Analog Front End Design for In-Vitro Diagnostic Applications

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In Vitro Diagnostic Equipment Landscape

	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

Key Technology Blocks

- **Precision Optical** – Precision measurement of charge or current from a opto-electronic receiver such as a photodiode is common in IVD. Many technologies such as PCR or Immunoassay systems use an assay or reagent to create a fluorescent or color change in a sample that will indicate the presence of a specific chemical or marker.
- **High Speed Optical**– In some cases, such as flow cytometry, the bandwidth requirements for light analysis can extend to several hundred Megahertz, requiring wide bandwidth amplifiers and Analog-to-Digital Converters (ADC).
- **Thermoelectric Cooling (TEC)** – Temperature measurement and control is essential for accuracy and fundamental for technologies such as PCR, where temperature cycling is required for sample analysis.
  Electrochemical Sensing Front End – Classic chemical measurement techniques are required for systems such as Blood Gas Analyzers, where voltage (potentiometry) or current (amperometry) measurements are needed for PH, CO2, Glucose and hundreds of other elemental quantities.
- **Motor Automation** – Motors play a key role in large lab-grade diagnostic equipment such as immunoassay analyzers, where sample throughput is critical.

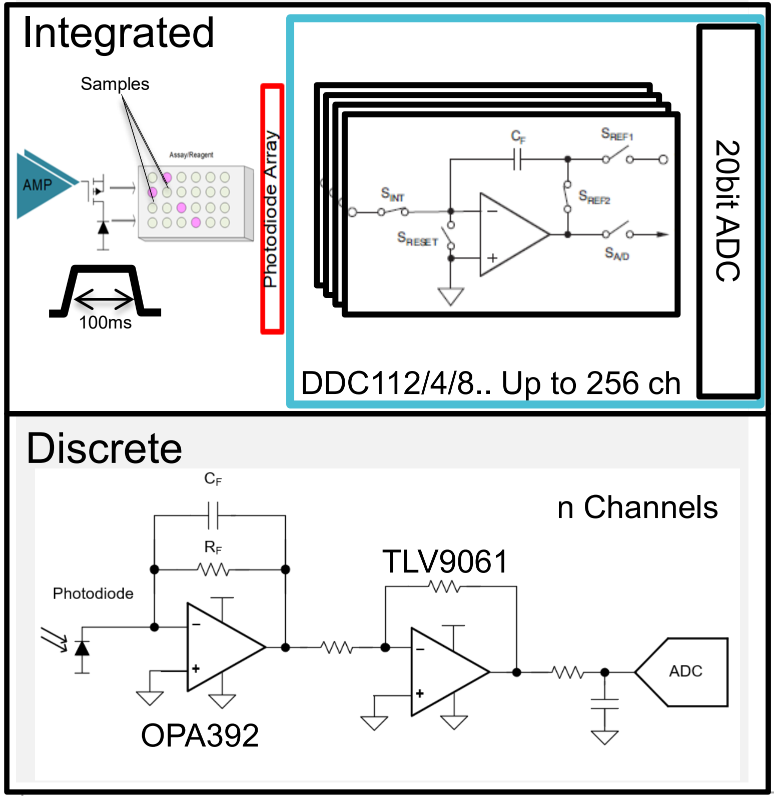
Agenda

- In Vitro Diagnostics Subsystems
  - Precision Optical
  - High-Speed Optical
  - Impedance Spectroscopy
  - Thermoelectric Cooling
  - Electrochemical Sensing
  - Motor/Motion Control

Precision Optical

Precision Optical: Overview

Block Diagram



System Design Challenge

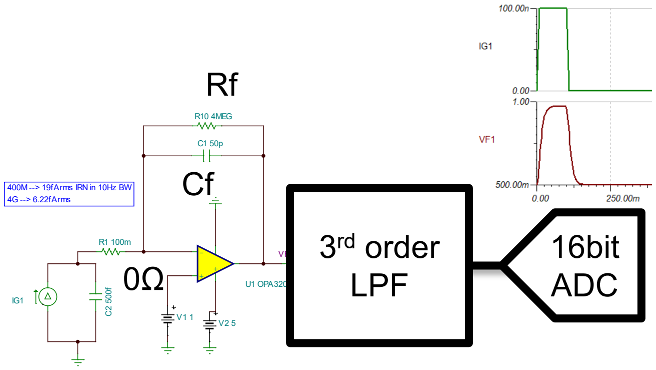
Design Challenge: Accurate detection of very low light levels is needed in NAAT to measure the instant (quantification cycle, Cp) at which the fluorescence emission exceeds a given threshold, right above the noise.

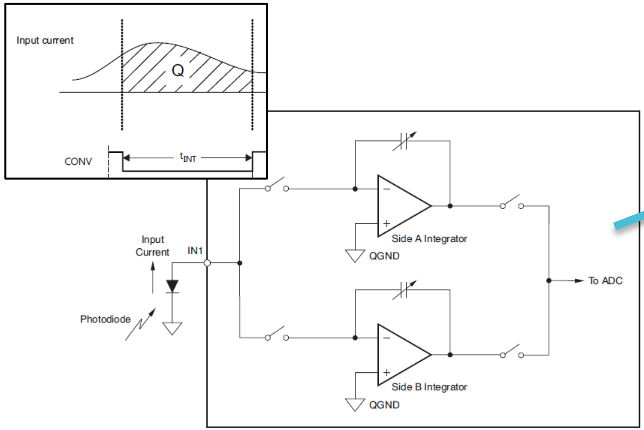
Solution: The DDC11x integrates all the signal between two instants in time delivering directly the answer (all emitted photons). The low noise and high accuracy (low Ibias and drifts) and integration of the full signal chain (TIA and ADC) saves space and hides the design complexity for designers, reducing time to market and lowering risk.

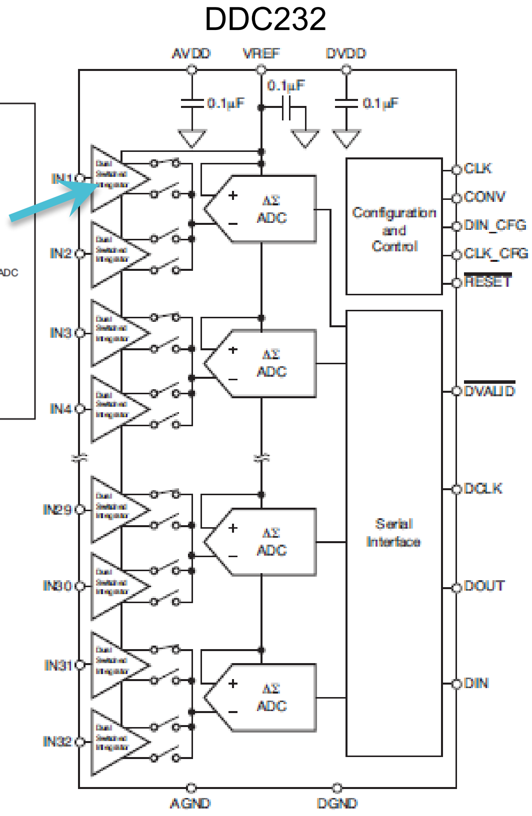
Key Devices + Collateral

Parameter	Integrated	Discrete
GPN	DDC112 (2 channels) DDC114 (4 channels) DDC118 (8 channels) DDC232 (32 channels)	OPAx392 Low I_B, Low noise precision amplifier TLV9061 Low I_B, tiny general purpose amplifier ADS7066 16ch SAR ADC ADS124S08 24 bit ΔΣ ADC
Description	Integrates all current between two instants in time + 20b ADC • Adjustable full scale range from 6.25pA to 3uA. • Fs: 1SPS to 100KSPS* • Up to 0.37fArms IRN • I_B: 0.1pA typical	Discrete Transimpedance Analog Front End allows for customization and flexibility OPAx392 has I_N : 40fA/rtHz, I_b : 10fA, GBW: 13MHz ADS7066 16 bit, 8 ch, F_s up to 250kSPS
MPM Collateral	▪ DDC11xEVM-PDK Eval Board ▪ In-Vitro Diagnostics EERD	

Precision Optical: Integrated Solution (DDCx)

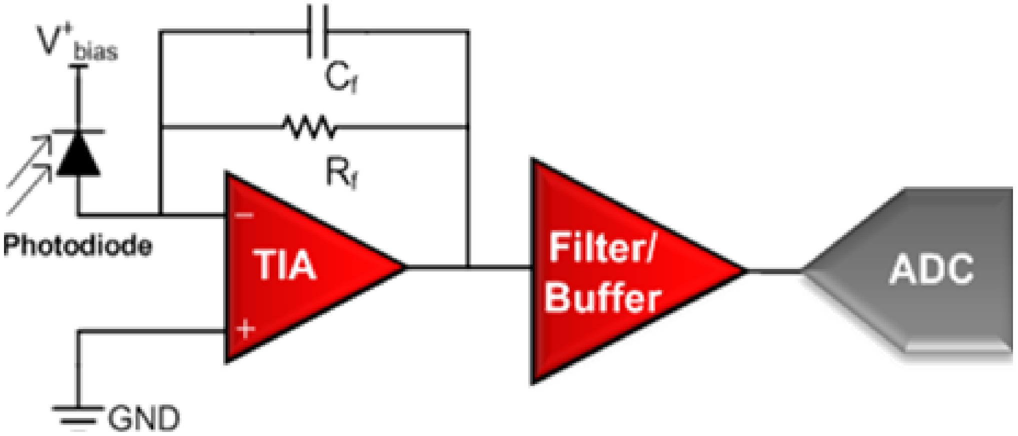






1. Large number of channels (from 2 to 256 channels fully integrated solution, including ADC).
2. Integration for total (or average) signal between two instants in time.
3. Programmability for different gain or bandwidth settings. Difficult to implement discretely and obtain excellent performance.
4. Easy of design and use. No calibration required in many cases. System performance reflected on the datasheet.
5. Relatively slow signals (~3KSPS max…). Integration BW ~MHz.
6. Relatively small currents ~1uA max. (There are techniques to extend the range but not out of the box and degrade performance).

Precision Optical: Electronic Signal Chain



1. **Transimpedance Amplifier (TIA):** converts current, generated by a photodiode, into voltage that drives the FDA for a differential input ADC. Must be low I_b and low I_n such as OPAx392)

2. **Filter/Buffer:** used to drive ADC input. Can also be used for additional filtering/gain. Could be Buffer/Amplifier (OPAx392/TLV9061) for single-ended ADC or FDA (THS4551) for differential ADC.

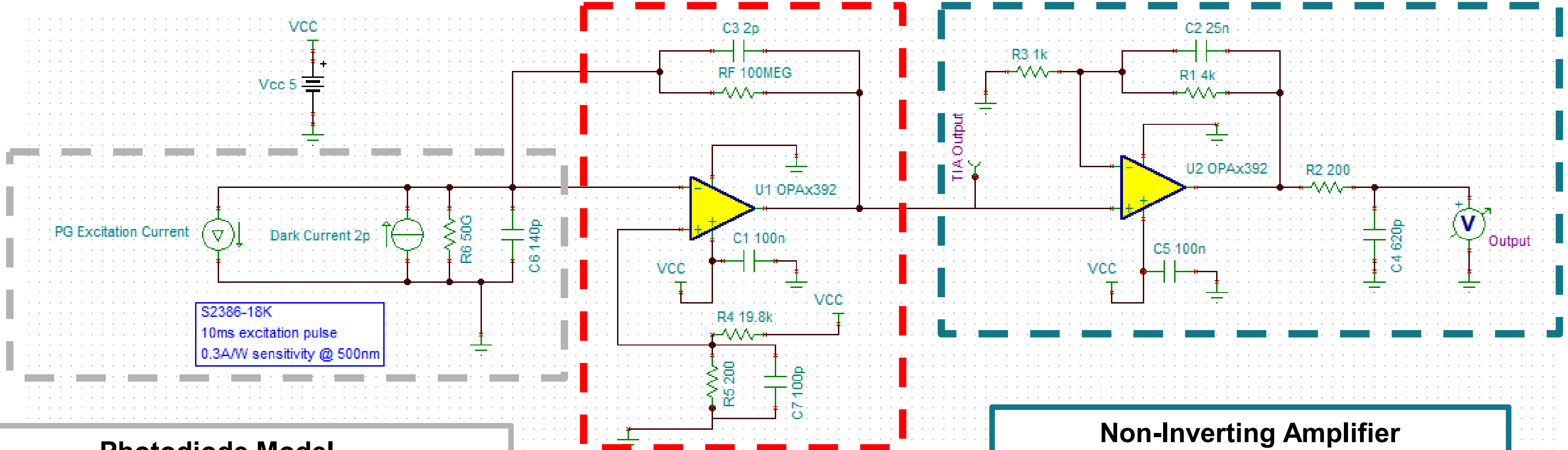
3. **ADC:** multiple channels at high resolution are often required. Could be SAR (ADS7066) or Delta-Sigma (ADS124S08) architecture depending on timing requirements.

Precision Optical: Schematic

Specifications

- **Excitation Pulse:** 10ms pulse, 32Hz
- **Current Range:** ~0.476pA to 9.4nA
- **Resolution:** 14.27bits
- **Supply Voltage:** 5V single rail

*Passive components can be adjusted for various excitation range and timing requirements



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 (10fA)

Non-Inverting Amplifier

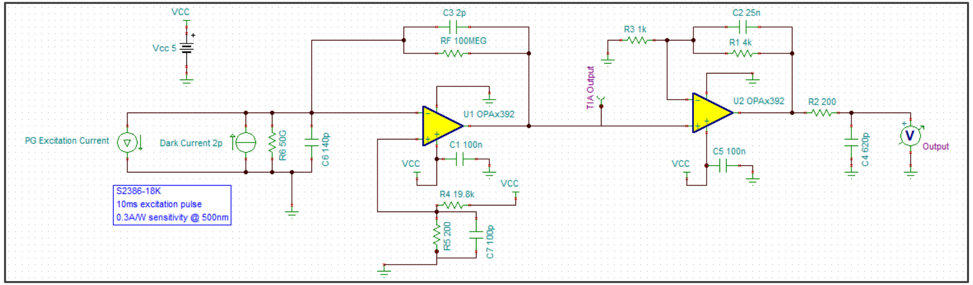
OPA2392 Precision Op Amp
- High GBW (13MHz)
- Smaller BOM using 2^{nd} channel

Precision Optical: Sensitivity

$$I_{max} = \frac{V_{max\_swing}}{R_F \times G_{NIA}} = \frac{4.70V}{500M} = 9.4nA$$

$$Optical\ Sensitivity = \frac{V_{n-out}}{R_F \times G_{NIA}}(rms) \times 6 = \frac{266.8uArms}{500M} \times 6$$
$$= \mathbf{3.19pA}\ (\mathbf{0.476pA}\ \text{with 50 sample averaging (6.8ksps)})$$

$$Dynamic\ Range = \frac{9.4nA}{4.41pA} = 2.2k$$
$$= \mathbf{11.1bits}\ (\mathbf{14.27bits}\ with\ 50\ sample\ averaging\ (6.8ksps))$$



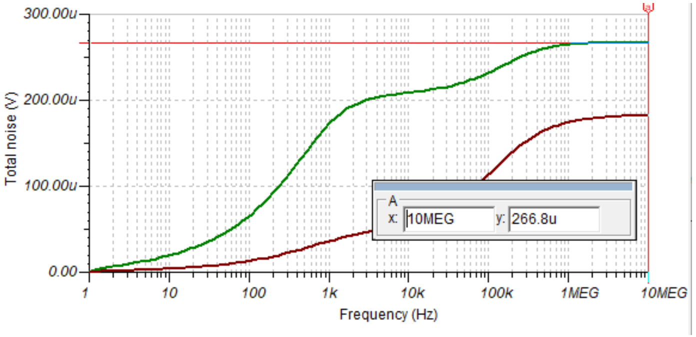


Figure 2. Total Noise vs. Frequency

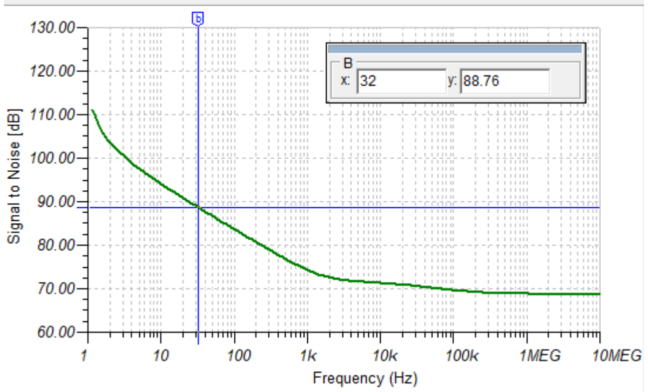


Figure 3. SNR at 32Hz input

G_{NIA} = Gain of Non-inverting amp

Texas Instruments

Precision Optical: AC Performance

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

$$F_{-3dB} = 670Hz$$

$$Phase\ Margin = 88.7°$$

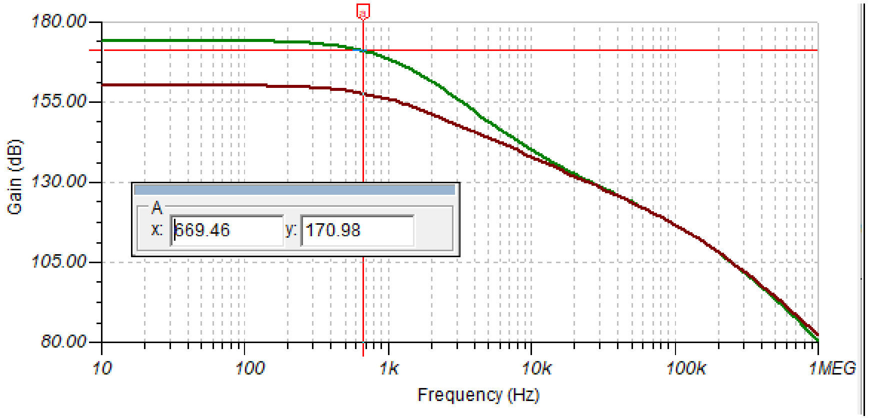
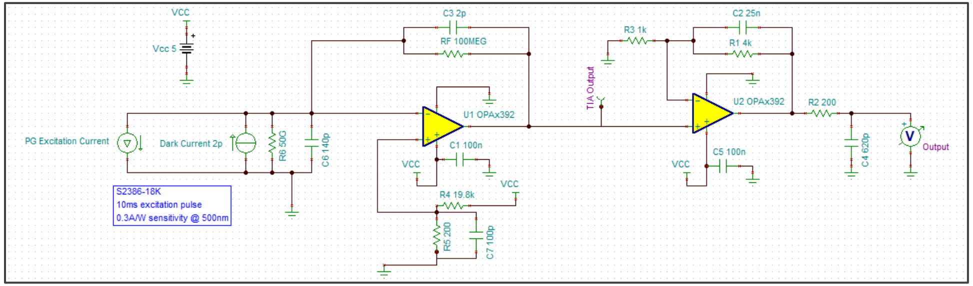


Figure 1. AC Transfer Characteristic

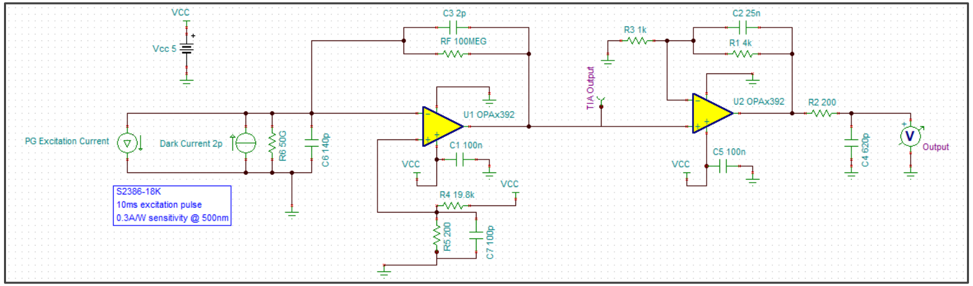


Precision Optical: Accuracy

Error:

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

$$Accuracy = 1 - \frac{Error\ (worst\ case)}{Full\ Scale\ Range} = 1 - \frac{12.9\text{mV}}{4.95\text{V}} = \mathbf{0.997}$$



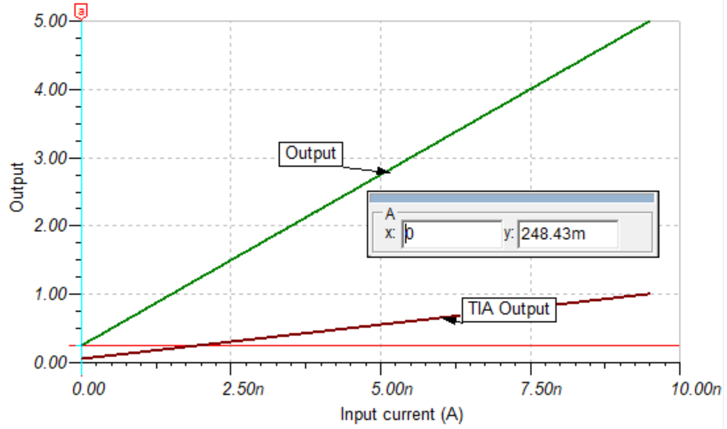


Figure 4. DC Transfer Characteristic

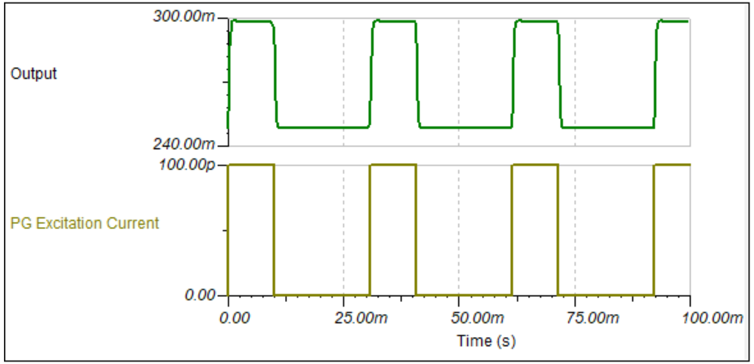
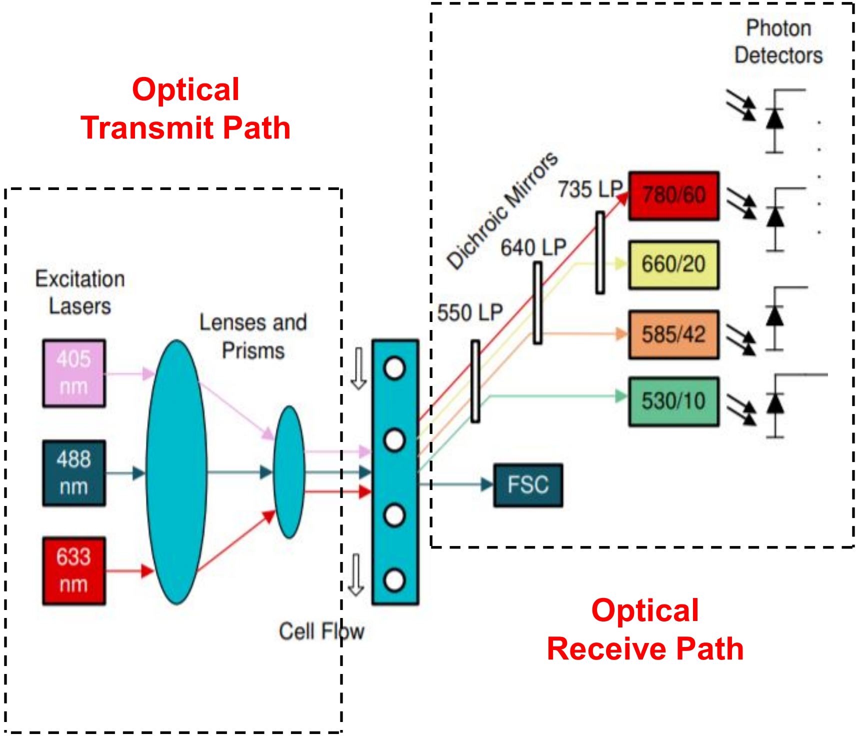


Figure 5. Transient Response 10ms 100pA pulse @32Hz

High Speed Optical

High Speed Optical: Optics and Sample



1. **Excitation Lasers:** Lasers are utilized as coherent, focused excitation light sources in order to excite florescent dyes and provide light for particle scatter measures.

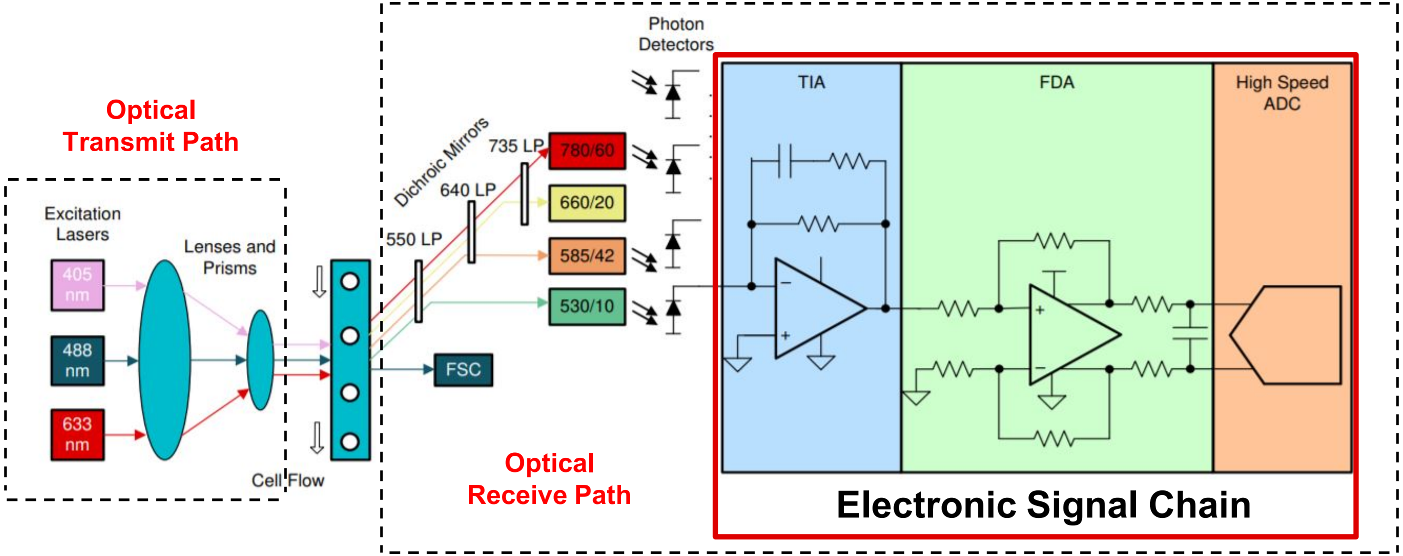
2. **Lenses and Prisms:** The light that shines through the cell and moves in various directions is collected by multiple detectors (either photodiodes or photomultiplier tubes, PMT).

3. **Cell Flow:** A constant, stable pressure is applied to a tank of fluid (called sheath tank) holding an isotonic solution (similar to a saline solution) to create a laminar flow for the cells to move in a single stream through a cuvette.

4. **Mirrors and Filters:** Dichroic mirrors are used to dissect the polychromatic fluorescence that is overlapping (acting as physical filters) from each cell scattering.

5. **Photo Detectors:** The electronic signal chain contains the electronics to convert current from the PMT or photodiode into digital electronic signals for plotting.

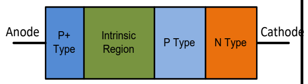
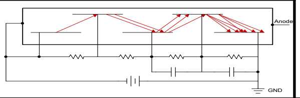
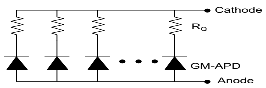
High Speed Optical: Electronic Signal Chain



1. **Transimpedance 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.

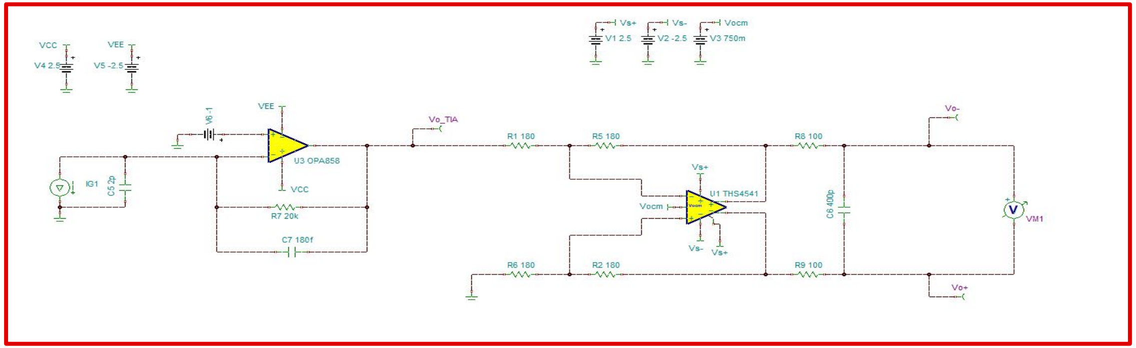
High Speed Optical: Photodetectors

Sensor	Description	Example Applications	Rise Time	Capacitance Range	Current Range	Dark Current
Photodiode (PD)  	• PN or PIN junction photodetector with no gain • Suitable for detecting bright forward light and side light scatter	• Chemistry Analyzer • qPCR • Optical Communication Systems	~30ps-1µs	~0.5pF-200pF	~10nA-100µA	~1pA-1nA
Avalanche PD (APD)  	• Similar in structure to a PIN PD, but has intrinsic gain due to use of different doping profiles • Higher photosensitivity, responsivity and SNR compared to PD	• Flow Cytometry • Lidar • Optical Communication Systems	~0.5ns-100ns	~1pF-150pF	~100nA-1mA	~1nA-50nA
Photomultiplier Tube (PMT)  	• Vacuum tubes that contains a photocathode, anode, and multiple stages of dynodes in between for amplification • Suitable for detection of very low light or low scattering signals down to single photons	• Flow Cytometry • Hematology Analyzer • Spectroscopy • Confocal Microscopy • PET • HEP	~0.5ns-50ns	~0.1nF-10nF	~10µA-100µA	~30pA-10nA
Solid-State Photomultiplier (SiPM)  	• Solid-State photomultiplier which contains a parallel combination of Geiger-mode silicon APD • Responsivity levels similar to those of PMTs	• Flow Cytometry • DNA sequencers • Laser scan microscope • PET Scanners • Fluorescence measurement	~1ns-1µs	~50pF-1nF	~1µA-10mA	~10nA-10µA

High Speed Optical: TIA + FDA Simulation

1. Calculate the Feedback Resistance based on the desired Output Voltage and the Photo Detector's peak current
    - Determine the Feedback Capacitance using feedback resistance and Photo Detector's signal bandwidth
    - Determine Amplifier GBWP using total input capacitance, feedback resistance, and feedback capacitance
    - TIA's feedback resistance dominates the TIA's output noise
    - CMOS/FET Input TIA is preferred at higher resistance such as in the MΩ
2. Use FDA to convert single ended to differential input to drive ADC
3. TIA's output noise from ADC's SNR in time domain
    - Higher order filter can be added for noise reduction
4. Maximize ADC's input full scale for unipolar pulse

Sensor	Rise Time	Frequency Range	Capacitance Range	Input Current	Feedback Resistor at 2Vpp	Approx. GBW Range
PMT	~0.5ns-50ns	100MHz – 500MHz	1n	100μA	10kΩ	5.5GHz



Simulation Results: Photomultiplier Tube (PMT)

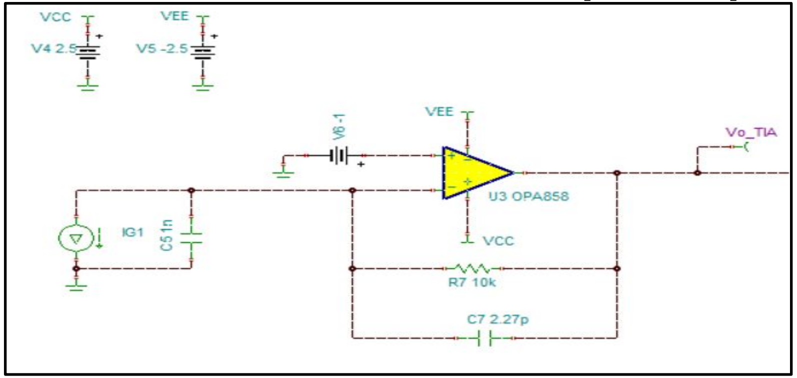
$$R_{Fmax} = \frac{V_{max\_swing}}{I_{max}} = \frac{1V}{100\mu A} = 10k\Omega$$

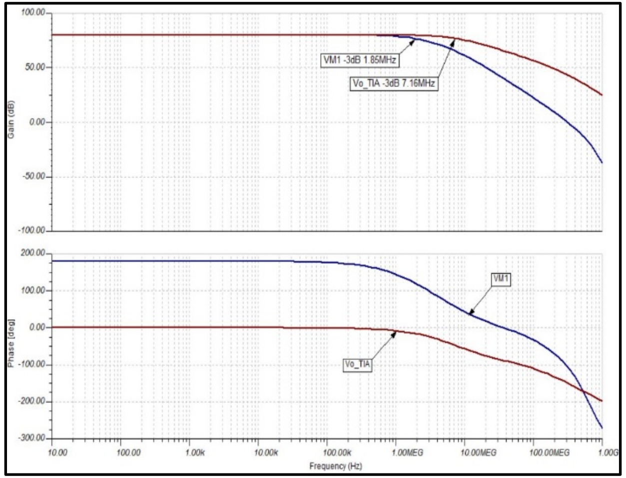
$$F_{-3dB} = \frac{0.35}{t_R} = \frac{0.35}{50ns} \approx 7MHz$$

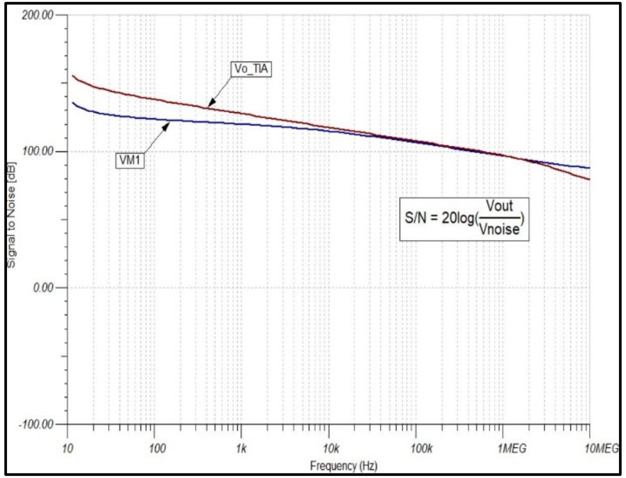
$$C_F = \frac{1}{2\pi R_F F_P} = 2.27pF$$

$$GBP \geq \frac{C_{TOT} + C_F}{2\pi R_F {C_F}^2} = 5.5GHz$$

OPA858: 5.5GHz
OPA855: 8GHz







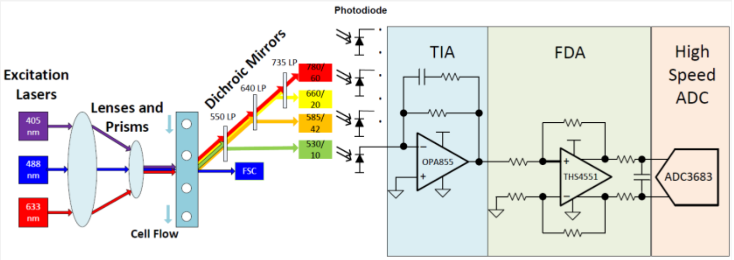
Simulation Results: TIA Selection

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	

High Speed Optical: Summary

Block Diagram

Flow Cytometry Front End



System Design Challenge

Design Challenge: Multiple channels (24~48) running at high speed (40~125MSPS) and high resolution (14~18bits). Received signals are typically low magnitude in uAs and hence need low noise transimpedance amplifier, >50MSPS, and 16~18bit multi-channel ADCs.

Solution: 14~16bit/80~125MSPS 4-8CH ADC family provide low power, high SNR, digital decimation/demodulation and advanced interfaces, eg. LVDS (1Gbps) and JESD204B (12.8Gbps). OPA818 provides low-noise current-to-voltage conversion. THS45xx acts as fully differential buffer for ADCs.

Key Devices + Collateral

Parameter	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
AFE Collateral	▪ Flow Cytometry Signal Chain ▪ Flow Cytometry Simulation TI.com ▪ Photodiode Amplifier Design	▪ Why use oversampling ▪ Understanding JESD204B Subclasses and Deterministic Latency

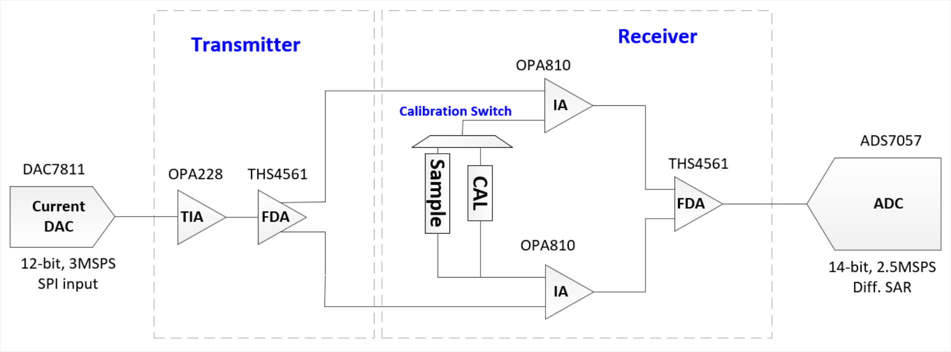
Impedance Spectroscopy

Impedance Spectroscopy: Overview

Design Challenge: Many Impedance Spectroscopy applications require customized excitation parameters while delivering measurements that have high SNR and minimized phase shift. These parameters affect how accurately a system can be calibrated to deliver highly accurate test results.

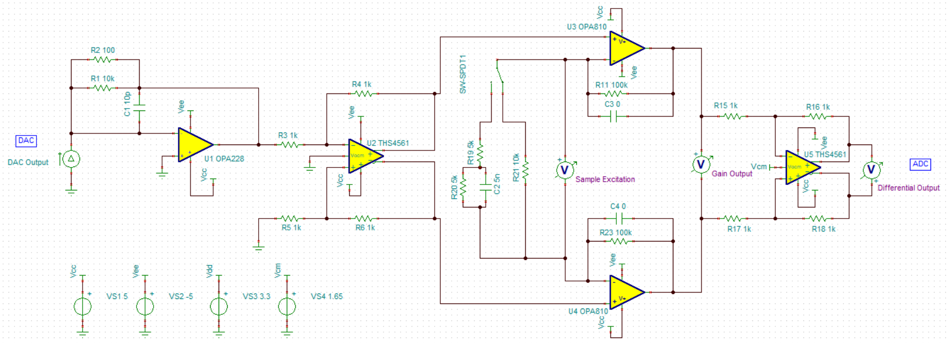
Solution: Impedance Spectroscopy measurements are applicable in many systems, ranging from blood test equipment to battery impedance testers. A discrete solution allows for a highly flexible solution that can deliver very low phase shift, and high SNR measurements using a wide range of excitation amplitudes and frequencies.

Key Devices + Collateral



Parameter	DAC	Amplifiers	Precision ADC
GPN	DAC7811	THS4561, OPA810, THP210, OPA228	ADS7057
Description	12-bit High Speed DAC with low noise for excitation signal generation	Precision High-Bandwith Amplifiers to maintain signal integrity while reducing signal phase shift	14-bit, 2.5MSPS Differential SAR ADC
MPM Collateral	Impedance Spectroscopy Simulation (Differential) Impedance Spectroscopy Simulation (Single-Ended)		

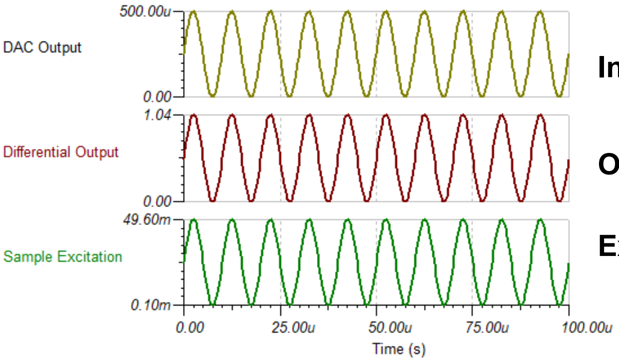
Impedance Spectroscopy: Simulation – Differential



Original Specifications

- **Excitation Frequency:** 10mHz-100kHz
- **Frequency resolution:** 12bit 2.5MSPS DAC
- **Excitation Voltage:** 1mV-200mV.
- **Impedance Range:** 1ohm-10Mohm
- **Number of electrodes:** Dual electrode probe, such as a coaxial probe

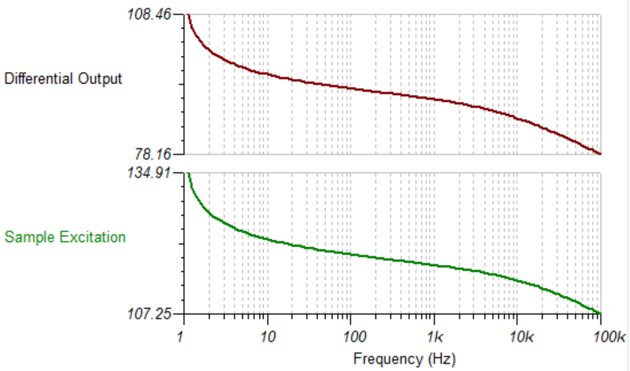
Impedance Spectroscopy Simulation (Differential) TI.com Link



Input Signal = 500uA p-p

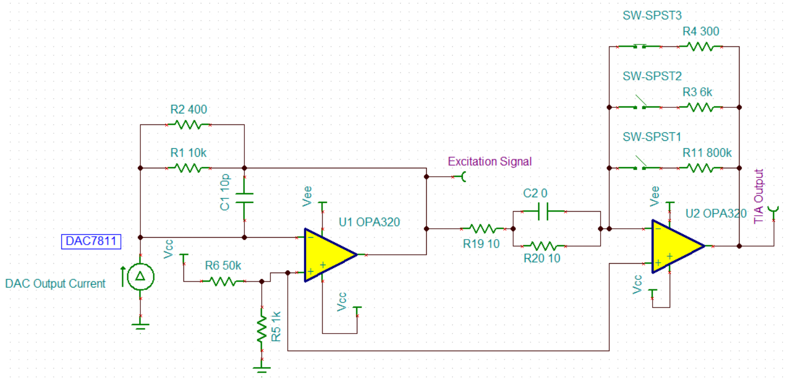
Output Signal = 192.3 mV p-p

Excitation= 49.5mV p-p



SNR @ output = 78.16dB @ 100kHz

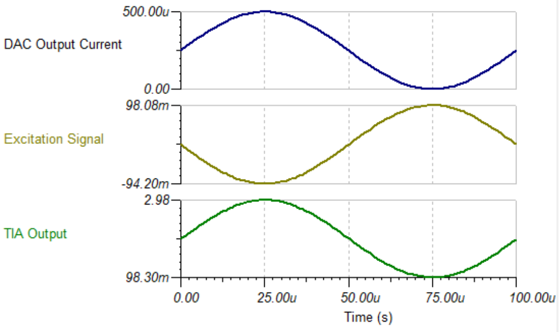
Impedance Spectroscopy: Simulation – Single-Ended



Original Specifications

- **Excitation Frequency:** 10mHz-30kHz
- **Frequency resolution:** 12bit 2.5MSPS DAC
- **Excitation Voltage:** 100mV-2V.
- **Impedance Range:** 1ohm-1Mohm
- **Number of electrodes:** Dual electrode probe, such as a coaxial probe

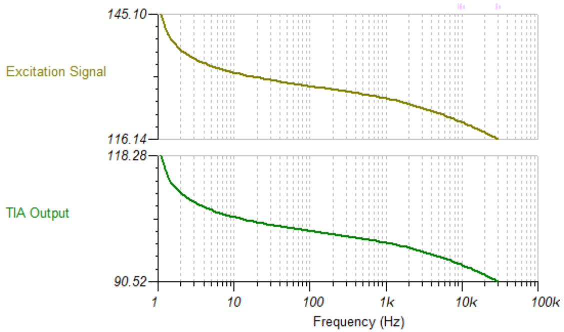
Impedance Spectroscopy Simulation (Single-Ended) TI.com Link



Input Signal = 500uA p-p

Excitation = 192.3 mV p-p

Output Signal = 2.88V p-p



SNR @ output = 90.52dB @ 30kHz

OPA3S328 – 1pA I_B, high precision, high speed (40MHz), zero-crossover RRIO with Integrated Switches

AFE4500: A Device Overview

Analog Front End for Voltage, Current and Impedance Sensing

Features

- ➢ Simultaneous signal acquisition from different LED sensors at different data rates, high input impedance INA and impedance.
- ➢ 24 highly flexible sampling phases.

OPTICAL SIGNAL CHAIN:

LED Receiver:

- 2 parallel receivers (two sets of TIA/ filter)
- Individual DC Offset Subtraction DAC at each TIA Input with 8-bit per-phase control , Range ~16µA-256 µA
- Automatic DC cancellation and dynamic LED DC cancellation at TIA input
- Trans-impedance Gain: 3.7 kΩ to 1 MΩ

LED Transmitter:

- 8-Bit Programmable LED Current with range adjustable from 25 mA to 250 mA
- Mode to fire two LEDs in parallel with independent per-phase current control
- Support of 8 LEDs in Common Anode configuration for Multi-Wavelengths

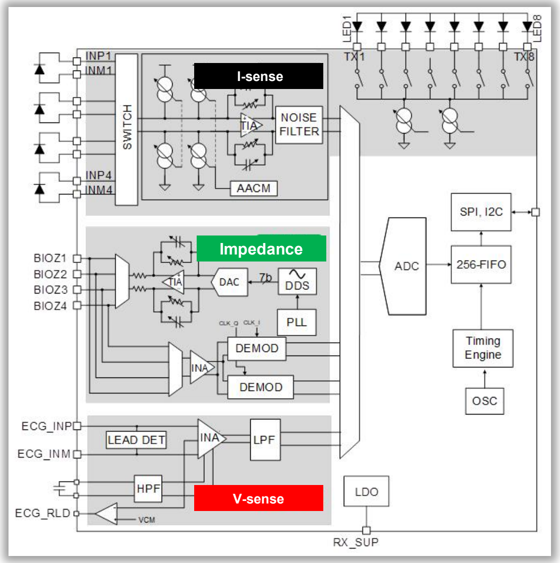
HIGH INPUT IMPEDANCE VOLTAGE CHANNEL:

- Sampling up 2 kHz
- Input noise (0.5-150 Hz): 0.75 µV at 1 kHz data rate
- Programmable INA gain: 2,5.5, 11, 21
- Integrated LPF, High pass filter: 0.4 Hz corner set by 10uF external capacitor, quick saturation recovery
- Bias voltage output, AC and DC sensor lead-off detect, lead-on detection.

IMPEDANCE SIGNAL CHAIN:

- Multi-frequency impedance Analysis - up to 250 kHz excitation frequency
- Complex (I,Q) Tetrapolar impedance measurement
- Sine-wave excitation with a 7-bit DAC and programmable amplitude
- Noise of 40 mΩpp over a 0.1Hz to 4Hz Bandwidth.
- Calibration scheme to compensate for electrode impedance
- Automatic impedance Calibration

- Supports external clock and internal oscillator modes
- Option to acquire data synchronized with a system master clock
- Option to Daisy chain 2 AFEs to acquire signals from 2x the number of LEDs and PDs synchronously
- FIFO with 256-sample Depth
- SPI, I2C interfaces: Selectable by pin
- 3-mm × 2.6-mm DSBGA, 0.4-mm Pitch
- Supplies: Rx:1.7-1.9V (LDO Bypass); 1.9-3.6V (LDO Enabled), Tx:3-5.5V, IO:1.7-RX_SUP



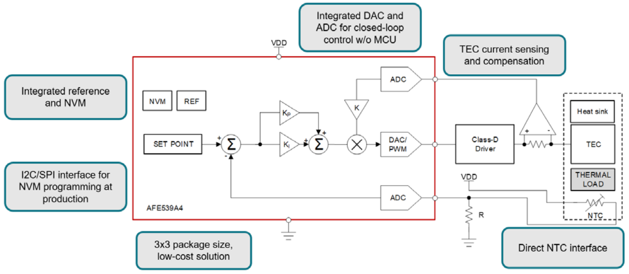
Thermoelectric Cooling

Thermoelectric Cooling: Overview

Design challenge/problem statement

- Thermoelectric Cooling is used in many different End Equipment's to provide precision temperature regulation of samples, light sources and system components.
- These EE's have a range of requirements for power (15W-100W), efficiency, size and integration.
- Implementation of a real time control loop that can add overhead to the main processor

Block diagram/schematic



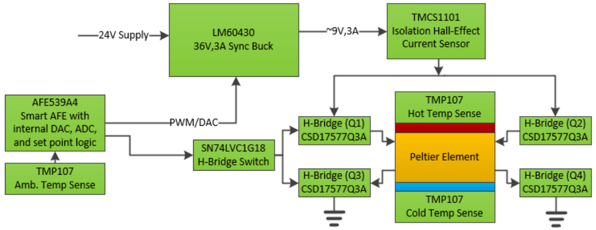
Additional resources

	Driver	Current Sense	Temp Sense
GPN	DRV8873 DRV8432	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	0.1°C Digital Temperature Sensor Lower power and Lower cost than Class AA RTD Equivalent
Technical resources	▪ Driving a Peltier Element (TEC) Reference Design ▪ Low Power TEC Driver Reference Design		

What differentiates this subsystem solution

- We have a wide range of proposals to meet customer needs depending on the system. We can implement integrated H-bridge drivers to deliver 2 to 4 channels at 15W-80W and >85% efficiency. We can also provide solutions using a linear buck converter to provide single channel solutions at >15W and >95% efficiency.
- The smart AFE (AFE539A4) allows customers to offload the real time control loop. This AFE uses a PID system in order to regulate the system to a set temperature point specified over I2C. This removes all needs of an interrupt or DMA based control system using their main controller.

TEC in a System



	Driver	AFE	Power MOSFET
GPN	LM60430	AFE539A4	CSD17577Q3A
Description	3.8-V to 36-V, 3-A, ultra-small synchronous step-down converter	10 bit Quad Smart AFE for closed loop regulation	30 V N-Channel NexFET™ Power MOSFET 5.3mOhm R_{DSon}
Technical resources	▪ Video Link		

AFE539A4: Device Overview

10 bit Quad Smart AFE – A new building block

Features

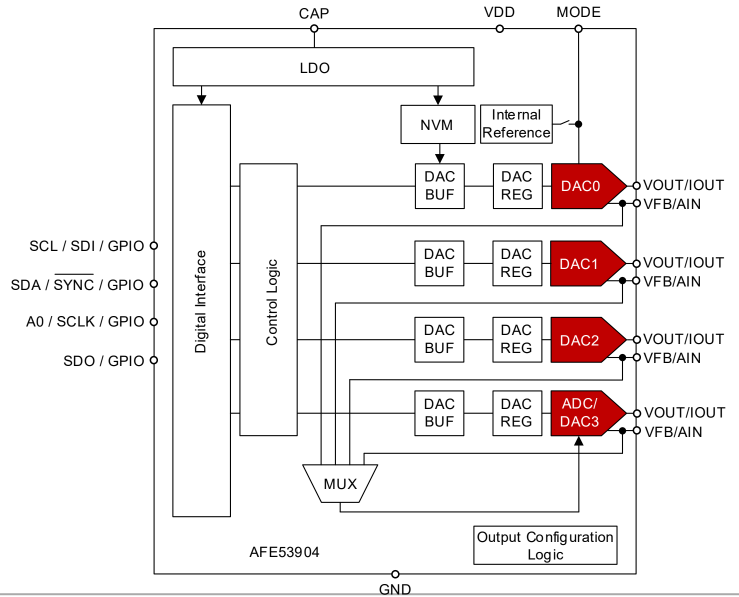
- **User programmable Nonvolatile Memory (NVM/EEPROM)**
- **I2C and SPI mode auto-detection**
- Internal 1.22-V reference
- **Hi-Z output during power-off condition**
- **GPIO pin configurable as LDAC/PRESET/SDO/PDN/ALARM**
- **10-bit ADC mode for all channels**
- **Control logic that supports feed-forward and closed-loop control**
- Voltage output with flexible configuration
  - 1 LSB INL and DNL, Gain of 1, 1.5, 2, 3 and 4
- Current output
  - 1 LSB INL (8-bit), 1 LSB DNL
  - Configurable output ranges
    - 0 µA to 25 µA, ±25 µA, ±125 µA, ±250 µA
- Wide operating range
  - **Power supply: 1.8 V to 5.5 V**
  - Temperature range: -40°C to +125°C
- Small packages
  - WQFN-16 (3x3)

End-equipment

- Ethernet switches and routers
- Handheld medical devices, test & measurement equipment
- TEC
- Land mobile radio

Benefits

- High design-reuse with multiple digital interface and analog output options
- Set-and-forget mode operation off-loads housekeeping MCU/EC
- Autonomous mode provides logic to analog circuits without software
- Ultra-low power enables longer run-time for battery-operated applications



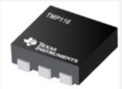
TEXAS INSTRUMENTS

Thermoelectric Cooling: TMP117 Benefits

TMP117 Advantages:

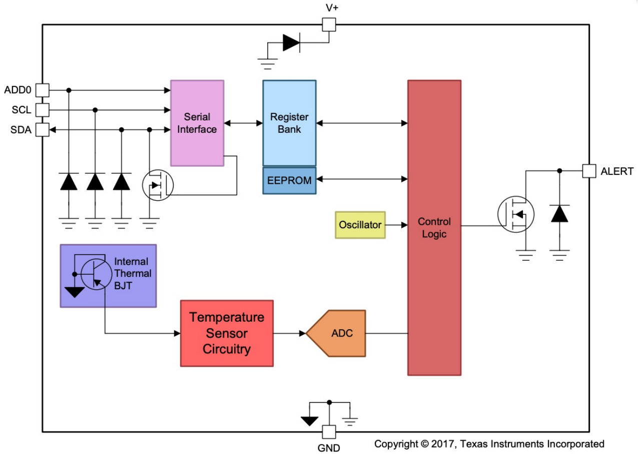
- Higher accuracy than Class AA RTD
  - 0.1°C (-20°C to 50°C), -55°C to 150°C operating range
- No calibration needed
- Simpler design with fewer components and less layout constraints
  - TMP117 includes ADC, I2C with interrupt, and EEPROM
- Significantly lower power than RTDs (TMP117: <9uW @ 1sps)

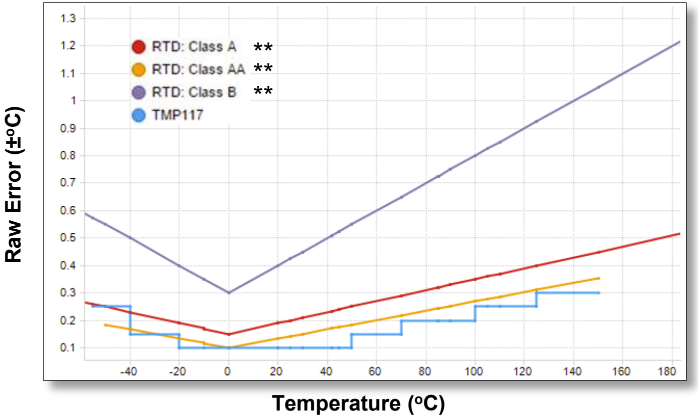
TMP117 Packages
CSP: 1.5mm x 1.0mm
WSON: 2mm x 2mm



Challenges with RTD

- Change in resistance is very small, which requires high precision components & AFE to achieve high accuracy.
- High cost of components
  - – Platinum RTDs are expensive, other materials used are less accurate
  - – Precision Bias & reference resistor network, current reference, amplifier, ADC
- Complex system design requiring precision matched traces, kelvin connections, and/or chopping circuits
- Complex error analysis due to the high number of contributing components. (RTD, resistors, amp, ADC, current source)
- Annual calibration



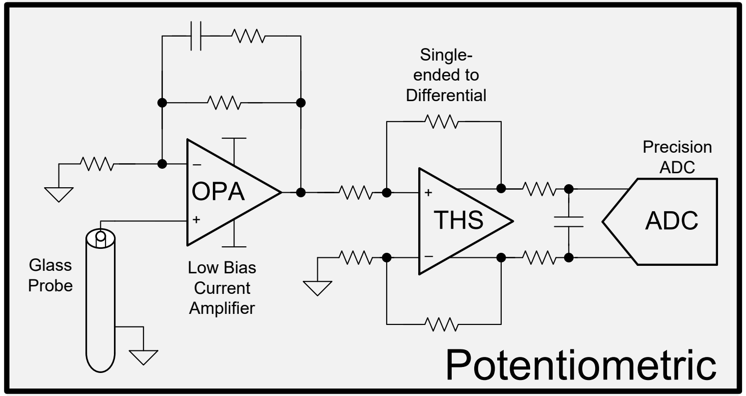


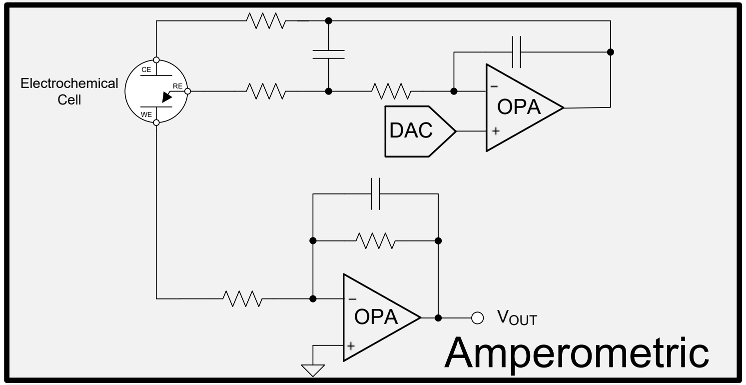
**Raw Error: Does not include error of additional circuitry for RTDs. TMP117 does not require additional circuitry

Electrochemical Sensing

Electrochemical Sensing: Overview

Block Diagram





System Design Challenge

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 OPA392 is used to measure low currents (100uA-100nA) for the Amperometric measurement.

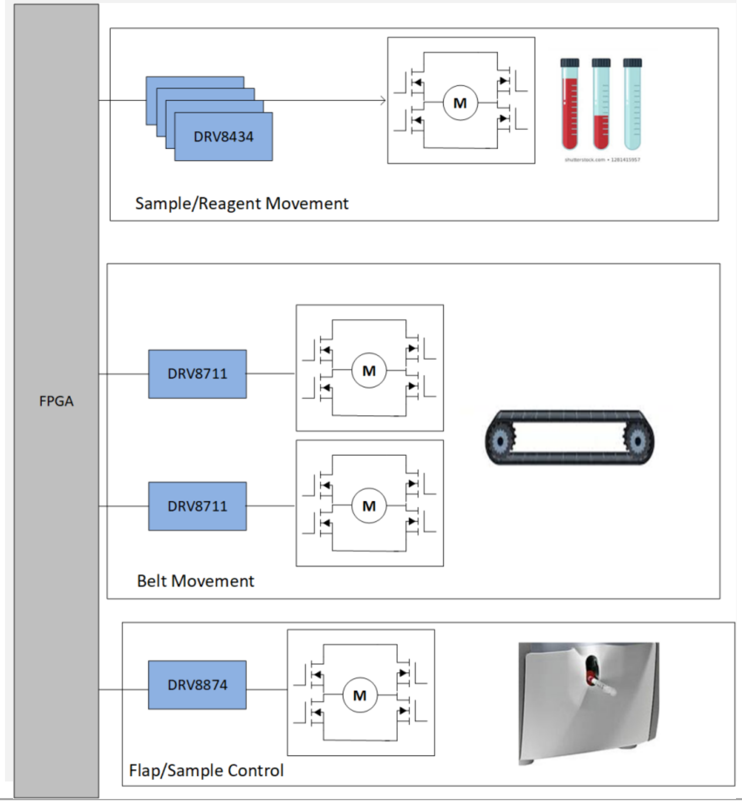
Key Devices + Collateral

Parameter	Low Offset and Bias Current Amplifiers	Fully Differential Amplifiers	Precision Analog-to-Digital Converters	Digital-to-Analog Converters
GPN	OPA192 OPA140 LMP91200	THP210 THP4551	ADS127L01 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			

Motor/Motion Control

Motion/Motor Control: Overview

Block Diagram



System Design Challenge

Design Challenge: In larger laboratory equipment, there are multiple motor opportunities to move different reagents into the sample and move the sample throughout the system. Increased ease of use, cost and size helps the customer replace external modules.

Solution: With 24V/36V/48V rails, 3-5A , stepper or brushed opportunities: integrated fets are preferred for ease of designing while external fets are preferred for higher current ratings. Using the DRV8711 with external fets, with the 1/256 micro-stepping, allows for a more precise distribution of reagents and samples in these systems.

Key Devices + Collateral

Parameter	Discrete	Discrete	Discrete
GPN	DRV8711	DRV8434 (50V) DRV8424 (35V)	DRV8876 DRV8874 DRV8873
Application	Belt movement	Test tube/plates/samples positioning	Sample slots
Description	52-V, bipolar stepper motor gate driver with 1/256 microstepping & stall detect	50V/35V, 2.5A FS with 1/256 microstepping and integrated current sensing	37V, 3.5/5/10A brushed driver with integrated current sensing
MPM Collateral	Understanding Smart Gate Drive Methods to Configure Current Regulation for Brushed and Stepper Motors (Rev. B)		

DRV84xx Family

Industry’s smallest P2P Family of stepper motor drivers with best in class motion control

Integrated Current sensing

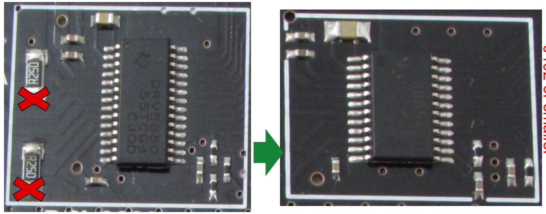
Eliminates ***all*** current sense resistors while providing accurate current regulation *(Maximum integration)*

Benefits

- ✓ **BOM reduction:** Removed sense resistors and reduced board size
- ✓ **Power management:** No power loss over the sense resistor
- ✓ **Easy design:** Hassle-free layout with no sense routing

More info

1206 or larger



0402 or smaller

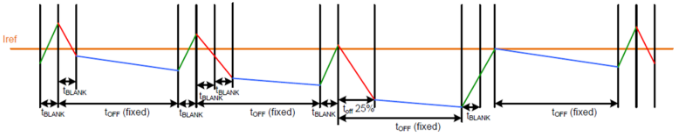
Smart Tune

Tune Stepper motors effortlessly & automatically *(TI Patented)*

Benefits

- ✓ **Seamless, quiet tuning:** Motor runs quietly without losing regulation
- ✓ **Power management:** Motor runs more efficiently than fixed decay modes
- ✓ **Shorter design cycle:** No need to spend months tweaking decay modes of motors
- ✓ **Reliability:** auto adjustment to motor parameters over lifetime
- ✓ **Thermal management:** makes system 5-12 degrees cooler than traditional decay modes
- ✓ **Ripple control:** automatically adjusts and controls the ripple current level resulting in higher average torque at each step

More info; slides



High Microstepping & more

1/256 Microstepping *(Industry highest)* with *(Industry best)* accuracy of current sense, wide input voltage, low Rdson and protection features

Benefits

- ✓ **Fine microstepping:** 1/256 microstepping for more accurate and controlled motion
- ✓ **Current Sense Accuracy to ± <5%**
- ✓ **5 level protection:** UVLO, CPUV,OCP, OL, OTSD
- ✓ **P2P scalability in QFN reducing size:**
  - ✓ **Smallest 16 Pin TSSOT 3x3mm Package** (1.5mΩ)
  - ✓ **P2P 4x4mm QFN** package with range of RDson options (0.3Ω – 1.2Ω)
- ✓ **Flexibility:**
- ▪ Wide operating voltage range (4V - 48V)
- ▪ Simple STEP/DIR interface and EN/PH interface

3.0x3.0mm, 16-pin QFN package

Resources

In-Vitro Diagnostics Resources on TI.com

Precision Optical	High Speed Optical	Impedance Spectroscopy
• DDC11xEVM-PDK Eval Board • DDC112 Datasheet • OPAx392 Product Page • Resolution-Boosting ADS7066 Using Programmable Averaging Filter	• 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 Simulation (Differential) • Impedance Spectroscopy Simulation (Single-Ended)
Thermoelectric Cooling	**Electrochemical Sensing**	**Motor Automation**
• Driving a Peltier Element (TEC) Reference Design • Low Power TEC Driver Reference Design • Smart AFE Overview Video • TEC Control with Smart AFE Video	• Sensor Front Ends • OPA192 Datasheet • ADS127L01 Product Page • Fundamentals of Precision ADC Noise Analysis	• DRV8711 Product Page • Understanding Smart Gate Drive • Methods to Configure Current Regulation for Brushed and Stepper Motors (Rev. B)

Questions?