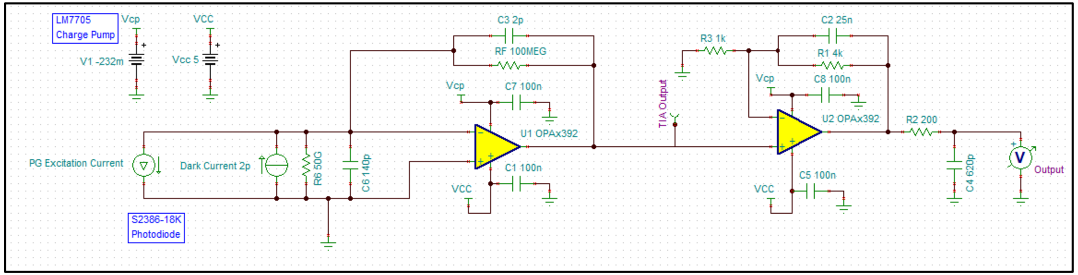


Simulation results | Accuracy

High accuracy enables good well-to-well reproducibility in qPCR measurements. Here the error is dominated by resistor gain error which can be reduced if less gain is needed or through an initial calibration

$$\begin{gathered}\text{Error:}\\ (\text{OPA392 } V_{OS})(\text{max}) \rightarrow 10\mu A \times 5 = \mathbf{0.05mV}\\ (\text{OPA392 } I_B)(\text{max}) \rightarrow 0.8pA \times 500M = \mathbf{0.4mV}\\ (\text{Dark Current})(\text{max}) \rightarrow 2pA \times 500M = \mathbf{1mV}\\ (Resistor\ Gain\ Error)(0.1\%\ tolerance) \rightarrow \mathbf{12.9mV}\end{gathered}$$

$$Accuracy = 1 - \frac{Error\ (worst\ case)}{Full\ Scale\ Range} = 1 - \frac{14.35\text{mV}}{4.95\text{V}} = \mathbf{0.997}$$



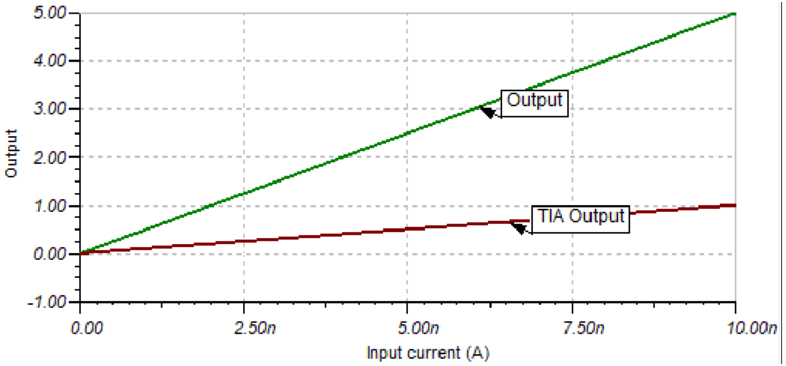


Figure 4. DC Transfer Characteristic

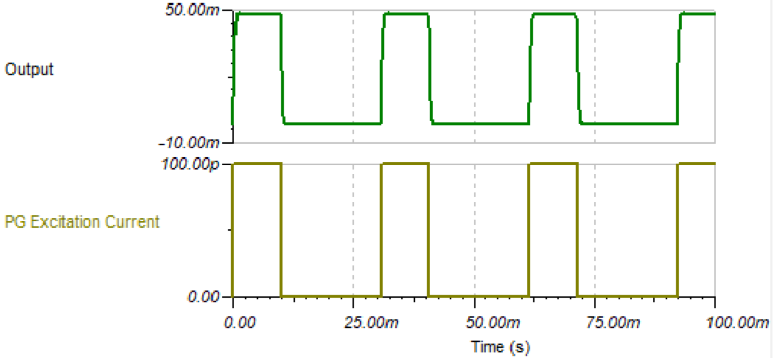
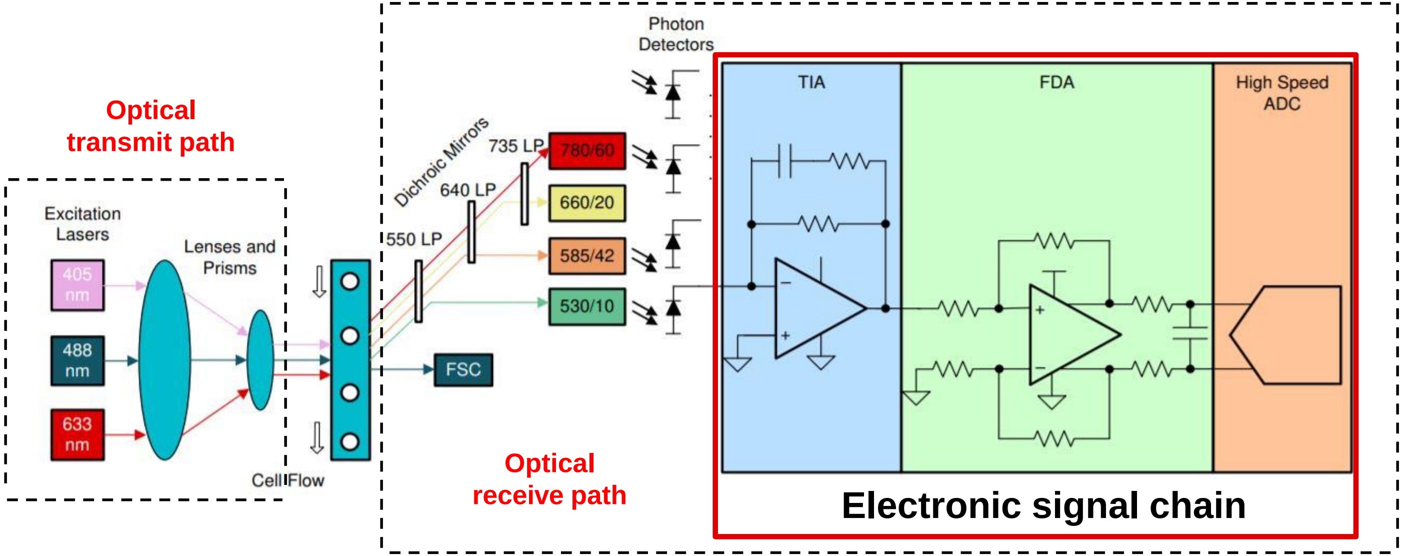


Figure 5. Transient Response 10ms 100pA pulse @32Hz

Flow Cytometry | Signal chain



1. **Trans-Impedance Amplifiers (TIA):** converts current, generated by a photodiode, into voltage that drives the FDA for a differential input ADC.

2. **Fully Differential Amplifiers (FDA):** drives single ended to differential input Analog to Digital Converter (ADC) for high precision designs.

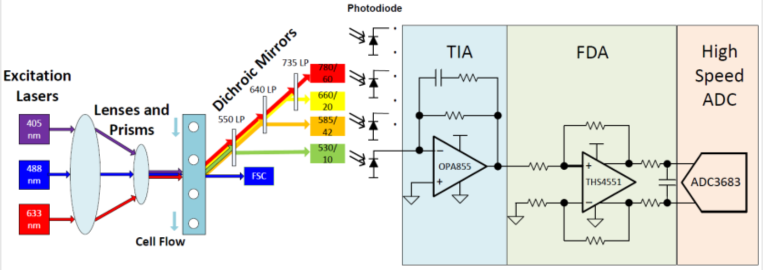
Optical signal chain | High speed TIA selection

Sensor	Frequency Range	Capacitance Range	Current Range	Feedback Resistor Range at 2Vpp	Approx. GBW Range	Example Transimpedance Amplifiers (TIA)
PD	100kHz – 5000MHz	0.5pF-200pF	10nA-100µA	10kΩ-100MΩ	10MHz-100GHz	**OPA855:** Low Noise, **8GHz**, Decompensated Bipolar-Input Amplifier **OPA857:** Low Noise, Fast Recovery Time, **6.8GHz**, Integrated TIA with Gain Control **OPA858:** Low Noise, **5.5GHz**, Decompensated FET-Input Amplifier **OPA818:** Low Noise, High Voltage, **2.7GHz**, Decompensated FET-Input Amplifier **OPA657:** High Precision, High Output Current, **1.6GHz**, Decompensated FET-Input Amplifier **OPA856:** Low Noise, Wide Output Swing, **1.1GHz**, Bipolar-Input Amplifier **LMH32401:** Programmable gain, Differential Output ADC driver, Integrated TIA, Ambient Light Cancellation, 100mA Protection Clamp, **450MHz** (1, 4 Channels, Q100 Option) **OPA656:** High Precision, High Output Current, **230MHz**, FET-Input Amplifier **OPA810:** Low noise, RRIO, High Output Current, **70MHz**, FET-Input Amplifier (1, 2 Channels) **OPA607**: High Precision, **50MHz**, RRO, Decompensated CMOS Amplifier (1, 2 Channels) **OPA320:** High Precision, **20MHz**, RRIO, Zero-Crossover, CMOS Amplifier (1, 2 Channels)
APD	10MHz - 1000MHz	1pF-150pF	100nA-1mA	1kΩ-10MΩ	100MHz-10GHz	
PMT	100MHz – 500MHz	0.1nF-10nF	10µA-100µA	10kΩ-100kΩ	1GHz-100GHz	
SiPM	1MHz – 100MHz	50pF-1nF	1µA-10mA	100Ω-1MΩ	100MHz-10GHz	

Optical signal chain| High speed summary

Block diagram/schematic

Flow Cytometry Front End



Design challenge/problem statement

- The main signal chain design considerations in Flow Cytometer systems are the SNR of the TIA stage, ADC SNR, and ADC Sample Rate.
- The system Dynamic Detection Range(DNR) is limited by the combined SNR of the signal chain. In most systems this needs to be above 80dB to be effective.
- The ADC sample rate determines the peak detection error of the system. ADC's with sample rates above 75MSPS are needed to achieve <1% error for common input pulses.

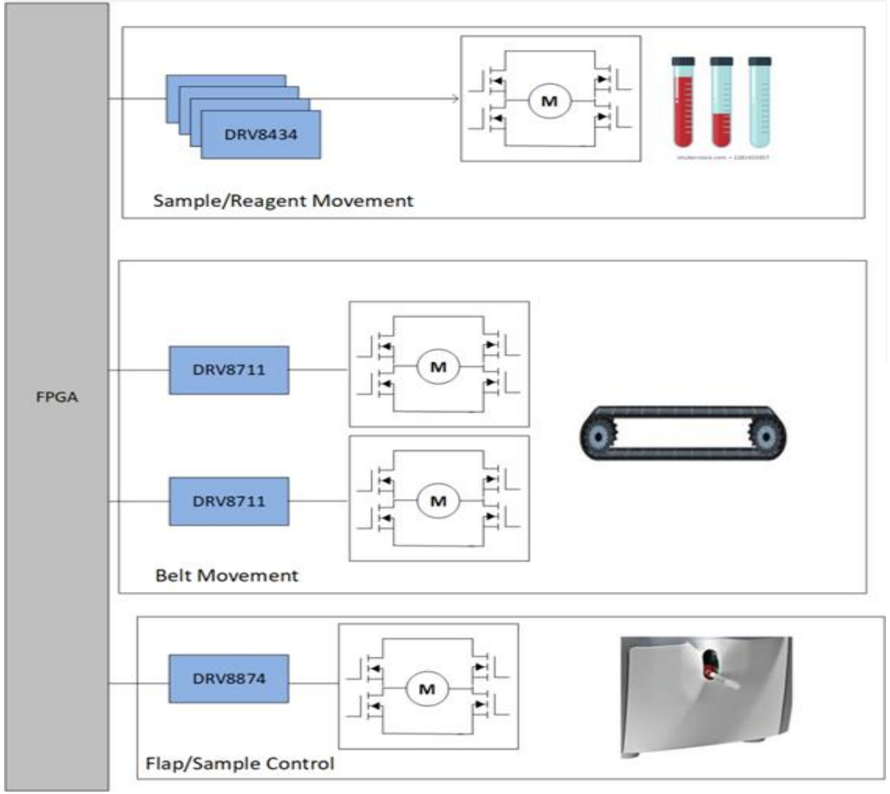
Key Device + Collaterals

	1~2CH Devices	4~16CH TI devices
GPN	OPA855 , OPA320 THS4551, ADC3683	LMH32404 / OPA2607 OPA2320 / THS4552 ADC3443
Description	TIA + FDA + 1~2 channel, 65~80 MSPS, 16~18 bit ADCs	TIA + FDA + 4~16 channel, 65~125 MSPS, 14~16-bit ADCs
Technical resources	▪ Flow Cytometry Signal Chain ▪ Photodiode TI Design ▪ Why use oversampling	▪ Understanding JESD204B Subclasses and Deterministic Latency

Motor automation

Motor automation| Motor driver overview

Application: Motor Driver



Products

Brushed motor drivers:

- Products: DRV8873, DRV8874, DRV8256
- Integration of current sense resistors, leading to BOM, space, cost reduction
- Dedicated IPROPI pin to feedback current to the MCU
- Pin-2-pin scalability across current (3.5A-6A)

Stepper/Dual motor drivers:

- Products: DRV8452, DRV8462, DRV8461, DRV8434/A/S, DRV8845/49
- Integration of current sense resistors, leading to BOM, space, cost reduction
- Smart Tune, Silent Step, and High microstepping enabling Smooth quiet motion
- Pin-2-pin scalability across current and voltage (3.5A-6A; 35V-50V)
- Stall Detection

Quad Half bridges:

- Integration of current sense resistors, leading to BOM, space, cost reduction
- Individual control and monitor of 4 channels

Gate Drivers:

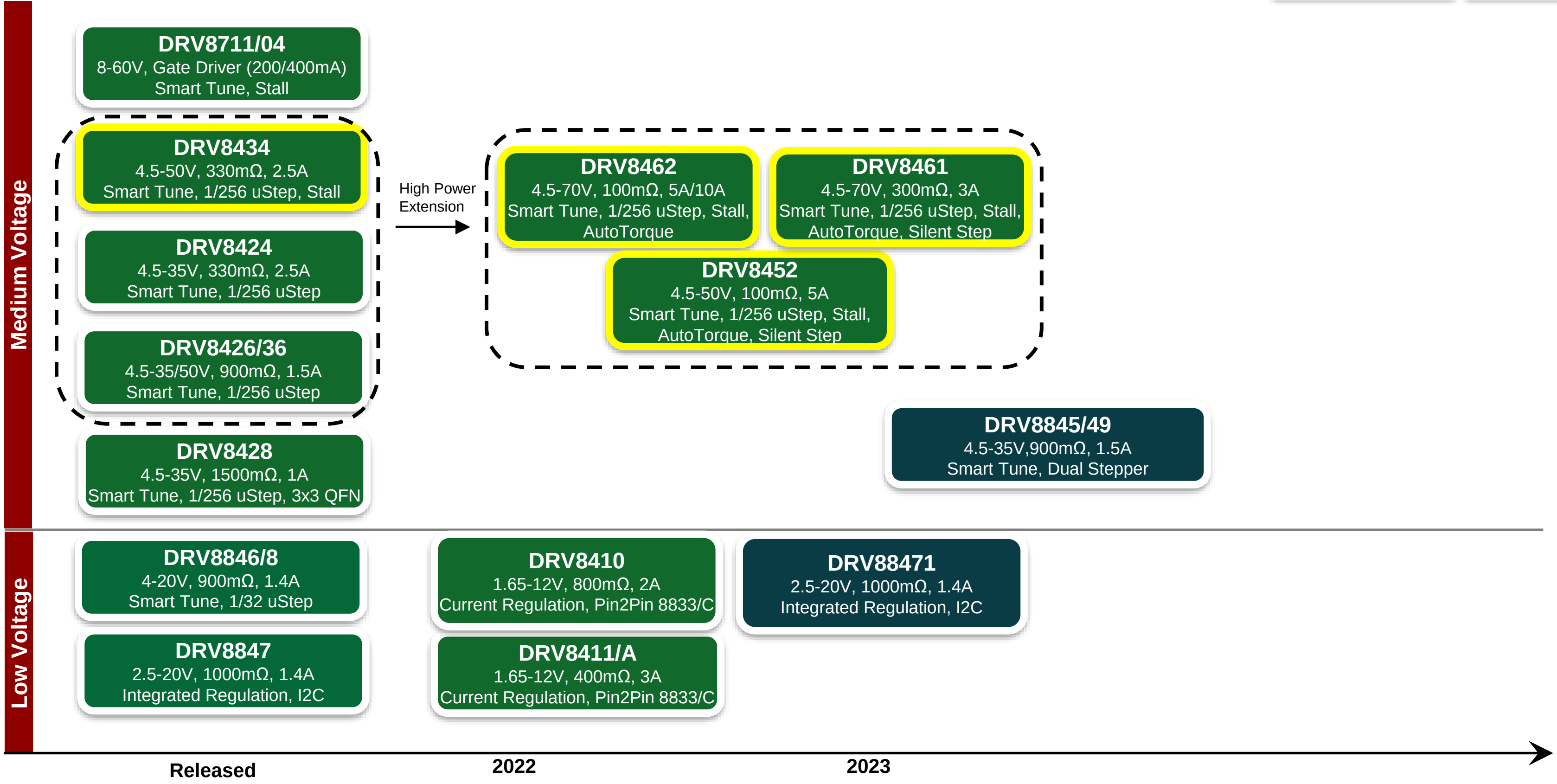
- Products: DRV8711, DRV8701
- Thermally enhanced packaging
- Adjustable gate drive
- Stall Detection

Stepper motor driver roadmap

🟨 Samples Available

Development **Deinition**

Roadmap **Released**



Medium Voltage

DRV8711/04
8-60V, Gate Driver (200/400mA)
Smart Tune, Stall

DRV8434
4.5-50V, 330mΩ, 2.5A
Smart Tune, 1/256 uStep, Stall

DRV8424
4.5-35V, 330mΩ, 2.5A
Smart Tune, 1/256 uStep

DRV8426/36
4.5-35/50V, 900mΩ, 1.5A
Smart Tune, 1/256 uStep

DRV8428
4.5-35V, 1500mΩ, 1A
Smart Tune, 1/256 uStep, 3x3 QFN

High Power Extension

DRV8462
4.5-70V, 100mΩ, 5A/10A
Smart Tune, 1/256 uStep, Stall, AutoTorque

DRV8461
4.5-70V, 300mΩ, 3A
Smart Tune, 1/256 uStep, Stall, AutoTorque, Silent Step

DRV8452
4.5-50V, 100mΩ, 5A
Smart Tune, 1/256 uStep, Stall, AutoTorque, Silent Step

DRV8845/49
4.5-35V,900mΩ, 1.5A
Smart Tune, Dual Stepper

Low Voltage

DRV8846/8
4-20V, 900mΩ, 1.4A
Smart Tune, 1/32 uStep

DRV8847
2.5-20V, 1000mΩ, 1.4A
Integrated Regulation, I2C

DRV8410
1.65-12V, 800mΩ, 2A
Current Regulation, Pin2Pin 8833/C

DRV8411/A
1.65-12V, 400mΩ, 3A
Current Regulation, Pin2Pin 8833/C

DRV88471
2.5-20V, 1000mΩ, 1.4A
Integrated Regulation, I2C

Released **2022** **2023**

Mid Voltage Stepper/Dual Brushed DC

Device Feature	**DRV8452**	**DRV8462/1**	**DRV8428**	**DRV8436** **DRV8426**	**DRV8425**	**DRV8434** **DRV8424**	**DRV8434A/S** **DRV8889-Q1**	**DRV8811**	**DRV8812** **DRV8813**	**DRV8886/AT**	**DRV8884** **DRV8885**	**DRV8880** **DRV8881**	**DRV8818**	**DRV8824** **DRV8825**
	New High Power Steppers		**DRV84XX P2P FAMILY**					**OLD GEN**						
Supply Voltage (V) (abs. max)	50	65	35	50 35	35	50 35	50 45	38	45 45	40	40 40	50 50	35	47 45
Output FS Current (A)	5	5 3	1.0	1.5	2.0	2.5	2.5 1.5	1.9	1.6 2.5	2.0	1.0 1.5	2.0 2.0	2.5	1.6 2.5
RDSon (HS+LS) Ω	0.1	0.1 0.3	1.5	0.9	0.5	0.3	0.3 0.9	1.0	1.0 0.4	0.5	1.4 0.8	0.6 0.6	0.37	0.4
Microstepping	1/256	1/256	1/256	1/256	1/256	1/256	1/256	1/8	-	1/16	1/16	1/16 -	1/8	1/32 1/32
Interface Control	STEP/DIR PWM PH/EN SPI	STEP/DIR PWM PH/EN SPI	STEP/DIR PWM PH/EN	STEP/DIR PWM PH/EN	STEP/DIR PWM PH/EN	STEP/DIR PWM PH/EN	STEP/DIR	STEP/DIR	PH/EN	STEP/DIR	STEP/DIR STEP/DIR	STEP/DIR PWM PH/EN	STEP/DIR	STEP/DIR
Auto Torque	✓	✓	-	-	-	-	-	-	-	-	-	-	-	-
Silent Step	✓	✓	-	-	-	-	-	-	-	-	-	-	-	-
Automatic Microstepping	✓	✓	-	-	-	-	-	-	-	-	-	-	-	-
Custom Microstepping	✓	✓	-	-	-	-	-	-	-	-	-	-	-	-
Stall Detection	✓	✓	-	-	-	-	✓	-	-	-	-	-	-	-
Smart Tune	✓	✓	✓	✓	✓	✓	✓	-	-	✓	-	✓	-	-
Integrated current sensing	✓	✓	✓	✓	✓	✓	✓	-	-	✓	✓	-	-	-
Packages	HTSSOP DDW	DDW DDV	HTSSOP (16pin) TSOT (16pin) QFN (16pin)	HTSSOP (28pin,) QFN (24pin)	HTSSOP (28pin) QFN (24pin)	HTSSOP (28pin) QFN (24pin)	HTSSOP (28,24 pin) QFN (24pin)	HTSSOP (28pin)	HTSSOP (28pin)	HTSSOP (24pin) QFN (28pin)	HTSSOP (24pin) QFN (28pin)	HTSSOP (28pin) QFN (28pin)	HTSSOP (28pin)	HTSSOP (28pin) QFN (28pin)
Package sizes	HTSSOP (7.7x4.4mm) DDV (14x6.1 mm)	DDV (14x6.1 mm) DDW (14x6.1 mm)	HTSSOP (5x4.4mm) TSOT (4.2x3.2mm) QFN (3x3mm)	HTSSOP (7.7x4.4mm) QFN (4x4mm)	HTSSOP (7.7x4.4mm) QFN (4x4mm)	HTSSOP (7.7x4.4mm) QFN (4x4mm)	HTSSOP (7.7x4.4mm) QFN (4x4mm)	HTSSOP (9.7x4.4mm)	HTSSOP (9.7x4.4mm)	HTSSOP (7.8x4.4mm) QFN (5.5x3.5mm)	HTSSOP (7.8x4.4mm) QFN (5.5x3.5mm)	HTSSOP (9.7x4.4mm) QFN (5.5x3.5mm)	HTSSOP (9.7x4.4mm)	HTSSOP (9.7x6.4mm) QFN (5.5x3.5mm)

DRV8452, DRV8462, DRV8461

High-powered integrated stepper family with industry leading power efficiency, precision, and noise levels

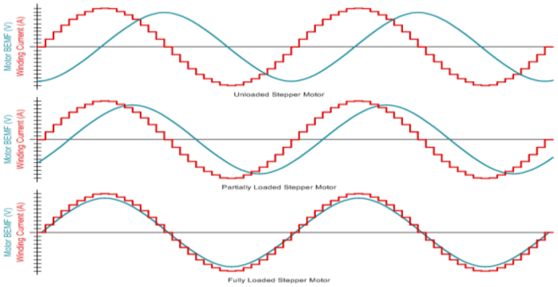
Power Efficiency and Density

Power Efficiency

- ✓ **Auto torque:** Improves system efficiency and thermal performance
- ✓ **Standstill Power Saving Mode:** User programmable stand still current automatically saving power during standstill

Power Density

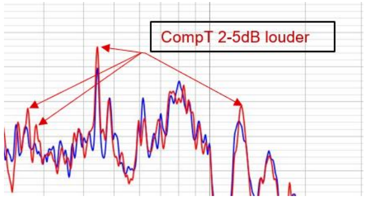
- ✓ **Integration:** Eliminates all passive components needed with external FETs reducing BOM cost and size
- ✓ **Integrated 100mΩ power FET:** low d/s On resistance with the ability to drive from 1-10A at ambient temperature

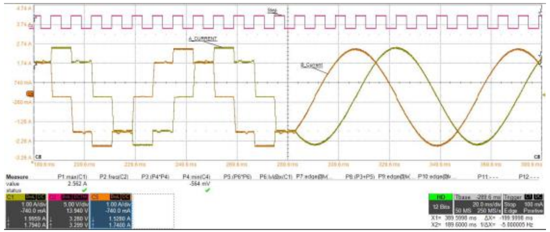


Silent Motor Rotation

- ✓ **Silent Step Low-noise decay modes:** Removes noise due to PWM switching at standstill and low speeds
- ✓ **Automatic microstepping:** interpolates STEP pulses to generate 1/256 microstepping current waveform. Decreases audible noise and reduces MCU overhead.
- ✓ **Custom microstepping:** customizable microstepping table for smooth output torque
- ✓ **Smart tune:** Innovative decay algorithm to quite operations at high speeds

More info; slides





Flexibility and Protection

- ✓ **Integrated current sensing and regulation:** reduce design complexity and BOM cost
- ✓ **Stall Detection:** Sensorless stall detection eliminates end switches decreasing cost and reliability
- ✓ **P2P scalability across voltages and current:**
  - ✓ Scale across voltage and current ranges with P2P devices – DRV8461, DRV8452, DRV8462
  - ✓ P2P compatible with DRV84xx PWP
- ✓ **Current Sense Accuracy to ± 5%**
- ✓ **nFault pin:** Allows for advanced diagnostics
- ✓ **Indexer output:** Allows angle/position tracking
- ✓ **nHome pin:** Indicates indexer home position
  - ✓ Allows sensorless homing
- ✓ **Comprehensive Protection:** UVLO, CPUV, OCP, OL, OTSD, OTW

14 x 6.1mm, 44-pin, HTSSOP package (DDW, bottom EP)

14 x 6.1mm, 44-pin, HTSSOP package (DDV, top EP)

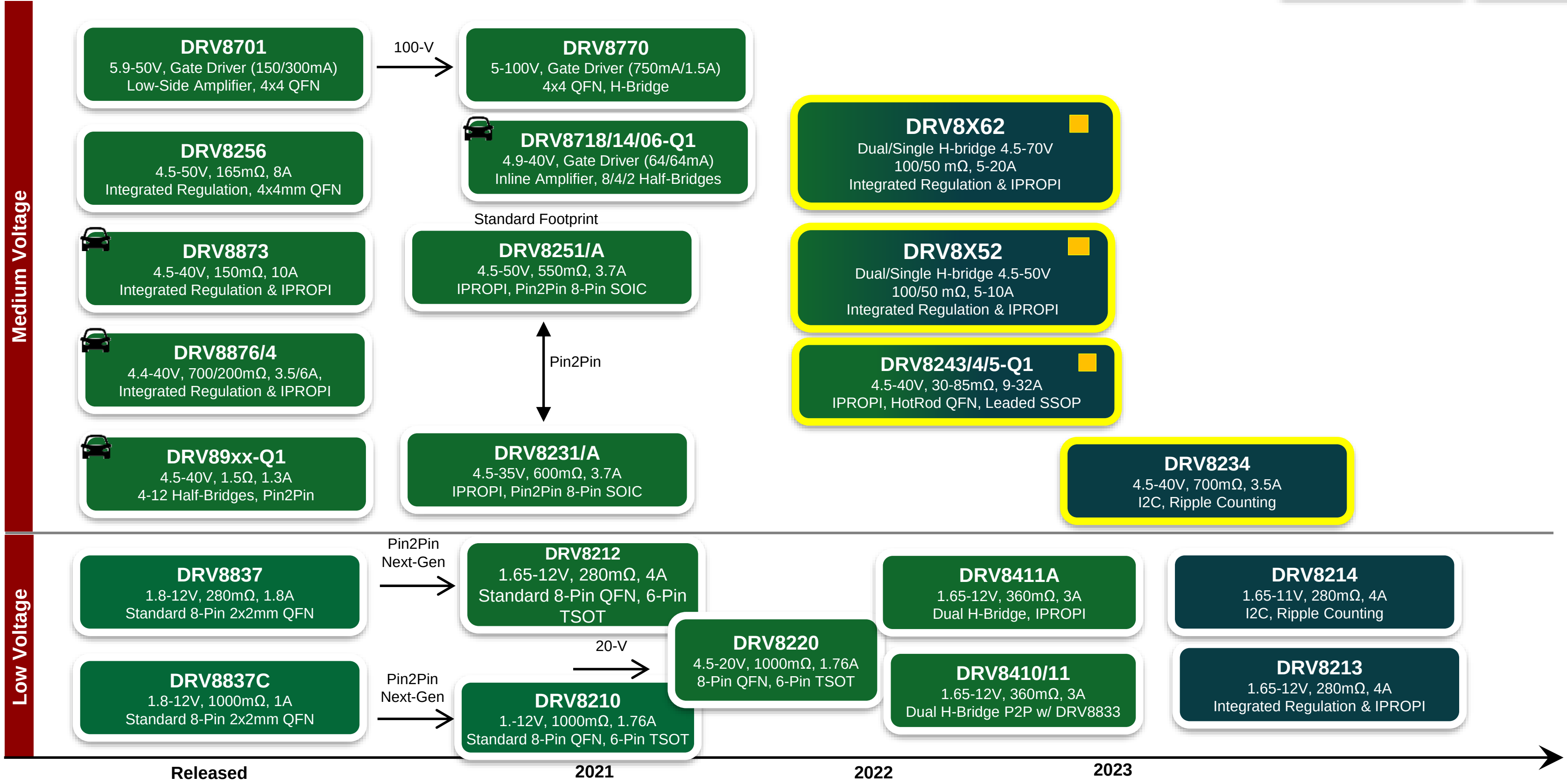
9.7 x 4.4mm, 28-pin, HTSSOP package (PWP)

Brushed motor driver roadmap

🟨 Samples Available

🚗 Auto Grade Available

Development | Definition | Roadmap | Released



Medium Voltage

DRV8701
5.9-50V, Gate Driver (150/300mA)
Low-Side Amplifier, 4x4 QFN

100-V →

DRV8770
5-100V, Gate Driver (750mA/1.5A)
4x4 QFN, H-Bridge

DRV8256
4.5-50V, 165mΩ, 8A
Integrated Regulation, 4x4mm QFN

🚗 **DRV8718/14/06-Q1**
4.9-40V, Gate Driver (64/64mA)
Inline Amplifier, 8/4/2 Half-Bridges

DRV8X62 🟨
Dual/Single H-bridge 4.5-70V
100/50 mΩ, 5-20A
Integrated Regulation & IPROPI

🚗 **DRV8873**
4.5-40V, 150mΩ, 10A
Integrated Regulation & IPROPI

Standard Footprint

DRV8251/A
4.5-50V, 550mΩ, 3.7A
IPROPI, Pin2Pin 8-Pin SOIC

DRV8X52 🟨
Dual/Single H-bridge 4.5-50V
100/50 mΩ, 5-10A
Integrated Regulation & IPROPI

🚗 **DRV8876/4**
4.4-40V, 700/200mΩ, 3.5/6A,
Integrated Regulation & IPROPI

Pin2Pin

DRV8243/4/5-Q1 🟨
4.5-40V, 30-85mΩ, 9-32A
IPROPI, HotRod QFN, Leaded SSOP

🚗 **DRV89xx-Q1**
4.5-40V, 1.5Ω, 1.3A
4-12 Half-Bridges, Pin2Pin

DRV8231/A
4.5-35V, 600mΩ, 3.7A
IPROPI, Pin2Pin 8-Pin SOIC

DRV8234
4.5-40V, 700mΩ, 3.5A
I2C, Ripple Counting

Low Voltage

DRV8837
1.8-12V, 280mΩ, 1.8A
Standard 8-Pin 2x2mm QFN

Pin2Pin
Next-Gen →

DRV8212
1.65-12V, 280mΩ, 4A
Standard 8-Pin QFN, 6-Pin TSOT

DRV8411A
1.65-12V, 360mΩ, 3A
Dual H-Bridge, IPROPI

DRV8214
1.65-11V, 280mΩ, 4A
I2C, Ripple Counting

20-V →

DRV8220
4.5-20V, 1000mΩ, 1.76A
8-Pin QFN, 6-Pin TSOT

DRV8837C
1.8-12V, 1000mΩ, 1A
Standard 8-Pin 2x2mm QFN

Pin2Pin
Next-Gen →

DRV8210
1.-12V, 1000mΩ, 1.76A
Standard 8-Pin QFN, 6-Pin TSOT

DRV8410/11
1.65-12V, 360mΩ, 3A
Dual H-Bridge P2P w/ DRV8833

DRV8213
1.65-12V, 280mΩ, 4A
Integrated Regulation & IPROPI

Released | **2021** | **2022** | **2023**

TEXAS INSTRUMENTS

Brushed motor technology

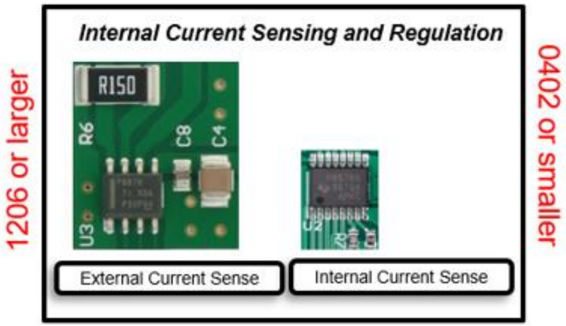
Integrated Current sensing

Eliminates large current sense resistors while providing accurate current regulation and current feedback

Benefits

- ✓ **BOM reduction:** Removed sense resistors and feedback amplifier used to send information back to MCU
  - ✓ Up to 3-5c savings per board
- ✓ **Power management:** No power loss over the sense resistor
- ✓ **Easy design:** Hassle-free layout with no sense routing

More info – video, tech doc



DRV8870 vs DRV8876

Devices offered with this feature:

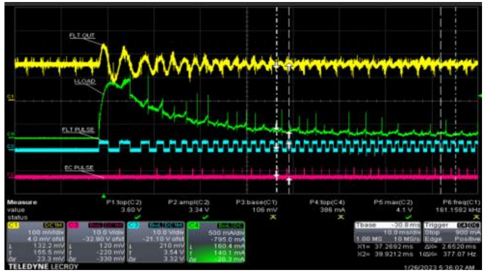
- DRV8231A
- DRV8251A
- DRV8876
- DRV8874
- DRV8873

Ripple Counting

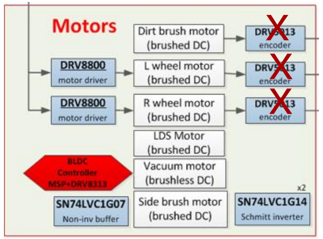
Ripple counting is a sensor-less approach to monitor DC motor position/speed

Benefits

- ✓ **BOM reduction:** Removes need for encoders, limit switches, hall sensors, accelerometer, magnets, and optical sensors used for detecting wheel position and obstacle avoidance
  - ✓ Up to $1 BOM savings
- ✓ **Reliability:** Can diagnose if the motor is jammed in an intermediate position
- ✓ **Easy design:** Reduces assembly complexity and improves reliability by removing sensors and magnets



Ripple counting with FPGA solution



Eliminate encoders

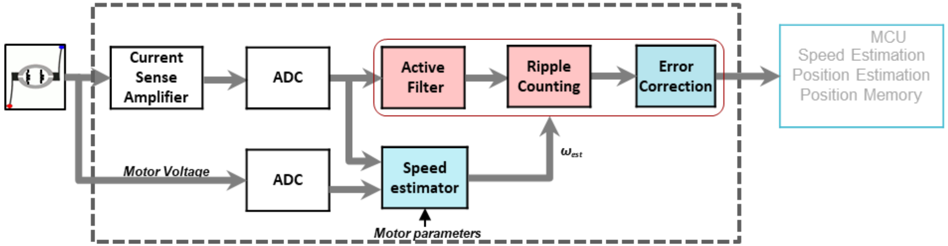
Devices offered with this feature:

- DRV8234
- DRV8214

Objective of ripple counting

- Ripple counting provides a sensor-less approach to monitoring motor position/speed
  - Detects motor stall conditions or end-of-travel
  - Replaces encoders, limit switches, Hall sensors, accelerometer, and optical sensors
- In DC motors, commutation is done using commutators & brushes to activate right coil at right time
  - As brushes move from commutator ring to ring, they short-circuit adjacent commutator rings for a brief time
    - Results in momentary spike in current waveform → ripple
  - Counting these ripples gives estimate for positional movement of the motor
- Ripple Counting Challenges
  - Widely varying common-mode DC component due to inrush/stall/load & line transients, PWMing, Direction change
  - Due to Motor geometry, out of phase commutation can cause multiple ripples per commutation
  - Ripple peak current magnitude might change with average motor current, operating voltage, winding resistance
  - Varying Ripple envelops/shapes due to brush tear/shift, motor Ageing

Different Current Ripple Profiles



Current Sense Amplifier

ADC

Active Filter

Ripple Counting

Error Correction

MCU
Speed Estimation
Position Estimation
Position Memory

Motor Voltage

ADC

Speed estimator

ω_{est}

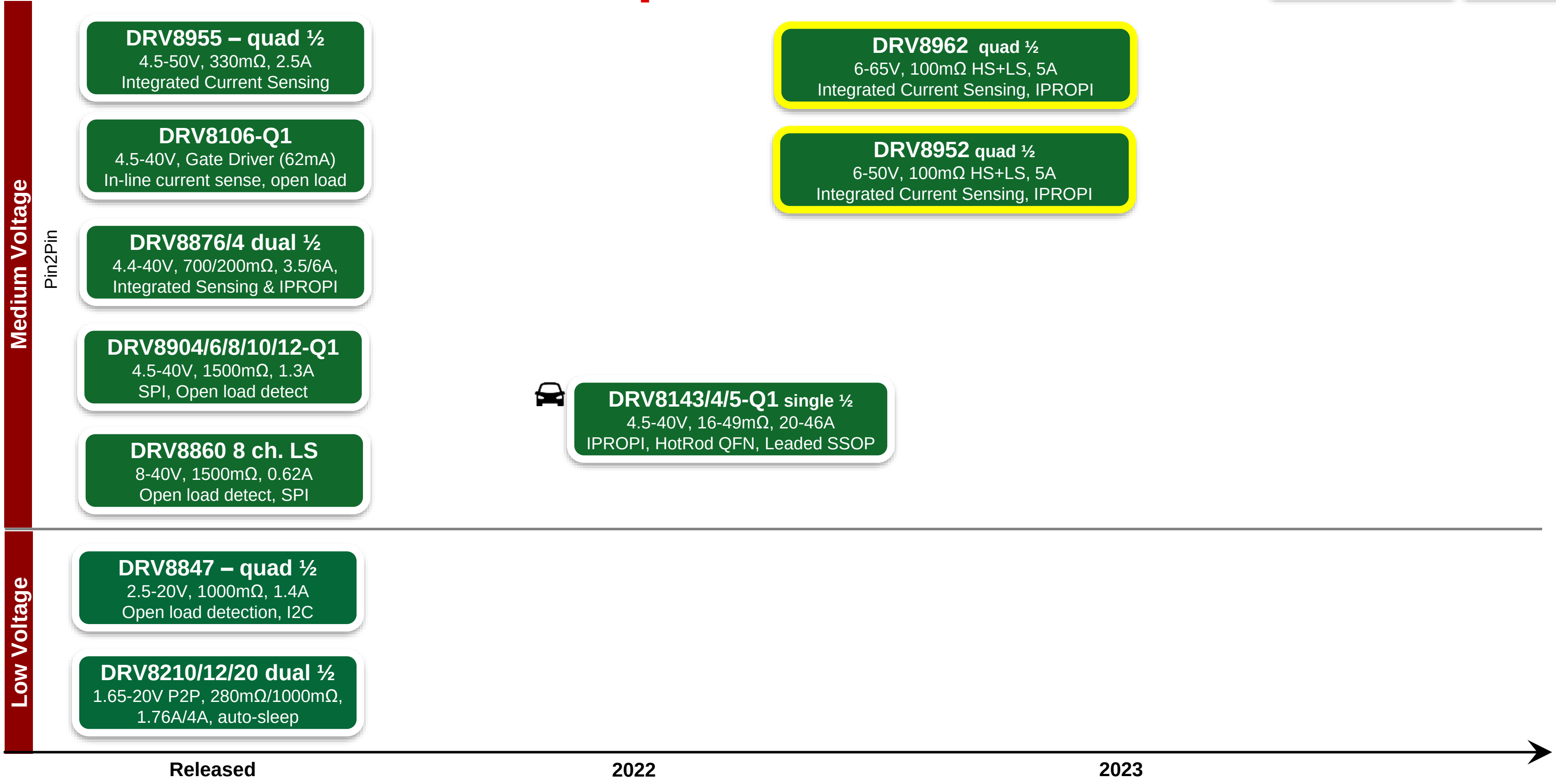
Motor parameters

Ripple Counting Algorithm Functional Block Diagram

Solenoid driver roadmap

🟨 Samples Available

Development **Definition**
Roadmap **Released**



Medium Voltage

Pin2Pin

DRV8955 – quad ½
4.5-50V, 330mΩ, 2.5A
Integrated Current Sensing

DRV8106-Q1
4.5-40V, Gate Driver (62mA)
In-line current sense, open load

DRV8876/4 dual ½
4.4-40V, 700/200mΩ, 3.5/6A,
Integrated Sensing & IPROPI

DRV8904/6/8/10/12-Q1
4.5-40V, 1500mΩ, 1.3A
SPI, Open load detect

DRV8860 8 ch. LS
8-40V, 1500mΩ, 0.62A
Open load detect, SPI

DRV8143/4/5-Q1 single ½
4.5-40V, 16-49mΩ, 20-46A
IPROPI, HotRod QFN, Leaded SSOP

DRV8962 quad ½
6-65V, 100mΩ HS+LS, 5A
Integrated Current Sensing, IPROPI

DRV8952 quad ½
6-50V, 100mΩ HS+LS, 5A
Integrated Current Sensing, IPROPI

Low Voltage

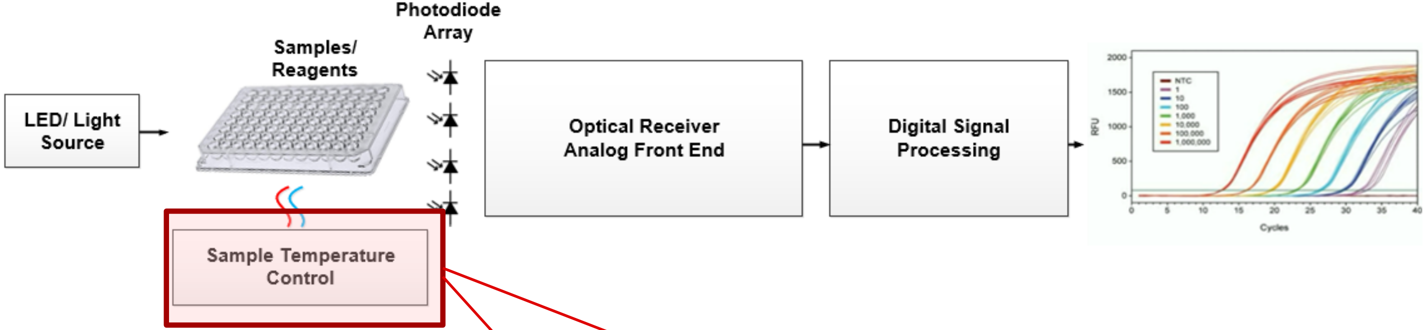
DRV8847 – quad ½
2.5-20V, 1000mΩ, 1.4A
Open load detection, I2C

DRV8210/12/20 dual ½
1.65-20V P2P, 280mΩ/1000mΩ,
1.76A/4A, auto-sleep

Released **2022** **2023**

Thermo-Electric Cooling (TEC)

Thermo-Electric cooling (TEC) | Solution overview



LED/ Light Source

Samples/ Reagents

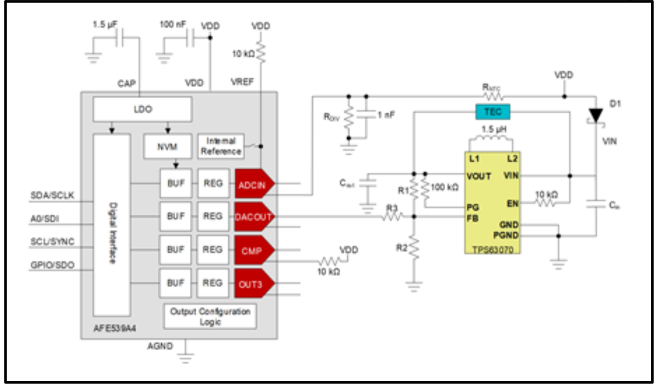
Photodiode Array

Optical Receiver Analog Front End

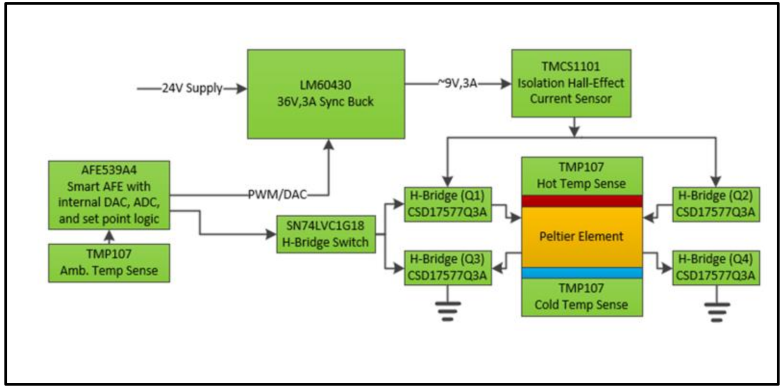
Digital Signal Processing

Sample Temperature Control

Buck- Boost regulator for TEC<40W



Discrete solution for High Power TEC



24V Supply

LM60430
36V,3A Sync Buck

~9V,3A

TMCS1101
Isolation Hall-Effect
Current Sensor

AFE539A4
Smart AFE with
internal DAC, ADC,
and set point logic

PWM/DAC

TMP107
Amb. Temp Sense

SN74LVC1G18
H-Bridge Switch

H-Bridge (Q1)
CSD17577Q3A

H-Bridge (Q2)
CSD17577Q3A

H-Bridge (Q3)
CSD17577Q3A

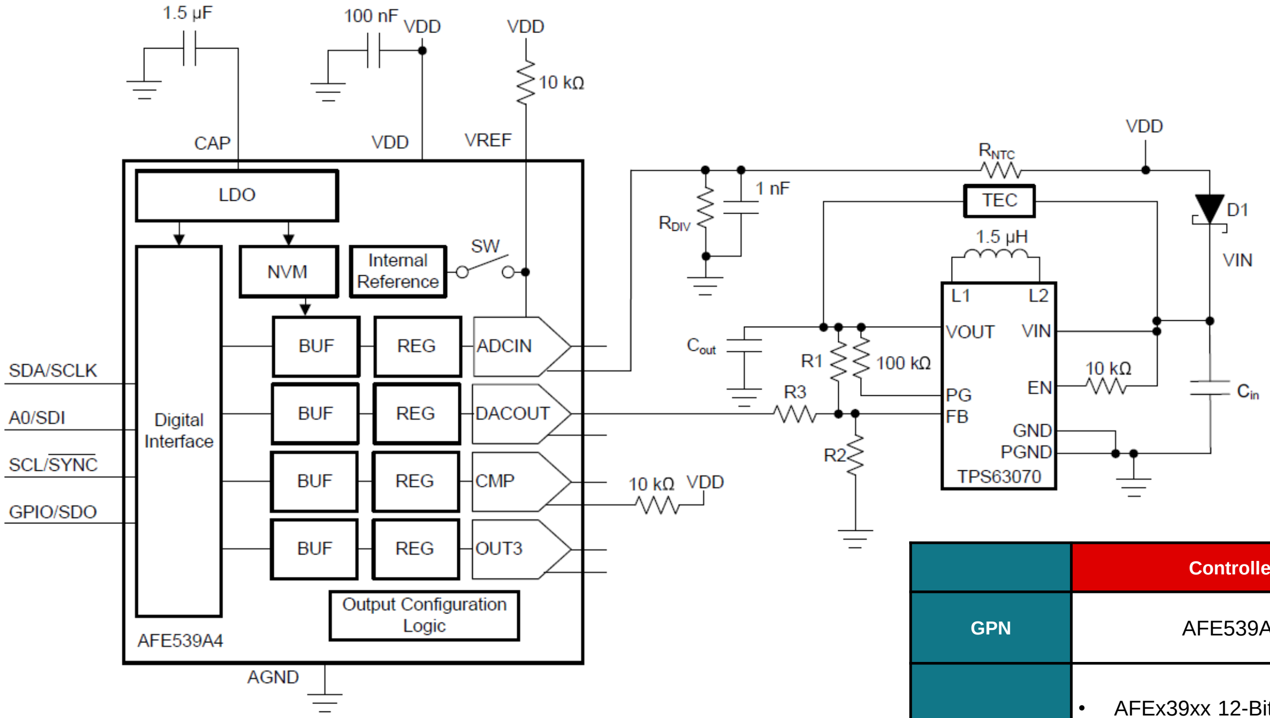
H-Bridge (Q4)
CSD17577Q3A

TMP107
Hot Temp Sense

Peltier Element

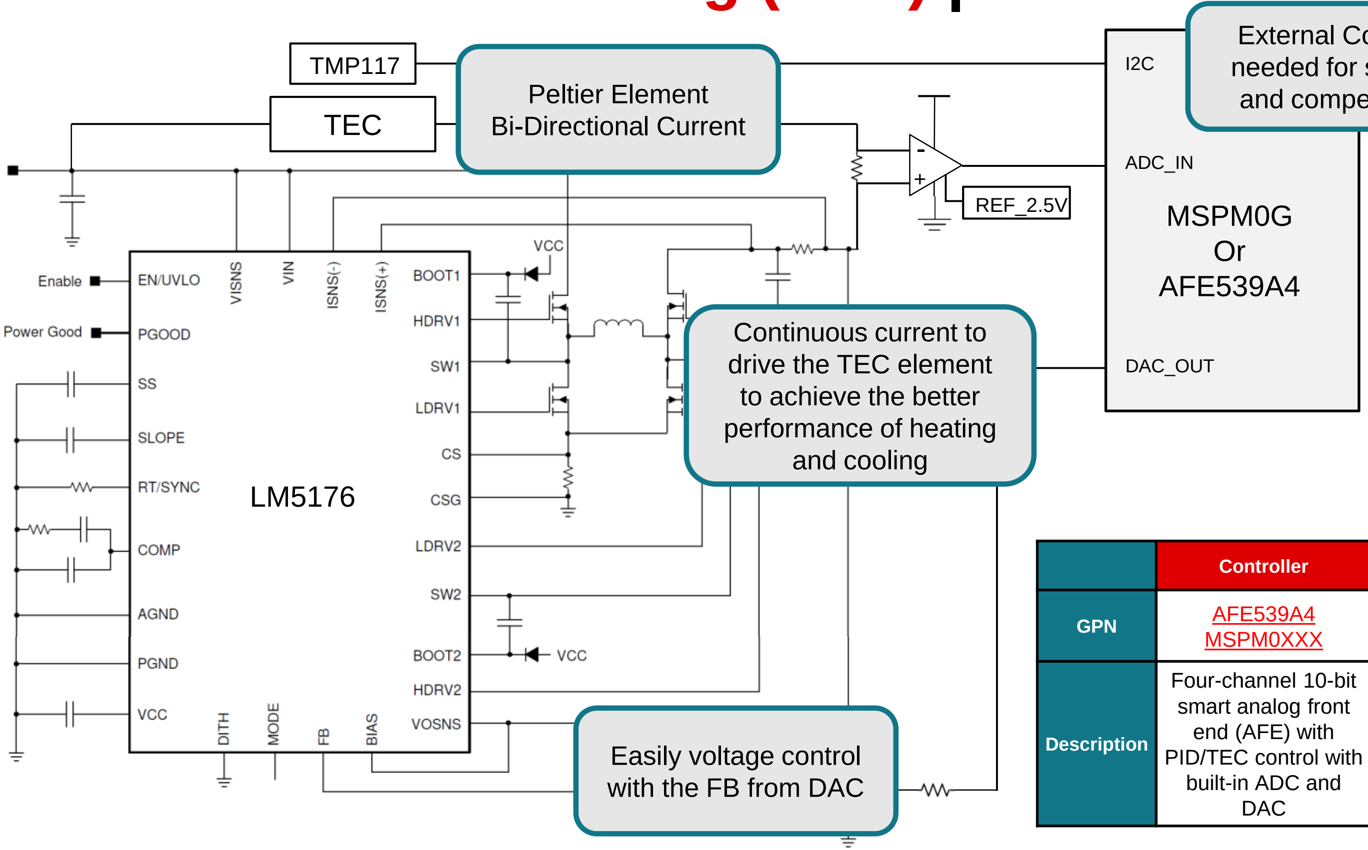
TMP107
Cold Temp Sense

Thermo-Electric Cooling (TEC) | Smart AFE + buck boost converter



	Controller	Buck-Boost
GPN	AFE539A4	TPS63070 TPS55288/9
Description	• AFEx39xx 12-Bit, 10-Bit, and 8-Bit Smart Analog Front Ends for TEC Control Using Voltage and PWM Output	• Wide input voltage (2V-16V) buck-boost converter • 36V, 16A buck-boost converter with PPS control

Thermo-Electric Cooling (TEC) | Buck-Boost regulator



Peltier Element
Bi-Directional Current

External Controller needed for set point and compensation

Continuous current to drive the TEC element to achieve the better performance of heating and cooling

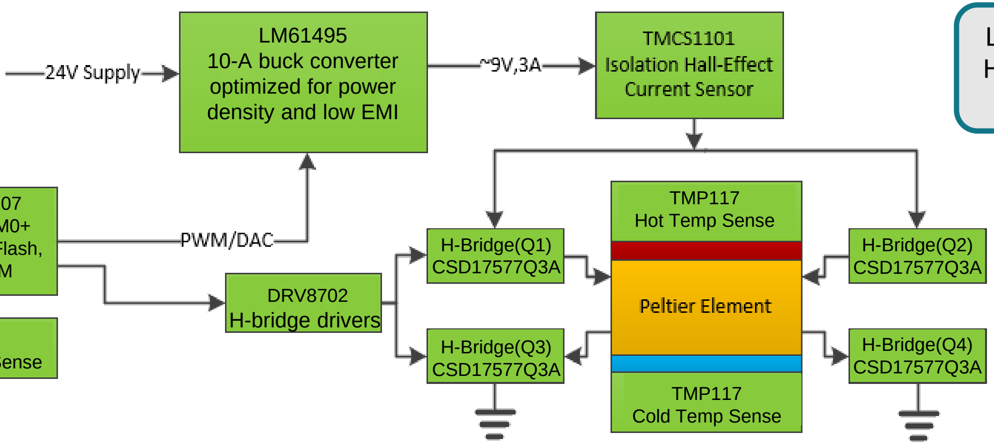
Easily voltage control with the FB from DAC

Design Spec:

- Vin = 15V
- Vout = 5V to 25V
- I_{max} = 4.75A
- I_{ripple} < 4%

	Controller	Buck-Boost	Temp Sense
GPN	AFE539A4 MSPM0XXX	LM5176	TMP117 TMP116
Description	Four-channel 10-bit smart analog front end (AFE) with PID/TEC control with built-in ADC and DAC	• 55-V Wide VIN Synchronous 4-switch Buck-boost Controller	0.1ºC Digital Temperature Sensor Lower power and Lower cost than Class AA RTD Equivalent

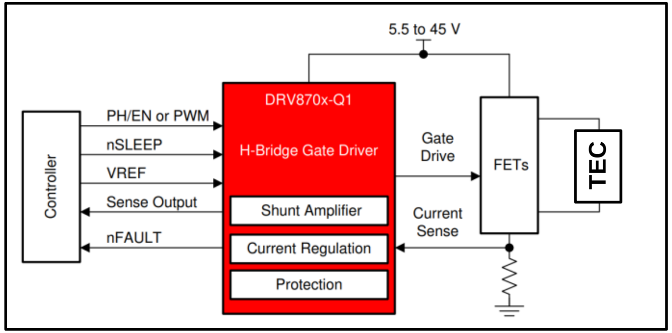
Thermo-Electric Cooling (TEC) | Discrete H-bridge driver



Low power, No calibration, Higher accuracy I2C digital Temp sensor

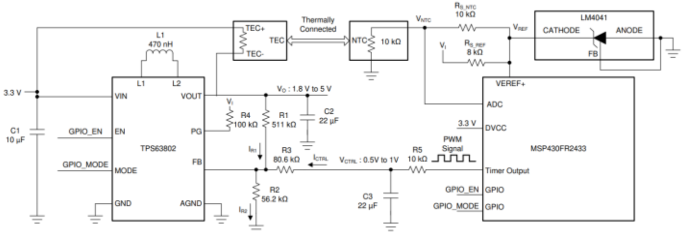
Flexible H bridge supports high power TEC application

	Driver	Current Sense	Temp Sense
GPN	DRV8702	INA260 TMCS1101	TMP117
Description	H-bridge motor drivers w/ low-pass filter to deliver high-efficiency bi-polar drive	Precision Current and Power Monitor With Low-Drift, Precision Integrated Shunt	0.1ºC Digital Temperature Sensor Lower power and Lower cost than Class AA RTD Equivalent



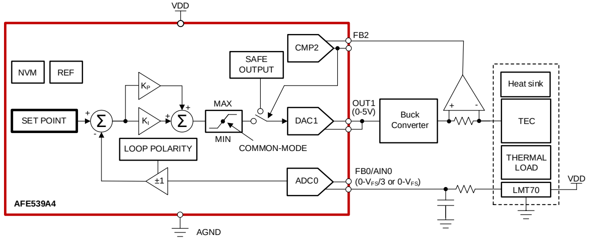
PID control | Smart AFE vs MCU

MCU



MCU-based PID control is suitable where the loop architecture needs to be highly flexible. These designs can handle complex control applications although the systems lack portability across designs due to software designed for specific processors.

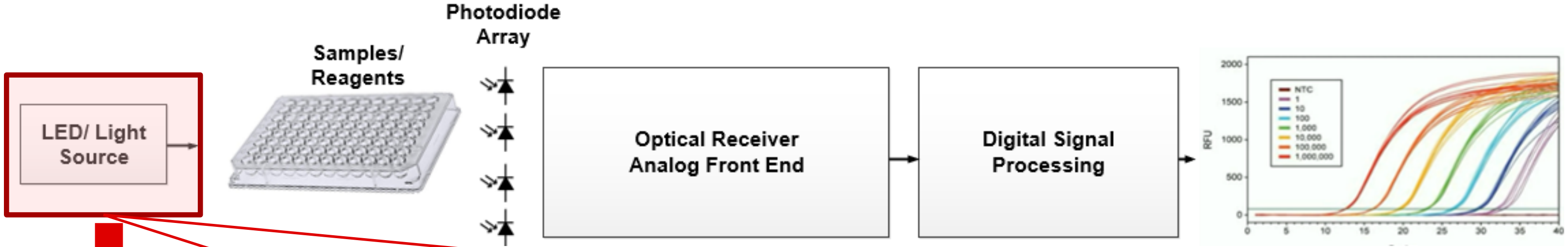
Smart AFE



Smart AFEs integrate PI control suitable for slow control loops like heating, cooling etc. These designs integrate the control loop while keeping the power converter outside thus making the system design modular, portable, and scalable. The smart AFEs can also work alongside MCUs to accept setpoints while controlling the loop autonomously.

LED / Laser driver

LED / Laser driver | Solution overview



LED/ Light Source

Samples/ Reagents

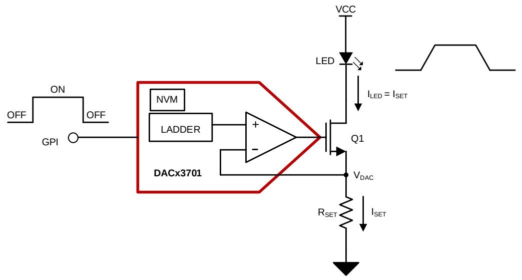
Photodiode Array

Optical Receiver Analog Front End

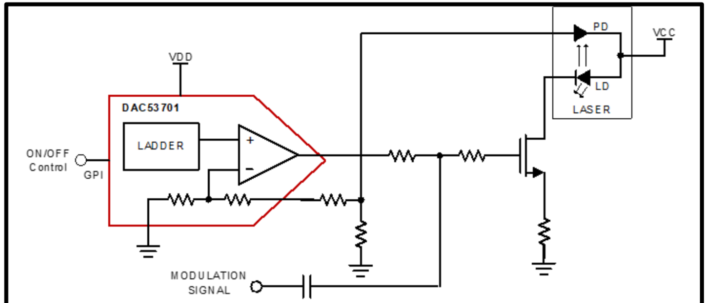
Digital Signal Processing

- Halogen Lamp
- Xenon lamp
- LED
- Laser

LED/Laser



Analog power control

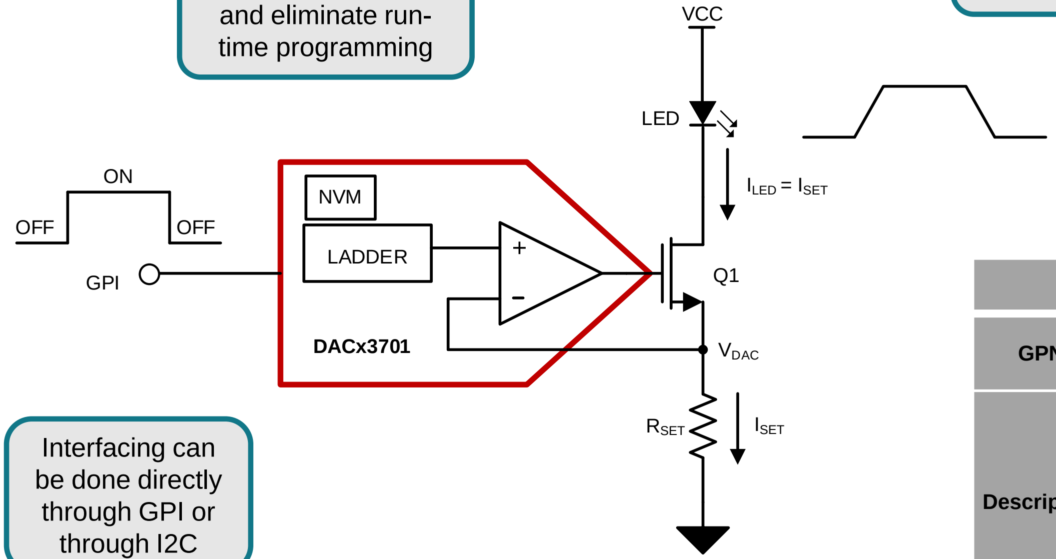


LED / Laser driver

DAC53701 LED Biasing

Program at factory and eliminate run-time programming

Simple way to set an accurate bias point for the LED



Interfacing can be done directly through GPI or through I2C

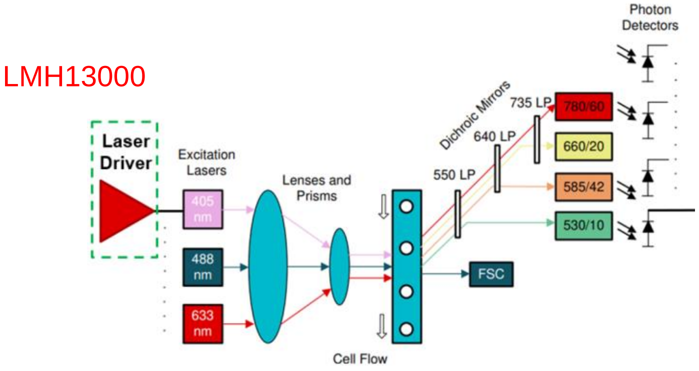
	Smart DAC	Precision DAC	Mosfet
GPN	DAC63004 DAC53701	DAC60501	CSD19538Q2
Description	Ultra-low-power quad-channel 12-bit smart DAC with I²C, SPI and PWM	True 12-bit, 1-ch, SPI/I2C, voltage-output DAC in WSON package with precision internal reference	100-V, N channel NexFET™ power MOSFET, single SON 2 mm x 2 mm, 59 mOhm

LED / Laser driver | High Speed laser diver LMH13000

Features

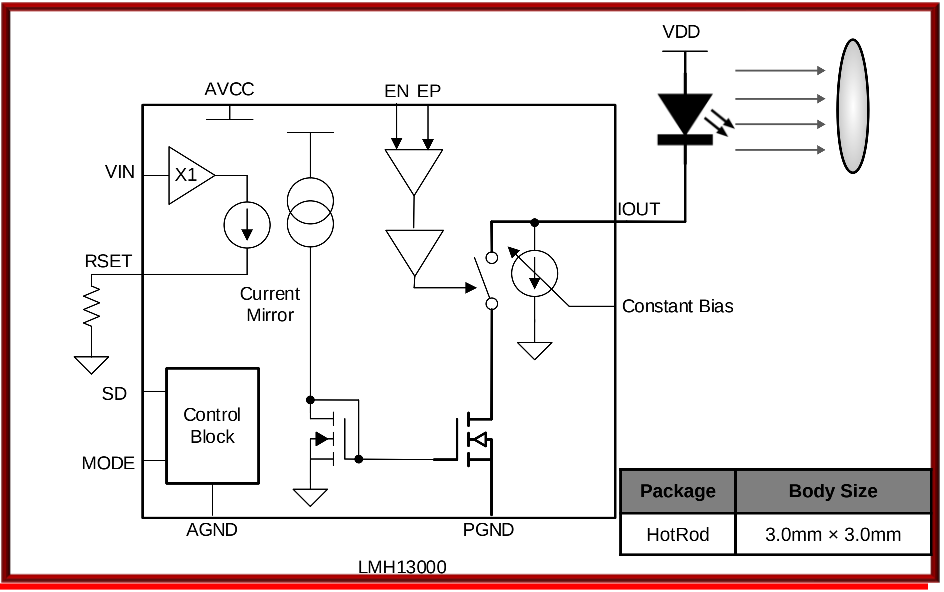
- **Adjustable IOUT current for power and λ :** 0.1A to 5 A
- **Adjustable output frequency:** DC to 250 MHz
  - **Use EP & EN for creating square wave / narrow pulses / DC**
- **Supply Range:** AVCC = 3 - 5V , VDD = 18V
- **IOUT Temp Drift:** < 0.5% between – 40C to125C
- **IOUT Noise** : < 0.5 % of IOUT value.

Applications



Benefits

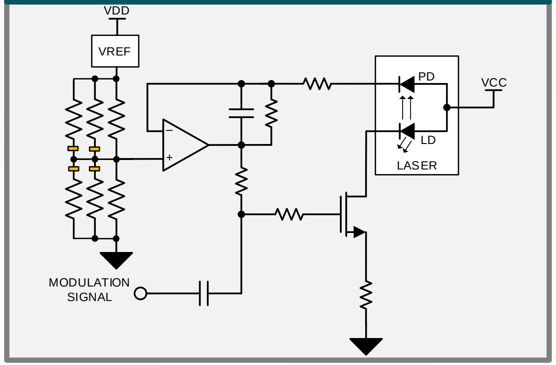
- Simplified Current Pulse generation using LMH13000
- Precise peak current control in pulsed / square wave / DC operation
- Integrated constant bias generator for achieving fixed DC current at IOUT
- Supports DC and High frequency current output



Package	Body Size
HotRod	3.0mm × 3.0mm

APC | Differentiation

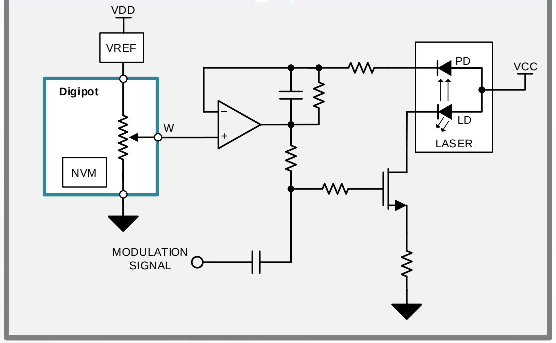
Resistor divider



Challenges:

- Requires external reference
- Limited programming steps
- Resistor mismatch

Digipot



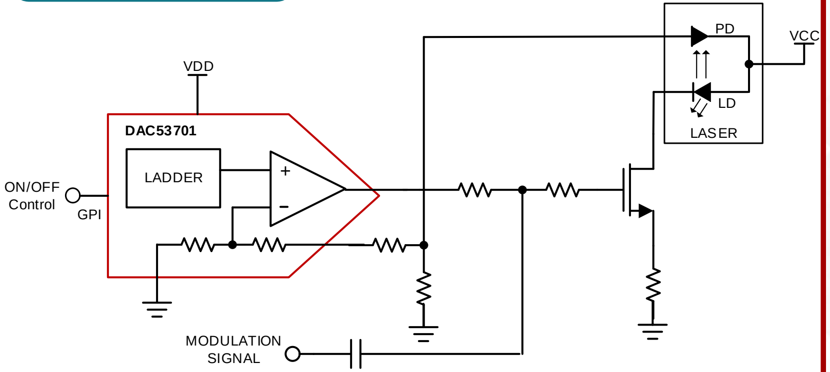
Challenges:

- Requires external reference
- Requires external buffer
- Large area

DAC53701 differentiation

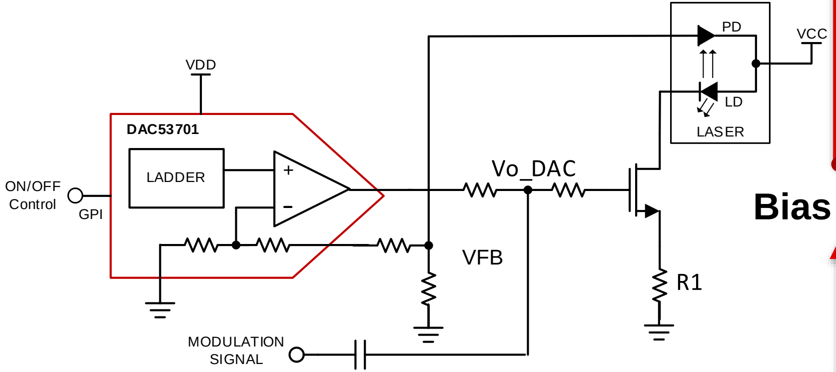
Integrated buffer and reference to minimize area

Simple way to create accurate bias point for the laser with closed loop control



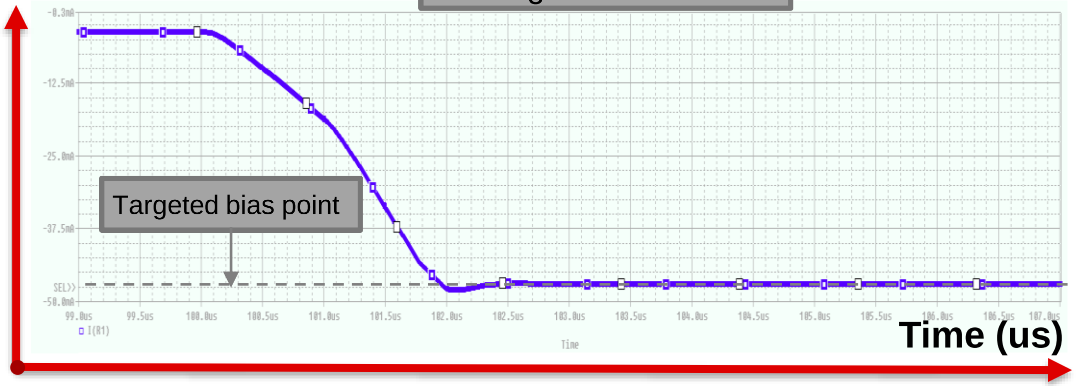
Store configurations and bias point in EEPROM for complete software independence

Simulation | Biasing



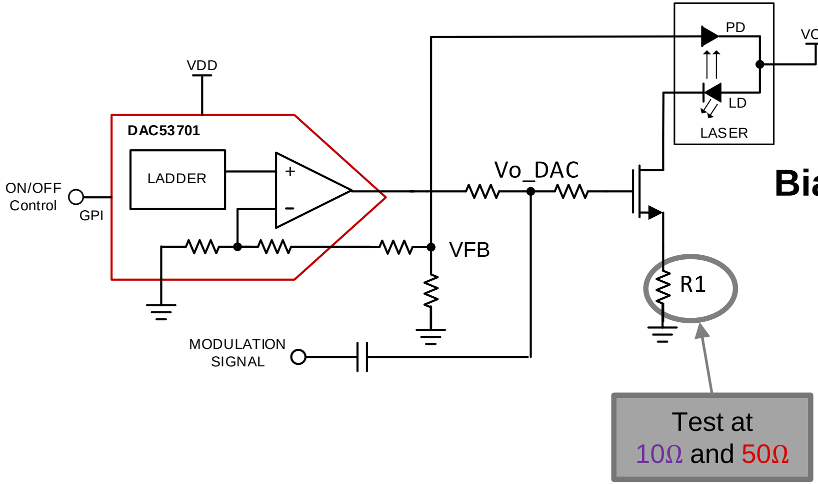
Bias current (mA)

Biasing current vs time

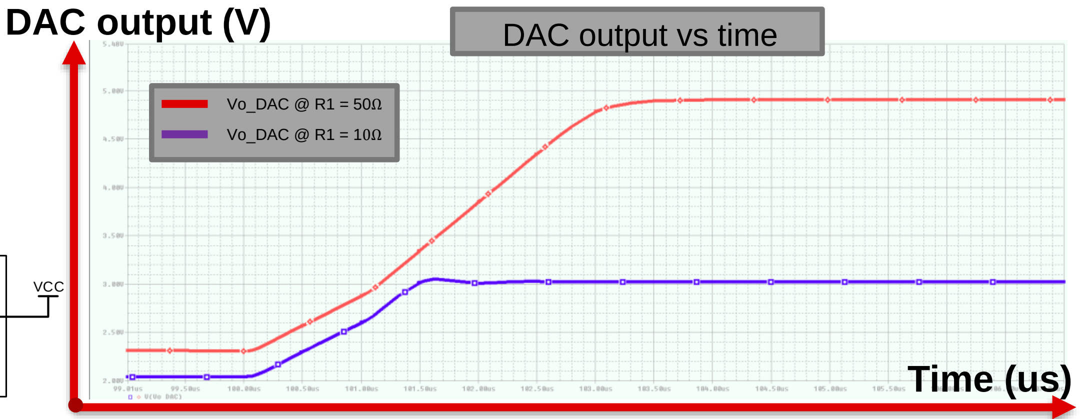


Targeted bias point

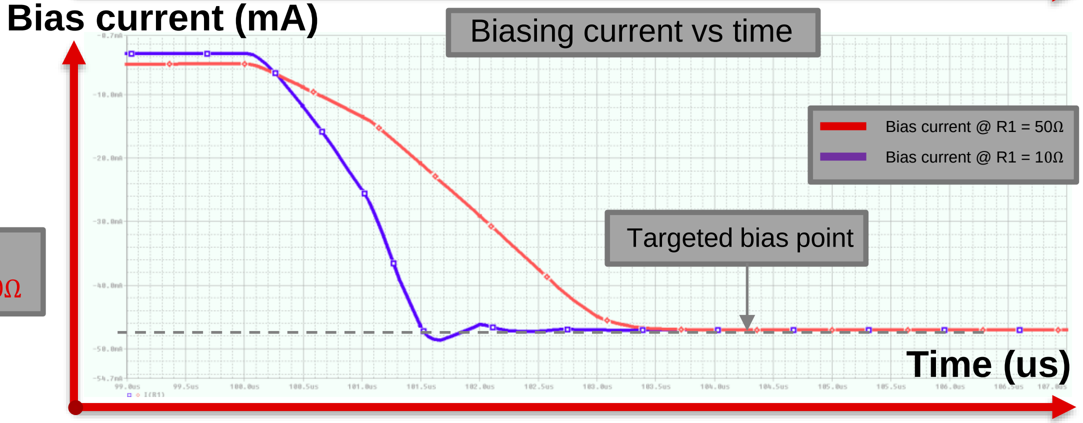
Simulation | Robustness



Test at 10Ω and 50Ω



DAC output vs time



Biasing current vs time

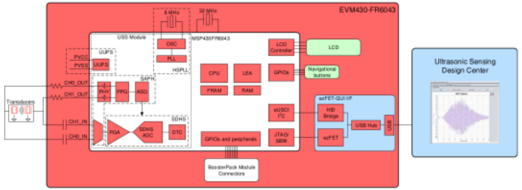
Targeted bias point

Liquid level sensing

Texas Instruments

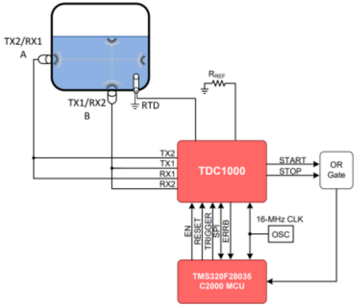
Liquid level sensing | Solution overview

MSP430FR5/604x



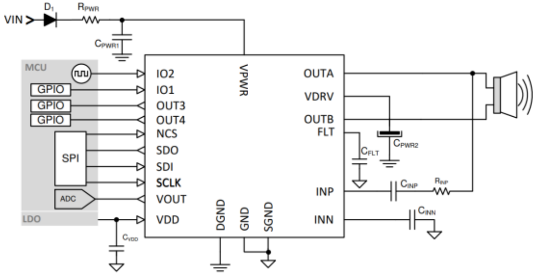
Supported Frequencies: 133kHz – 2.5MHz
Device: AFE+MCU
Voltage range: 2.2V – 3.6V
Output: TOF
Current Consumption: 3µA @ 1SPS (Water)
Other Features: Low Energy Accelerator, Full-MCU, 6.5dB – 30.8dB PGA, 30nA Shutdown

TDC1000



Supported Frequencies: 31.25kHz – 4MHz
Device: AFE
Voltage range: 2.7V – 5.5V
Output: Start/Stop Signals
Current Consumption: 1.8µA @ 2SPS
Other Features: Temp Sense Interface for 2 RTDs, 0dB -21dB PGA

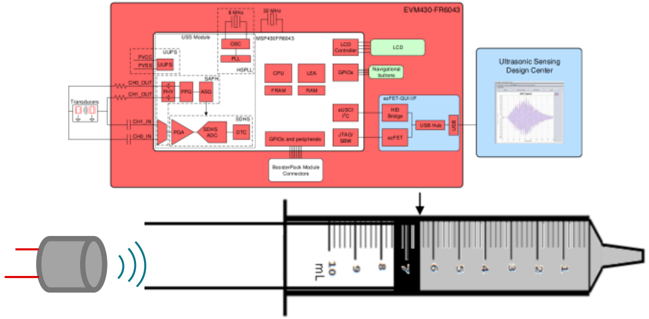
TUSS4470

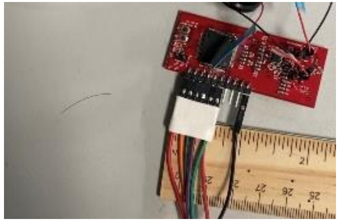


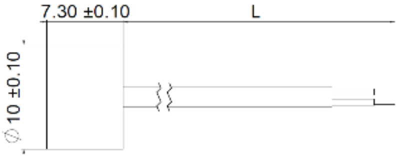
Supported Frequencies: 40kHz – 1MHz
Device: AFE
Voltage range: 5V – 36V
Output: Demodulated Echo Envelope
Current Consumption: 1.7mA Standby
Other Features: Up to 86dB of gain, LNA, configurable Band-pass filter, Log amplifier.

Liquid level sensing | µm distance sensing for dosing (Ultrasonic)

Solution Overview







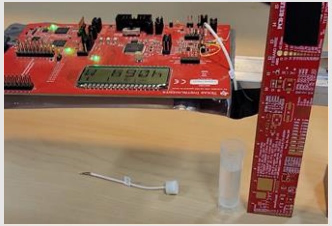
Complete Assembly

300kHz Transducer (Units: mm)

Key Spec of the Ultrasound solution

- ✓Sub to 50µm Distance sensing accuracy
  - <0.004mL Steps with a 10mm diameter plunger
- ✓Because a full MCU is used, this solution can be used as main processor or co-processor to control other peripherals
- ✓ Possibility to multiplex several sensor nodes

Parameter	Value
Power Consumption	49µW / Sample
Response time	7ms

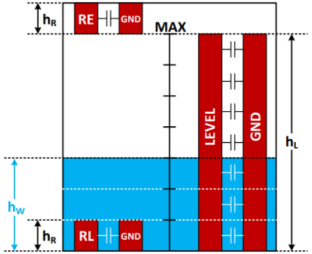


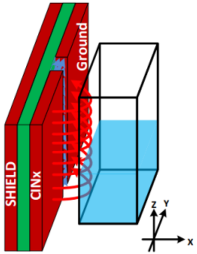
Distance Sensing Demo

Liquid level sensing | Capacitive level sensing

What is Capacitive Level Sensing

As a dielectric liquid is introduced between the electrodes of the capacitor, the capacitance changes proportionately and liquid level can be determined. TI's solution incorporates **an active shield** to further stabilize the measurements and maximize the SNR.

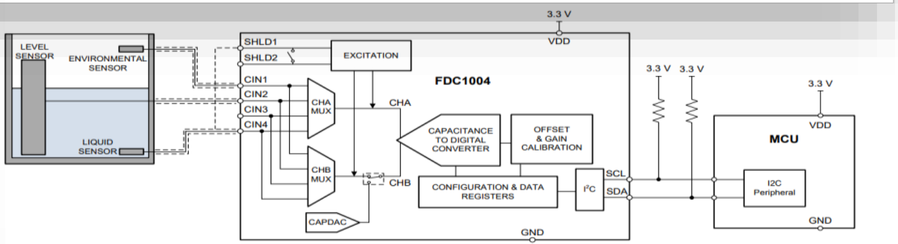




$$Level = h_{RL}\frac{C_{level} - C_{level}(0)}{C_{RL} - C_{RE}}$$

Capacitive Technology Benefit

- ✓ Contactless solution can be prone to rust
- ✓ Low cost and highly flexible system design
- ✓ Accurate liquid height resolution (<1mm)
- ✓ Can implement using a flex PCB



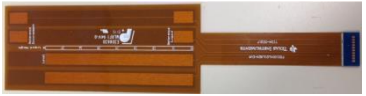
Reference Design

Video Series:

- Liquid-level sensing using the FDC1004EVM

Technical Articles:

- A novel approach for capacitive based liquid level sensing



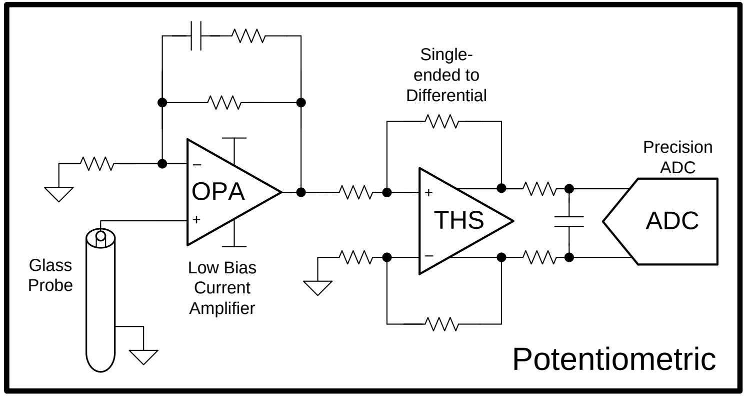
Reference Design

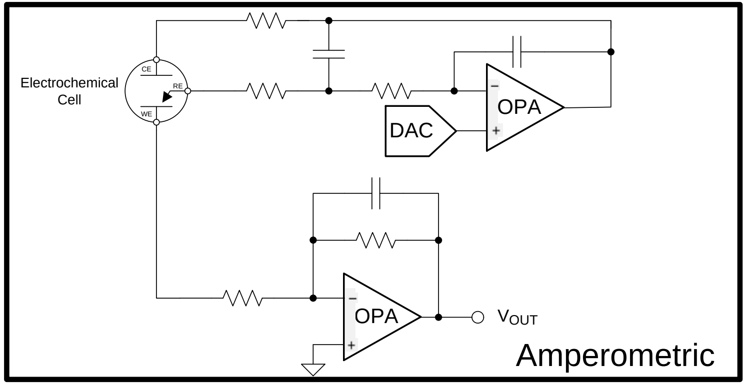
- TIDA-00317 Capacitive-Based Liquid Level

Part Number	Description
FDC1004	• 4-Channel Capacitance-to-Digital Converter for Capacitive Sensing Solutions
FDC2212/4	• 28-Bit,12-Bit Capacitance-to-Digital Converter for Proximity and Level Sensing Applications – 13.3 ksps (FDC2112, FDC2114) – 4.08 ksps (FDC2212, FDC2214)
FDC2112/4	

Electrochemical sensing

Electrochemical sensing | solution overview





Design Challenge: Accurate detection of low voltages and currents to measure blood gases, pH and electrolytes using Potentiometric and Amperometric measurements.

Solution: A low noise and high accuracy (including low Ibias and drifts) analog front ends are essential for accuracy & reliability. The OPA192 is used to measure low currents (100uA-100nA) for the Amperometric measurement.

Parameter	Low Offset and Bias Current Amplifiers	Fully Differential Amplifiers	Precision Analog-to-Digital Converters	Digital-to-Analog Converters
GPN	OPA391 OPA140 OPA928	THP210 THS4551	ADS127L01 ADS127L11 ADS8900B	DAC60501 DAC70501 DAC80501
Description	Low I_B, Low noise precision amplifiers	Low noise, fast transient response FDAs	Wide Bandwidth, High Resolution ADCs	Small 12–16 bit DACs with multiple channel options
MPM Collateral	▪ In-Vitro Diagnostics EERD ▪ Sensor Front Ends			

In-Vitro Diagnostics Resources on TI.com

Precision Optical

- Designing signal chains for portable diagnostics
- Achieving faster, more accurate patient diagnoses with molecular test technology
- OPA928 Product Page
- Resolution-Boosting ADS7066 Using Programmable Averaging Filter

High Speed Optical

- High speed ADCs and Amplifiers for Flow Cytometry
- Flow Cytometry PSPICE Simulation
- Photodiode Amplifier Design
- Why Oversample when Undersampling can do the Job?
- Understanding JESD204B Subclasses and Deterministic Latency

Impedance Spectroscopy

- Impedance Spectroscopy Simulation (Differential)
- Impedance Spectroscopy Simulation (Single-Ended)

Thermoelectric Cooling

- Driving a Peltier Element (TEC) Reference Design
- Low Power TEC Driver Reference Design
- Bidirectional TEC Driver Design for 40-W TEC
- Closed-Loop TEC Control Circuit Using a Voltage-Output Smart AFE and DC/DC

Electrochemical Sensing

- Compensate Transimpedance Amplifiers Intuitively (Rev. A)
- Micropower Electrochemical Gas Sensor Amplifier Reference Design (Rev. B)
- ADS127L01 Product Page
- Fundamentals of Precision ADC Noise Analysis

Motor Automation

- DRV8462 Product Page
- Methods to Configure Current Regulation for Brushed and Stepper Motors (Rev. B)
- How to Reduce Audible Noise in Stepper Motors
- Sensorless Stall Detection With the DRV8889-Q1

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