Meeting Space-Grade Requirements for Mission Critical Applications

Precision Analog solutions for Satellite Subsystems

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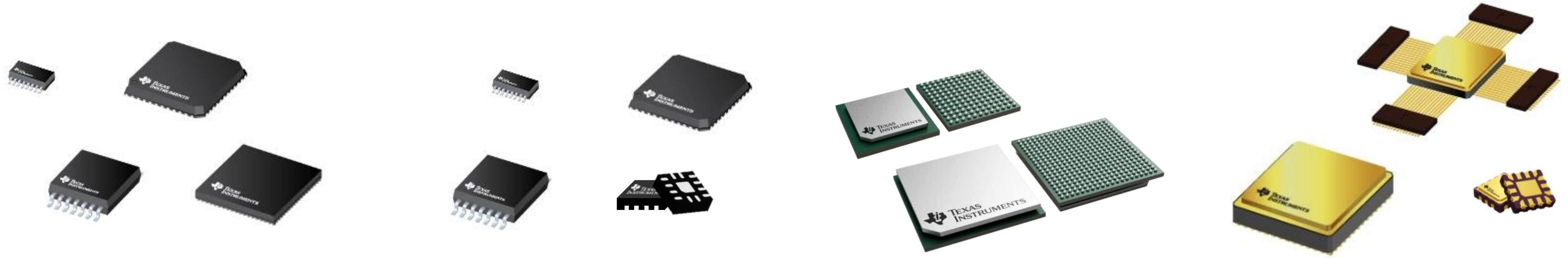
Agenda

- **Space Product Overview**
- **Analog front-end design with TI tooling landscape**
- **Space-grade, 50-krad, overcurrent event-detection circuit**
- **Linear Thermoelectric Cooler (TEC) Driver Circuit with high accuracy and stability and minimized noise emissions**
- **Rad-Hard and Rad-Tolerant Current Measurement Solutions**

Texas Instruments
Space Product Overview

June 2022
www.ti.com/space

Space Products Types



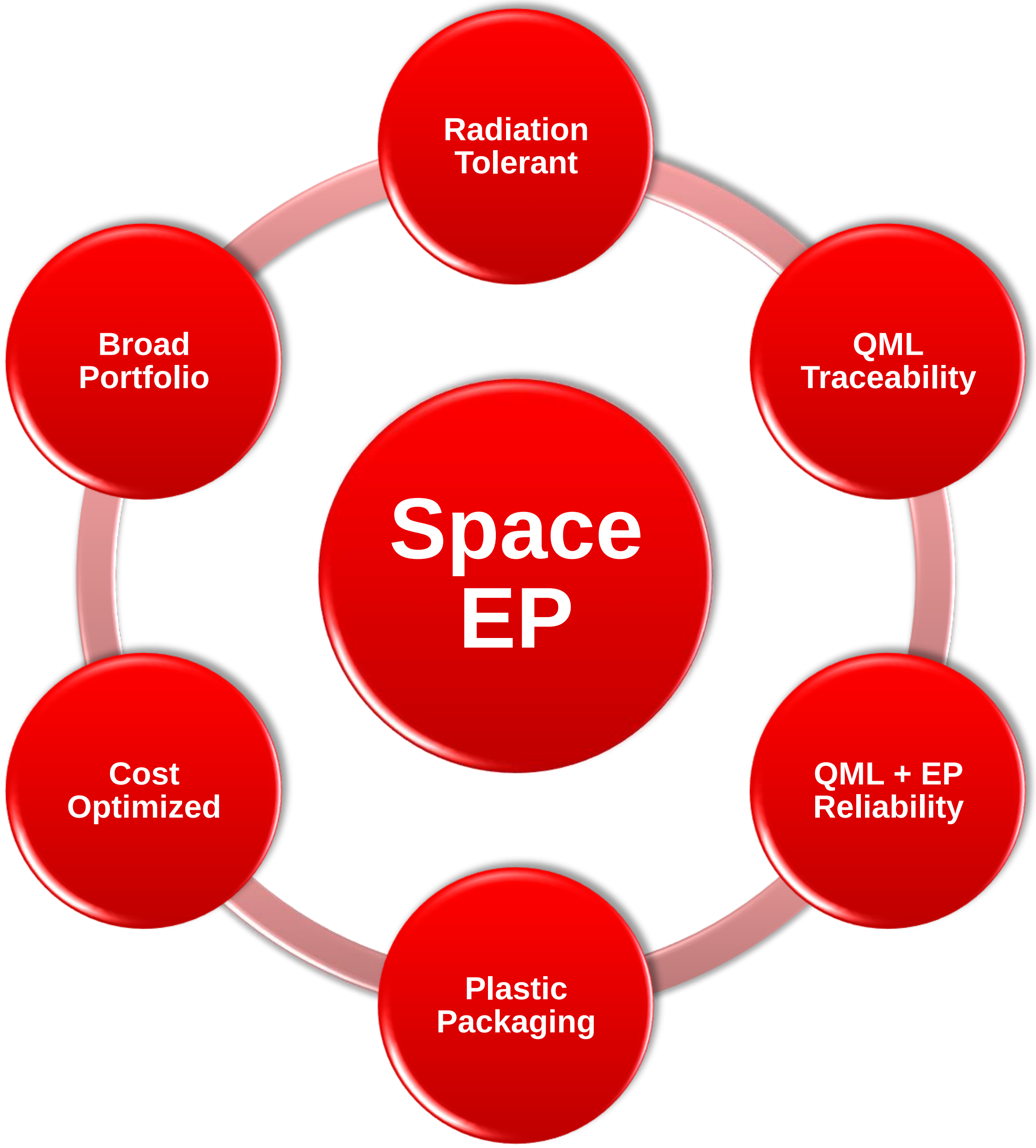
Rad Tolerant Plastic	Rad Hard Plastic	Rad Hard FC BGA	Rad Hard Hermetic
TI Space EP	QML Class P Precursor	QML Class Y Precursor with Organic Substrate	QML Class V

Packaging	Plastic	Plastic	FC on Organic Substrate	Ceramic / Metal Can
Mil. Spec	VID	VID/SMD*	VID/SMD*	SMD
Burnin	No	Yes	Yes	Yes
TID Char	30 – 50 krad(Si)	50 – 300 krad(Si)		
TID RLAT	20, 30, or 50 krad(Si)	Non-RHA, 50, 100, or 300 krad(Si)		
DSEE/SEL	43 MeV·cm²/mg	≥ 60 MeV·cm²/mg		

What is Space EP?

- Cost effective **radiation tolerant** solution typically for shorter duration high volume small satellites

- **Space EP = Radiation + Reliability + Traceability**
  - **Radiation**
    - TID Characterization **30 - 50 krad (ELDRS-Free)**
    - TID Radiation Lot Acceptance **(RLAT): 20, 30, or 50 krad**
    - SEL/SEB/SEGR Immune to **43 MeV-cm^2/mg**
  - **Reliability**
    - Military Temperature Range : -55°C to +125°C
    - Robust Material Set:
      Lead Frame, Mold Compound, Au Bond Wire, etc.
    - Enhanced Qualification (HAST, Extended Temp, Meets MIL-PRF 38535 Class N)
  - **QML-Like Traceability**
    - Wafer Lot Traceability
    - Vendor Item Drawing (VID) – MilSpec



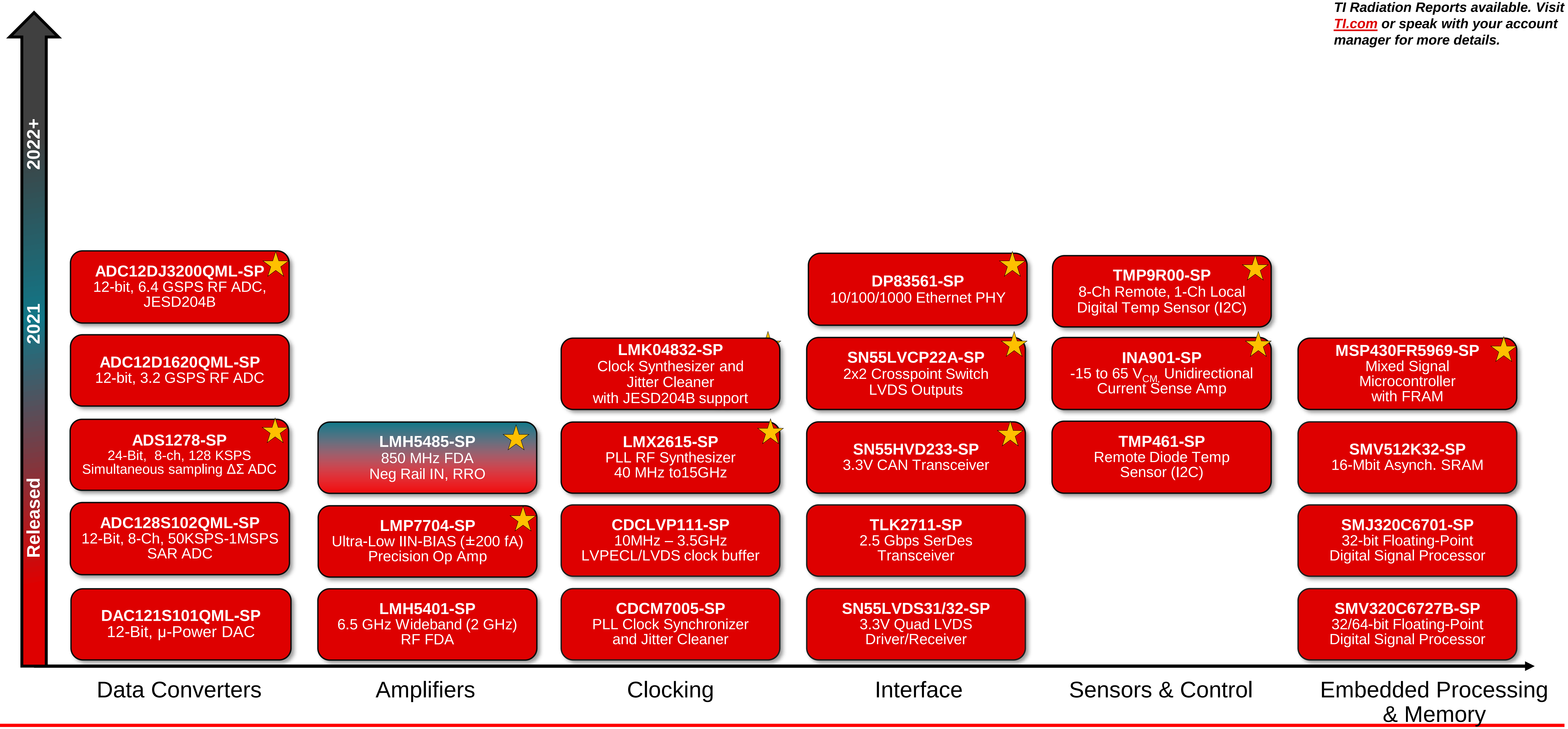
Space Signal Chain Products Roadmap

★ New (2018~22)

Released

In Development

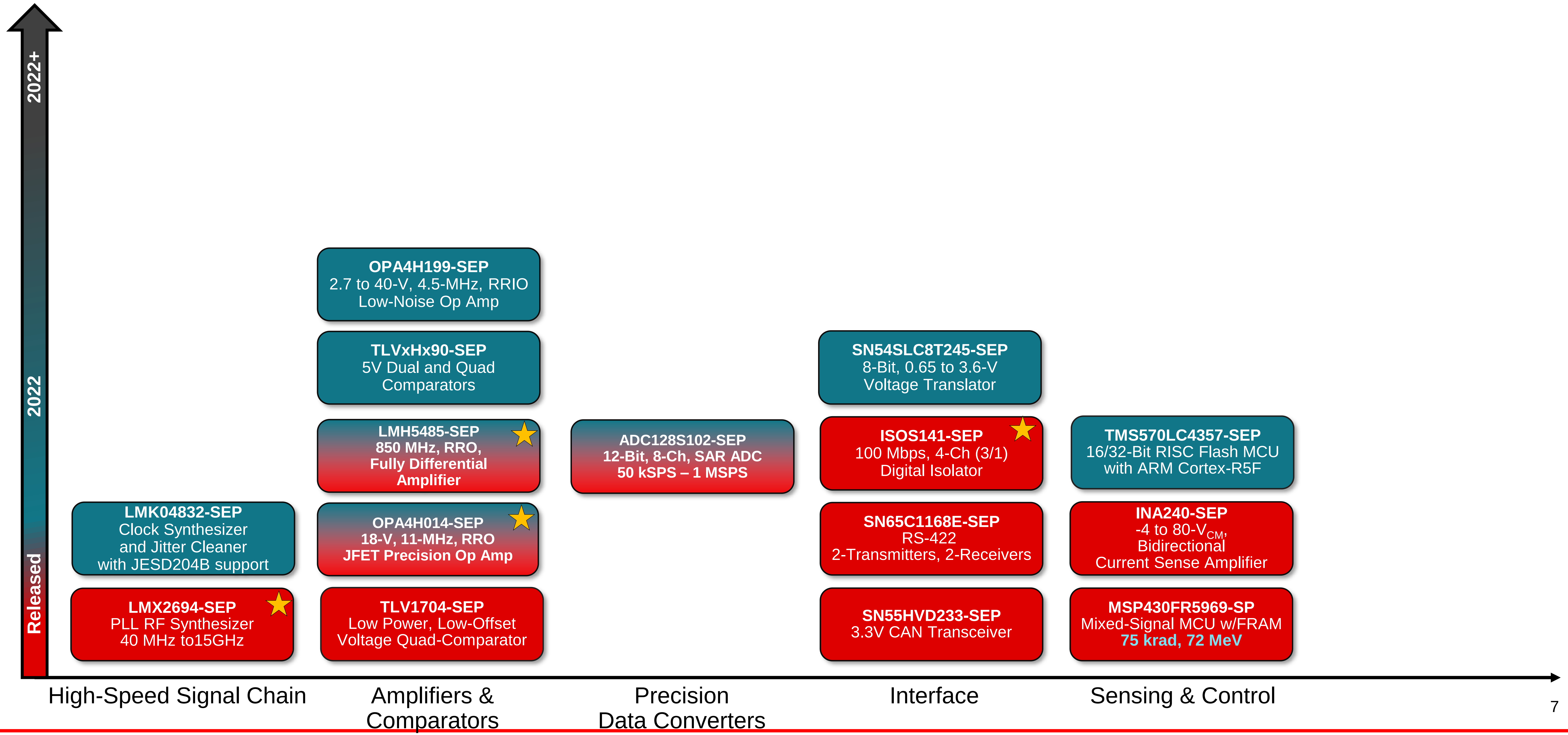
TI Radiation Reports available. Visit TI.com or speak with your account manager for more details.



Concept | In Development | Released

Space EP Products Roadmap

★ New (2021~22)



Space Power Roadmap

Concept | Released | In Development | Plastic Package

Future+ ↑ Today

Switching Regulators
- TPS7H4001-SP (QML-V) 7 V, 18 A Buck converter
- TPS7H4002-SP (QML-V) 5.5 V, 3 A Buck converter
- TPS50601A-SP (QML-V) 7 V, 6 A Buck converter
- TPS7H4003-SEP 7V, 18 A Buck converter 50krad/43MeV
- TPS7H4010-SEP 32 V, 6 A Buck converter 30krad/43MeV

High Voltage Power
- TPS7H5005/6/7/8-SEP 2 MHz PWM controller 50krad/43MeV
- TPS7H5001/2/3/4-SP 2 MHz PWM controller
- UC1843B-SP PWM controller
- UC1825B-SP PWM controller

Linear Regulators
- TPS7H3301-SP 3 A Source-Sink DDR termination regulator
- TPS7H1101A-SP 1.5 V to 7 V input, 3 A, LDO
- TPS7A4501-SP 2.3 V to 20 V input 1.5 A LDO
- TPS7H1210-SEP -3 V to -16.5 V, 1 A Neg LDO 30krad/43MeV
- TPS73801-SEP 2.2 V to 20 V input, 1 A, LDO 50krad/43MeV

Power Switches
- TPS7H2211-SP 14 V, 3.5 A load switch/efuse w/RCP
- TPS7H2201-SP 7 V, 6 A load switch/efuse w/current limiting + RCP

Ref & Supervisors
- TL1431-SP 36V, adjustable shunt VREF
- LM4050QML-SP 2.5V, 5V precision shunt VREF
- TL7700-SEP 40V Supervisor 30krad/43MeV

Space Grade Satellite Telemetry Reference Design

TIDA-010197

Benefits

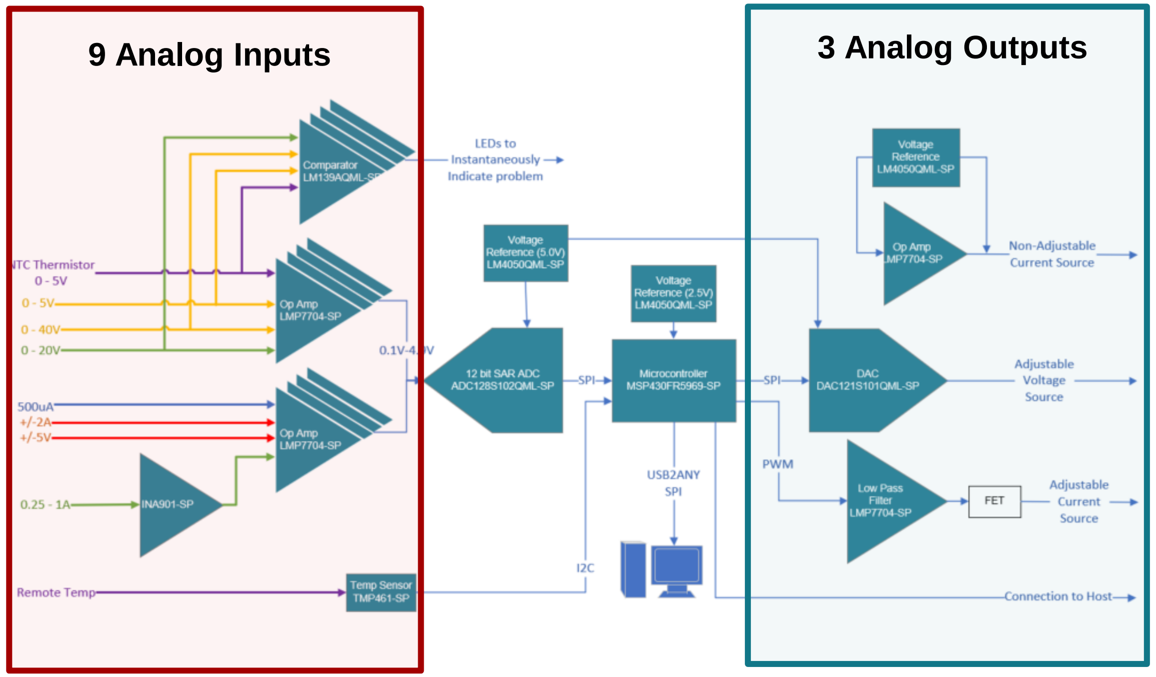
- All inclusive telemetry module to monitor a variety of measurements:
  - Voltage, Current, Temperature, Sensors (Current Output)
- Options for “5 V Rail” or“ 5 V and 12V Rails”
- Multiple integration options for different size, cost, and accuracy needs
  - Integrated MCU ADC (50~75 krad and 72 MeV)
  - ADC128S102QML-SP 12-Bit ADC (100 krad and 75 MeV)

Target Applications

- Satellites
  - Health Monitoring / Telemetry
  - Power Monitoring on Busses
  - RF PA Biasing
  - TEC Monitor
  - Attitude & Orbit Control System (AOCS)

Devices

- ADC128S102QML-SP 8-Ch, 12-bit ADC
- MSP430FR5969-SP FRAM Mixed-Signal Microcontroller
- LMP7704-SP Precision Quad Op Amp
- LM158QML-SP GP Dual Op Amp
- DAC121S101QML-SP 12-Bit DAC
- LM4050QML-SP Shunt Voltage Reference
- TMP461-SP Digital Output (I2C) Temp Sensor
- INA901-SP Current Sense Amp
- LM139QML-SP Quad Comparator



Multichannel JESD204B Clocking Reference Design for Space Payloads - TIDA-010191

Features

- Multi-channel JESD204B complaint clocking solution,
  - Converter Device clock frequency – **LMX2615–SP** (max – **15 GHz)**
  - Converter SYSREF provided for JESD204B interface – **LMX2615-SP**
- Scalable clocking solution, which can generate various DEVCLK by LMX2615-SP or LMK04832-SP
- Option to generate high frequency local oscillator for front end mixer
- Complete small, highly efficient power subsystem using DC/DC and LDO regulators/modules

Benefits

- JESD204B compatible clocking solution for high dynamic range and high SNR multi-channel signal chain
- Configurable phase synchronization to achieve low skew in multi-channel system
- Power efficiency optimized power subsystem for clock generation
- Easily interface with high speed data converters and synchronization
- Compares performance of multiple clocking solution of different complexity and cost

Target Applications

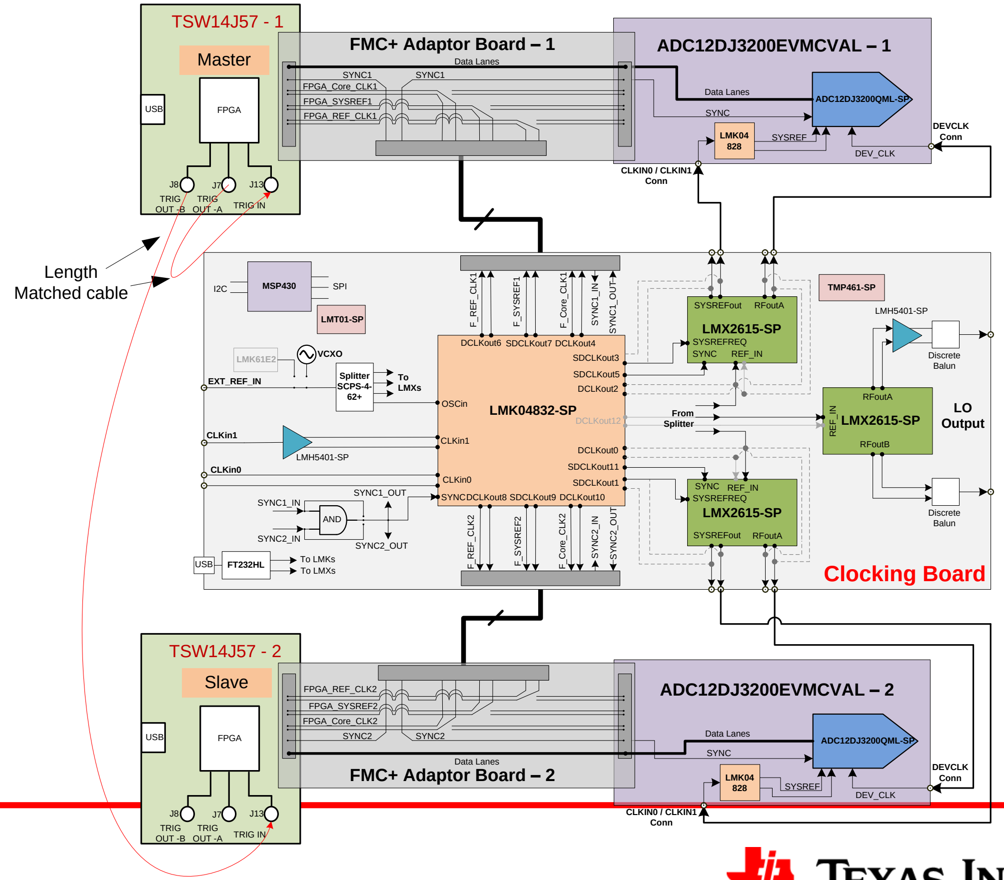
- Communications Payload
- Radar Payload
- Command and data handling

Tools & Resources

- TIDA-010191
- Design Guide
- Design Files: Schematics, BOM, Gerber, Software

Devices:

- ADC12DJ3200QML-SP
- ADC12DJ3200EVMCVAL
- LMX2615-SP
- LMK04832-SP
- TSW14J57EVM



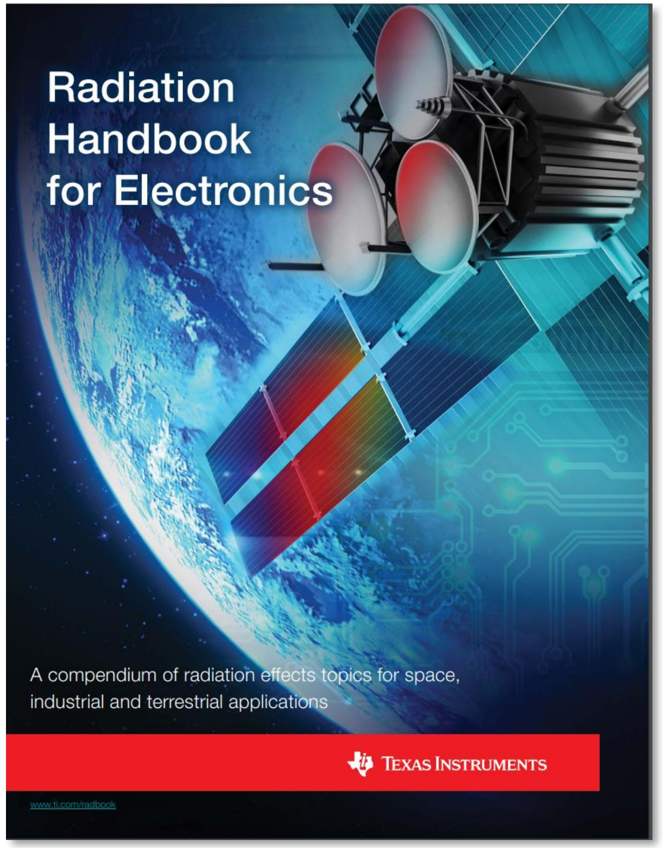
TI Space Documentation

Space Product Guide

- All TI products for Space
- Includes device listing for QMLV, Space-EP, Die, EMs, and Mechanical Samples
- Updated in March 2022

Space Circuit Handbook

- Ebook of useful space circuit designs including step-by-step instructions, formulas, and simulations to quickly get your design started



Radiation Handbook

- Provides explanation of radiation effects on semiconductors including TID, NDD, and SEE
- Written by industry experts Rob Baumann and Kirby Kruckmeyer

Visit www.ti.com/space for additional information

Analog front-end design for data acquisition systems with TI’s tooling landscape

Agenda

Analog front-end design for data acquisition systems with TI’s tooling landscape

- Data acquisition system design goals & challenges
- Component & topology selection with Analog Engineer’s Calculator
- Design iterations with TINA-TI simulator
  - Basic functionality
  - Noise analysis / ENOBs
  - Linearity / frequency response
  - Stability (Phase- & gain margin)
  - Settling time
- Summary

Space-grade precision data acquisition

Target applications

Satellite precision data acquisition systems:

- Thermal control of optical instruments / camera system
- Linear displacement (position) sensing / motion control
- Gyro sensor
- Atomic clock

Design goals and challenges

- **Strong signal performance for ENOB of 16 and higher:**
  - Low noise addition from active components
    - Low noise floor (single digit nV/√Hz)
    - High linearity for low distortion from harmonics (< -110dBc, up-to 40kHz)
  - Low quantification noise / short enough settling time (uV-level after 1/fz)
  - Strong common mode noise suppression (down to zero impact)
  - Low drift (e.g. offset drift of < 1 µV/°C; input bias current drift of < 20nA)
  - high stability (phase margin of 60°+)
- **Low power consumption per channel** (down to 10s of mW, highly dependent on mode of operation)
- **Smallest possible board area & cost**
- **Optimized input buffer stage:**
  - Input impedance target >100kOhm
  - Input full scale range (FSR) much smaller or much greater than ADC’s FSR of typically 5V
  - Common mode voltage equal or unequal to 0V

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Component & topology selection

Identifying the right ADC

Example specification / design goals:

- Channel Count: 8 Channels
- Bandwidth and Sampling Rate:40 kHz, > 100 kSamples/s
- Input Full Scale Range (FSR) : +- 10V FSR
- Common Mode Voltage:~ 0V common mode
- Target Resolution/ENOB: > 16 Bit
- Input Impedance (ZIN) Target: > 100 kOhm

TI Space Products (Rev. I)

Find the right parts for your space grade design with our updated Space Products Guide

Download (PDF, 4292KB)

http://www.ti.com/spaceguide

https://www.ti.com/applications/industrial/aerospace-defense/space/overview.html

Precision ADCs (≤ 10 MSPS)

Part Number[1]	Military Spec	Qualification Level	TID Char. (krad)	TID RLAT (krad)	SEL (MeV•cm²/mg)	Res. (Bits)	Sample Rate (Max) (kSPS)	# of Ch	Multi-Ch Config.	SNR (dB)	INL (Max) (± LSB)	Input Type	Ref. Voltage (V)	Power (Typ) (mW)	Type	Package Group	ECCN[2]
ADC128S102QML-SP	5962-07227	QMLV-RHA	100	100	120	12	1000	8	Multiplexed	72	1.1	Single ended	Supply	2.3	SAR	CFP, Die	EAR99†
ADS1278-SP	–	TI Space Grade	75	50	68	24	128	8	Simultaneous	111	201.4	Differential	External	530	ΔΣ	CQFP	EAR99‡
ADS1282-SP	5962-14231	QMLV-RHA	50	50	60	32	4	2	Multiplexed	130	–	Differential	External	25	ΔΣ	CFP	EAR99‡

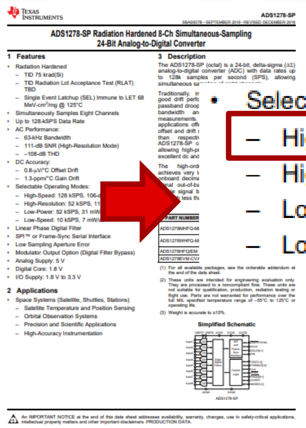
Component & topology selection

Identifying the right op amp

Example specification / design goals:

- Channel Count: 8 Channels
- Bandwidth and Sampling Rate:40 kHz, > 100 kSamples/s
- Input Full Scale Range (FSR) : +- 10V FSR
- Common Mode Voltage:~ 0V common mode
- Target Resolution/ENOB: > 16 Bit
- Input Impedance (ZIN) Target: > 100 kOhm

Step 1:
Read modulation frequency from ADS1278-SP data sheet:



- Selectable Operating Modes:
  - High-Speed: 128 kSPS, 106-dB SNR
  - High-Resolution: 52 kSPS, 111-dB SNR
  - Low-Power: 52 kSPS, 31 mW/ch
  - Low-Speed: 10 kSPS, 7 mW/ch

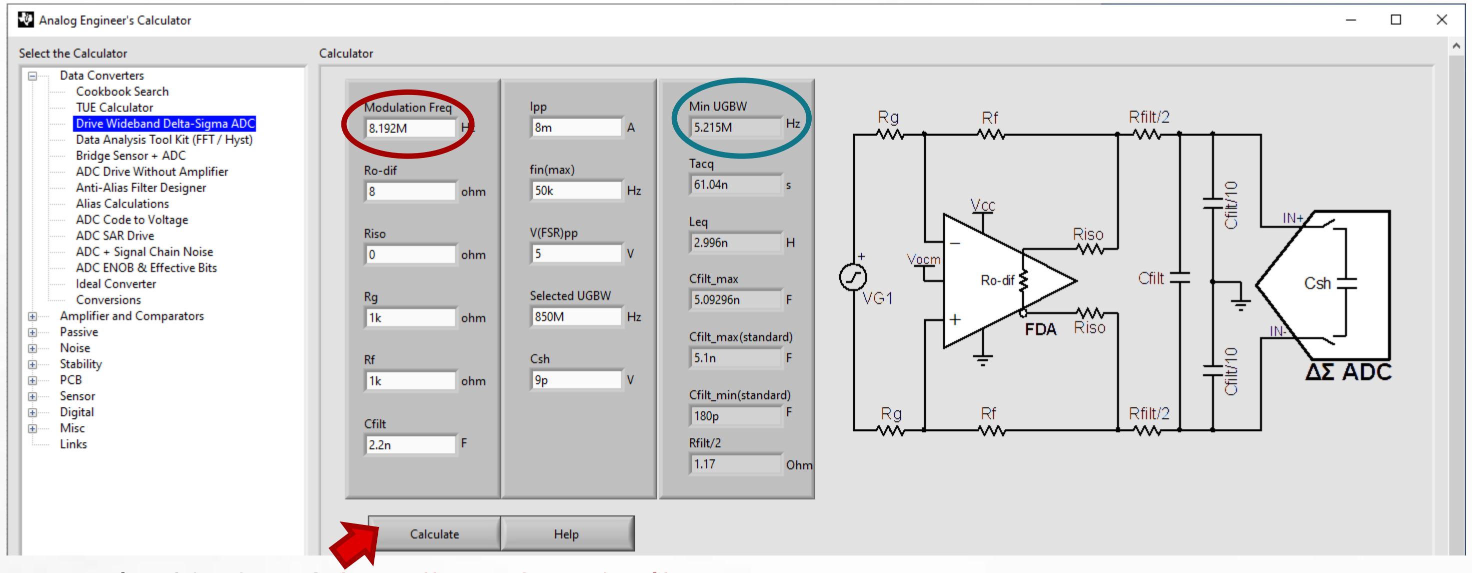
Input leakage	0 < $V_{IN\ DIGITAL}$ < IOVDD	±11
Master clock rate (f_{CLK})	High-Speed mode (4)	32.768
	Other modes	27
POWER SUPPLY		

Table 4. Modulator Frequency (F_{MOD}) Mode Selection

MODE SELECTION	CLKDIV	f_{MOD}
High-Speed	1	f_{CLK} / 4

32.768MHz / 4 = 8.192MHz

Step 2:
Enter modulation frequency of 8.192 MHz in **ANALOG-ENGINEER'S CALCULATOR** tool*, click 'Calculate' and read back the Min UGBW = 5.215 MHz.



*Download for free @ https://www.ti.com/tool/ANALOG-ENGINEER-CALC

Step 3:
Select OpAmp. E.g. LMH5485-SP

Fully Differential Amplifiers (FDAs)

Part Number[1]	Military Spec	Qualifi-cation Level	TID Char. (krad)	TID RLAT (krad)	SEL (MeV•cm²/ mg)	V_s Min (V)	V_s Max (V)	GBW (MHz)	BW @ A_{CL} (MHz)	Min. A_{CL} (MHz)	Slew Rate (Typ) (V/µs)	V_n at Flatband (nV/√Hz)	CMRR (Typ) (dB)	Rail-t Rai
LMH5401-SP	5962-17214	QMLV-RHA	100	100	85	3.15	5.25	6500	4100	5	17500	1.25	72	No
LMH5485-SP	5962-19204	QMLV-RHA	100	100	75	2.7	5.4	850	620	1	1500	2.2	100	In to V–
THS4511-SP	5962-07222	QMLV	150	–	Bipolar	3.75	5.25	3000	1100	1	5100	2	80	In to V
THS4513-SP	5962-07223	QMLV	150	–	Bipolar	3	5.5	3000	1100	1	5100	2.2	90	No

Getting started with the design

R0-dif = Open-loop output impedance
closed-loop output impedance x open-loop gain = open loop output impedance

LMH5485-SP data sheet:

	Closed-loop output impedance	f = 10 MHz (differential)	0.1	Ω

Figure 7.1: Gain vs. frequency curve:
~38dB @ 8.192 MHz

→ ~80 x 0.1 Ohm = 8 Ohm

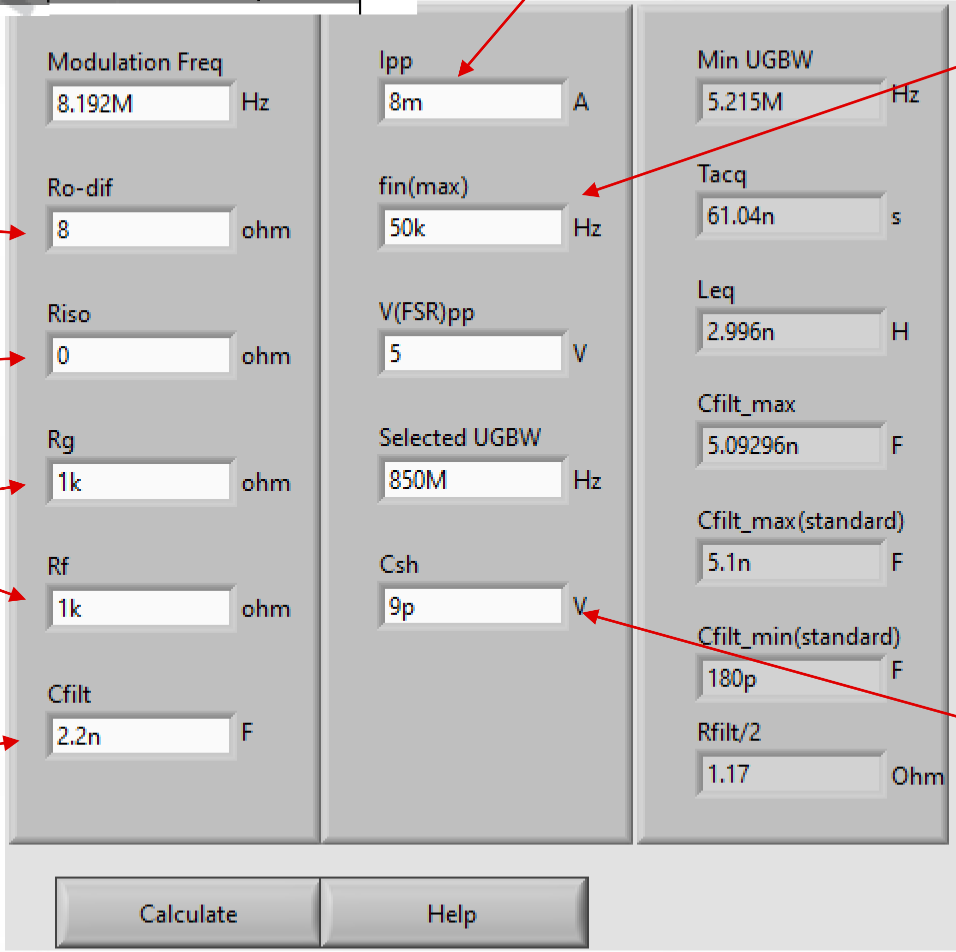
Riso typically small, use '0' for now:

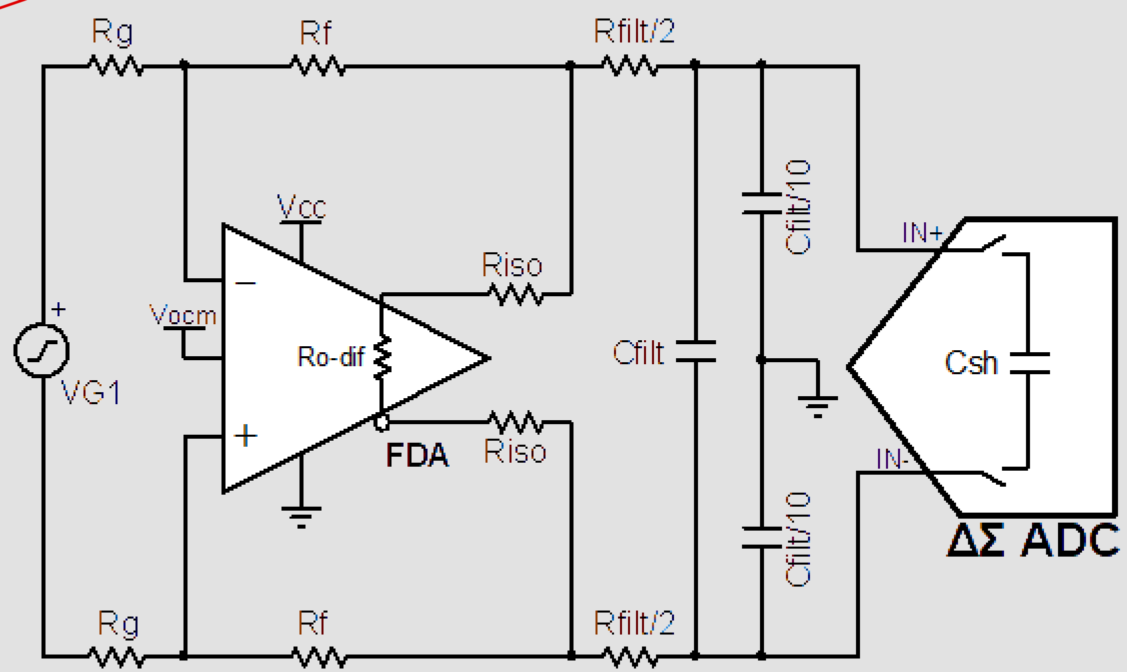
Rg & Rf must be the same for unity gain. Use 1K.

Cfilt shall be at least 20x bigger than Csh. 2.2nF is in the middle of Cfilt_min & Cfilt_max.

Ipp data sheet allows for up-to 75mA. 8mA shall be enough to calculate with. With that Cfilt_max comes out as 5.1nF.

fin required bandwidth is 40kHz. Let's give some margin





From ADS1278-SP data sheet, Figure 63:

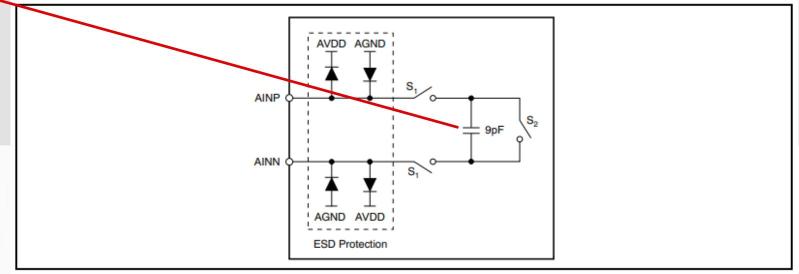


Figure 63. Equivalent Analog Input Circuitry

Agenda

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- Data acquisition system design goals & challenges
- Component & topology selection with Analog Engineer's Calculator
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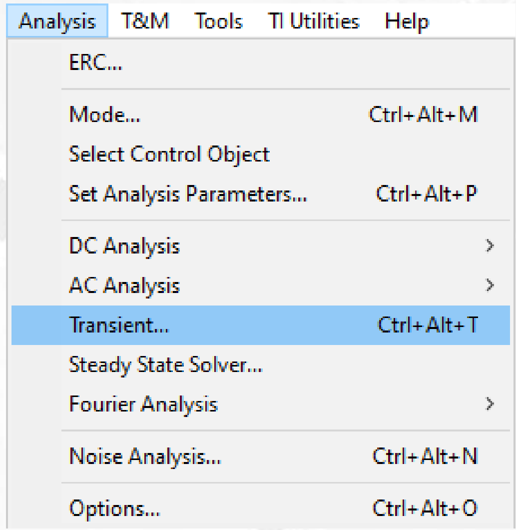
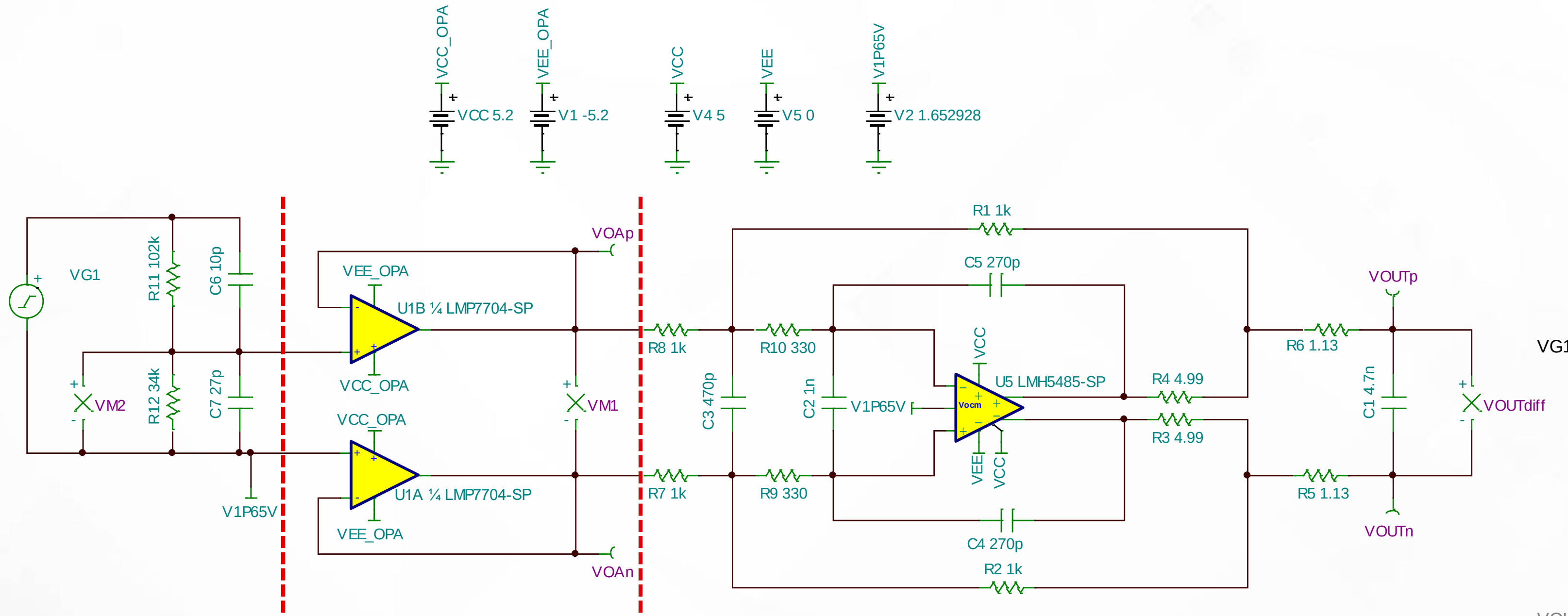
  - Basic functionality
  - Noise analysis / ENOBs
  - Linearity / frequency response
  - Stability (Phase- & gain margin)
  - Settling time
- Summary

Basic functionality: Time domain response

Complete the design for simulation:
- Add VG1 with 40 kHz, ± 10V.
- Add attenuation Stage for ± 10V Input (with Z_{IN} ≥ 100 kΩ || 10 pF): ± 2.5V
- Add Input buffer stage based on LMP7704-SP

- Use Analysis → Transient...



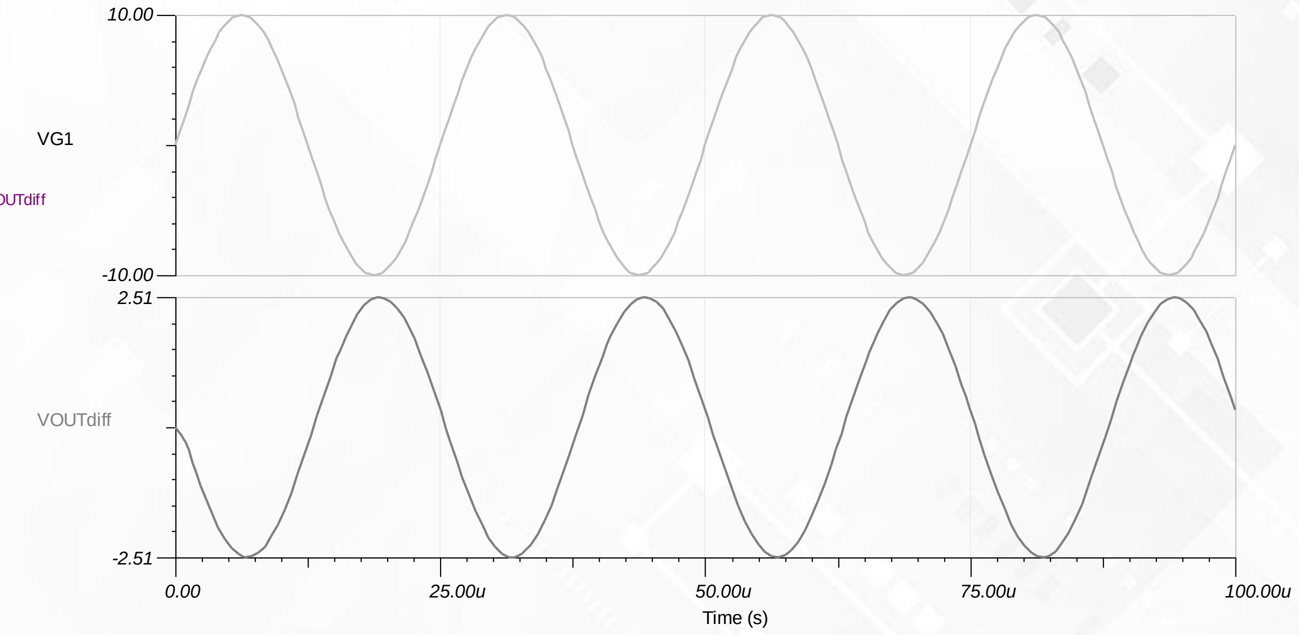


Attenuation Stage
(Only for ± 10V Input)

RIN > 100 kOhm

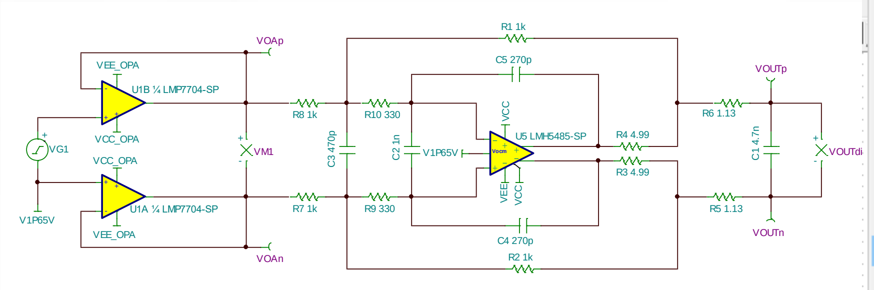
Input Buffer Stage
(with Ultra-Low I_B OpAmp)

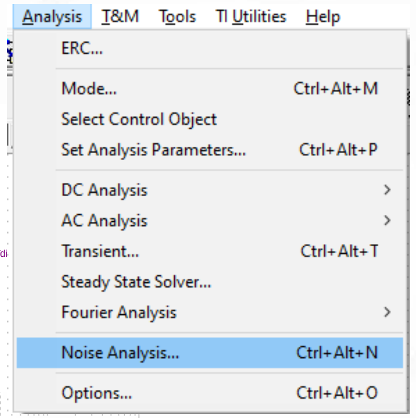
ADC Driver
(using Fully-Diff Amp)

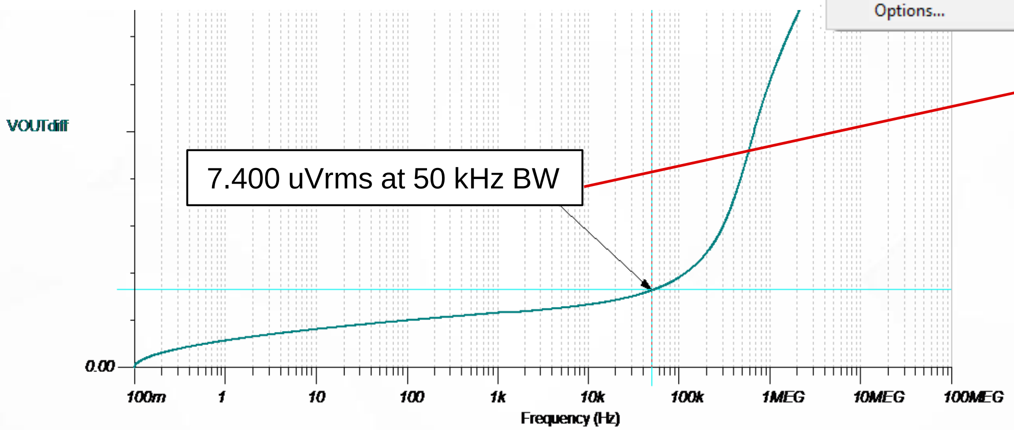


Noise and ENOB

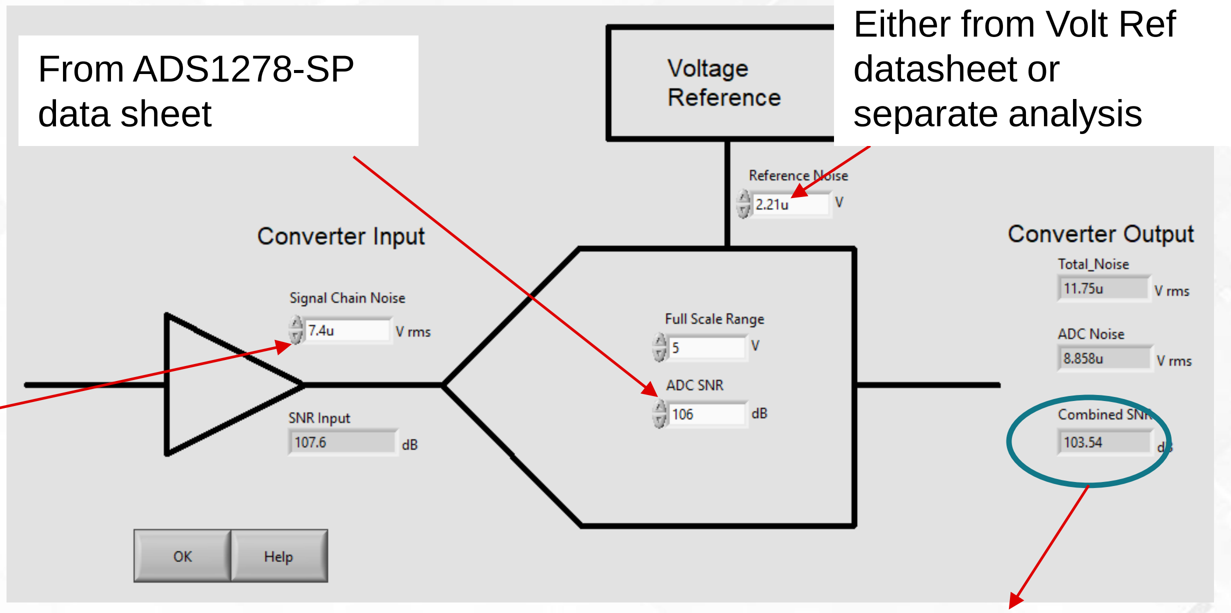
1. Use Analysis → Noise Analysis







2. Enter data into **ANALOG-ENGINEER'S CALCULATOR** tool 'Data Converters' → 'ADC + Signal Chain Noise':



➢ SNR based on AFE Noise + VREF Noise = 103.54 dB

3. Use of standard conversion formula 'ENOB = (SNR – 1.76)/6.02 dB' to calculate **ENOB = 16.91 Bits**

4. TINA-TI does not account for non-linearity. A quick look at the THD is necessary:
LMH5485-SP data sheet shows distortion from HD2 of –118 dBc for 50 kHz and below. Much lower than 103.54dB identified above and can be ignored.

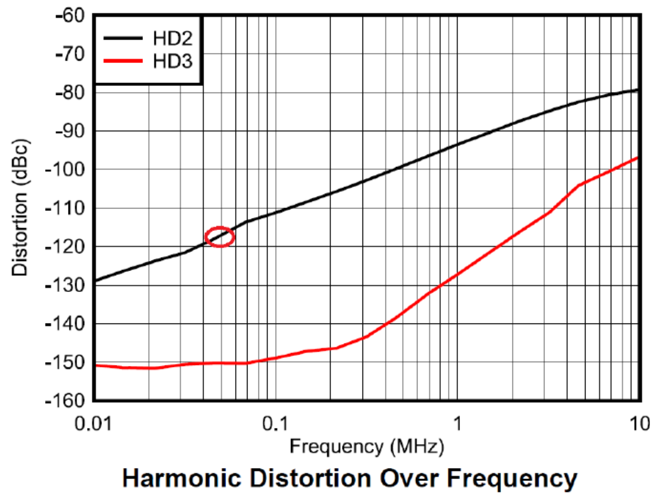
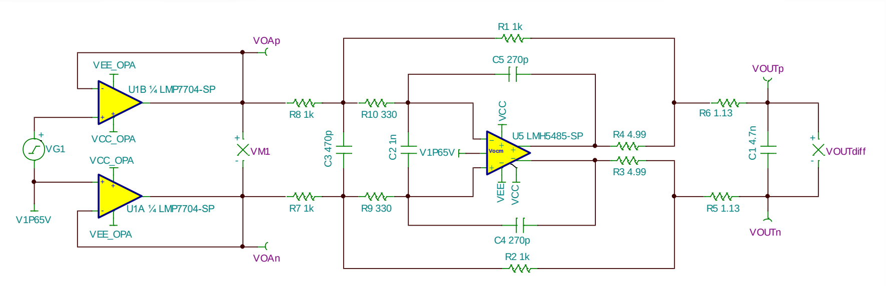
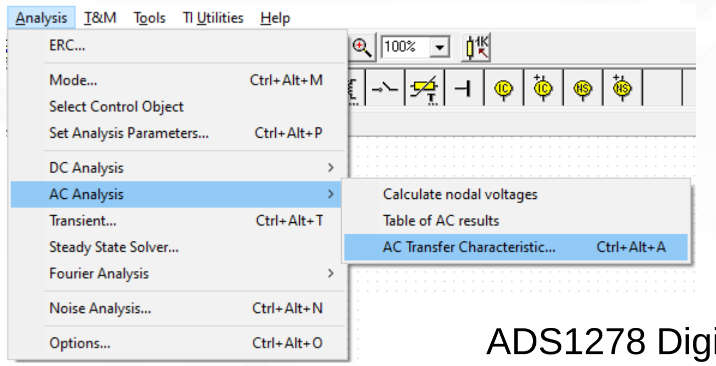


Figure 2-7. LMH5485-SP Data Sheet Shows THD of About –118 dBc for f = 50 kHz in its Harmonic Distortion Over Frequency Chart

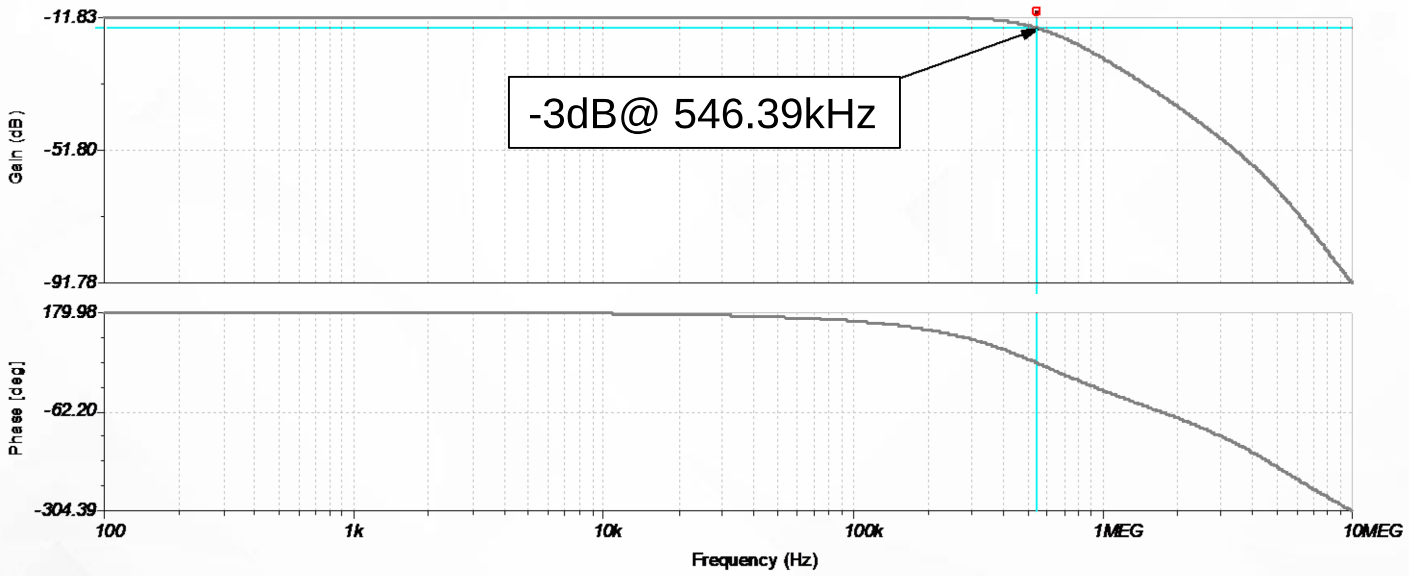
Linearity / frequency response

Use Analysis → AC Analysis → AC Transfer Characteristics





ADS1278 Digital Filter Response F_{in}/F_{data}=0.5;
F_{data} = 128ksps → Cut-off@ ~60kHz



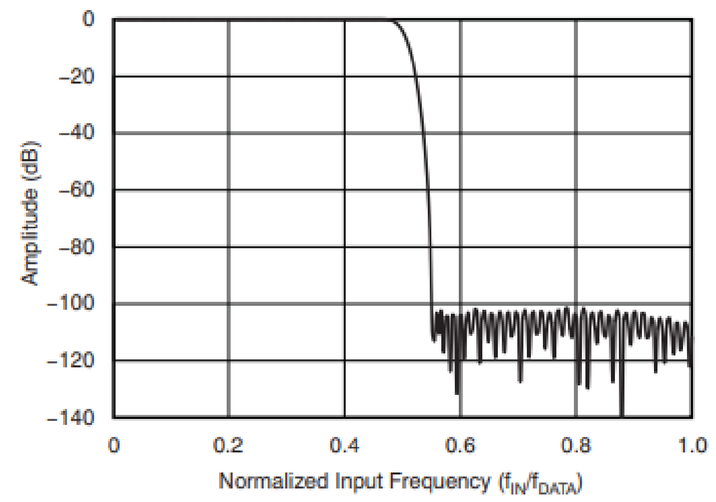
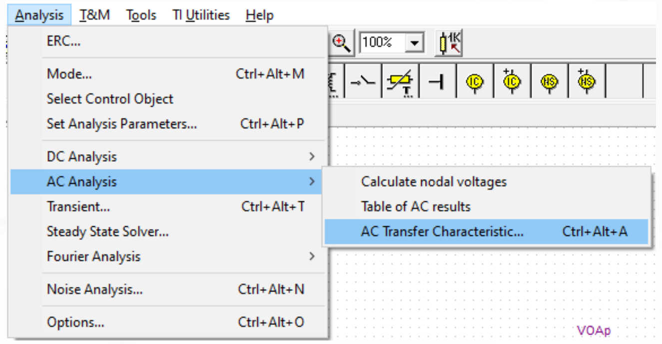


Figure 54. Frequency Response For High-Speed, Low-Power, And Low-Speed Modes

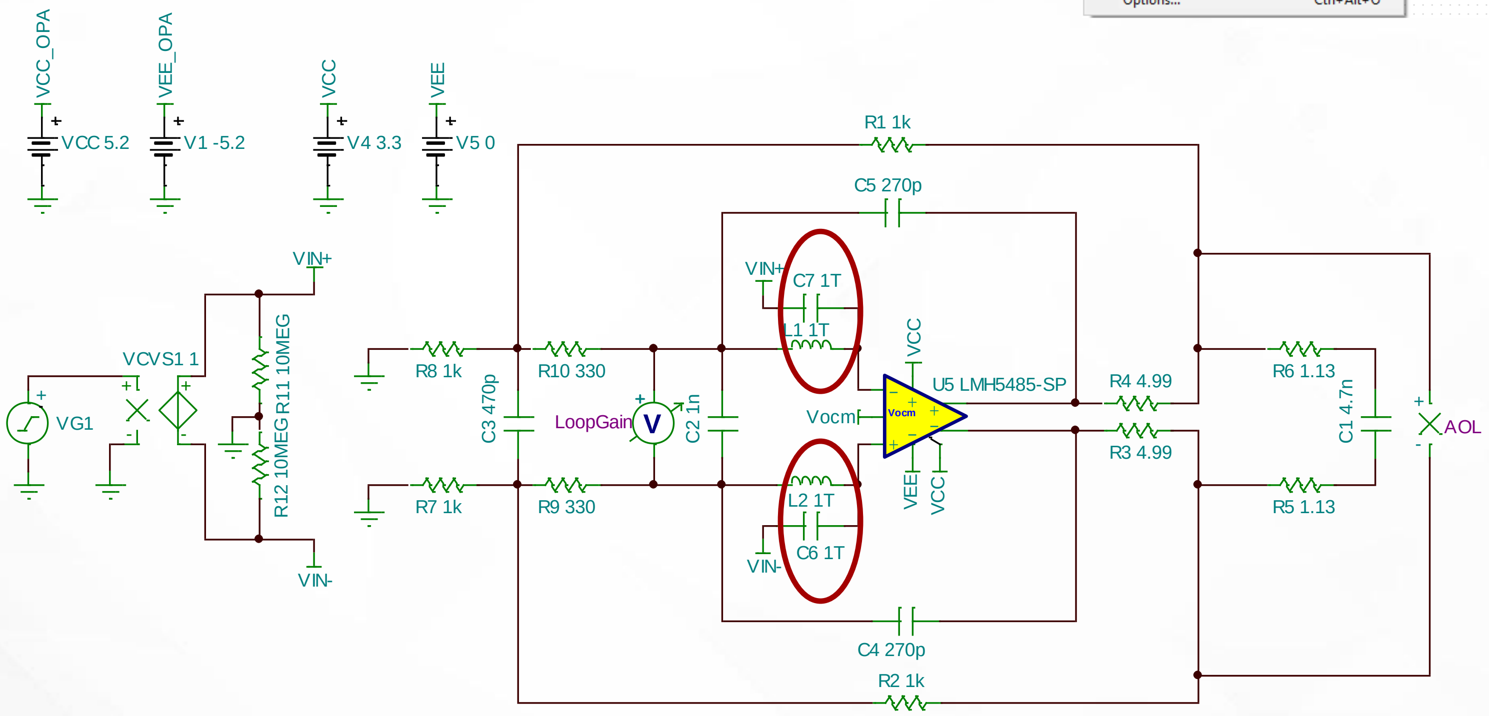
- -3 dB Bandwidth 546.39 kHz for AFE
  - very well above the cut off frequency of 60kHz of ADS1278's digital filter response. → Meets the linearity requirement
  - f_{mod} = 8.192 MHz . Provides 60dB+ anti-aliasing suppression for signal components at 4.096MHz and higher.

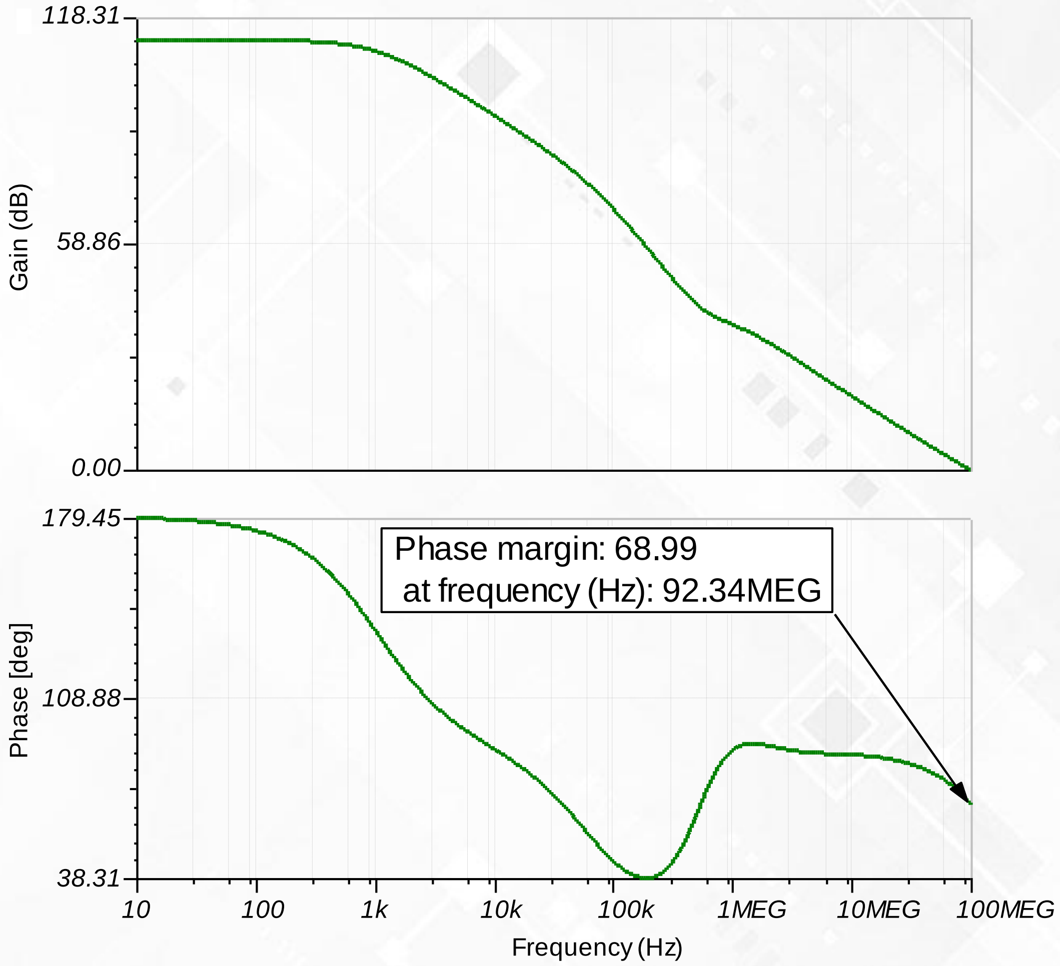
Stability analysis of closed loop system

Use Analysis → AC Analysis → AC Transfer Characteristics



To enable simulation from DC to high frequency:
Add L1 & L2 with Terra Henry (open for AC / short for DC)
And C7 & C8 with Terra Farad (short for AC / open for DC)

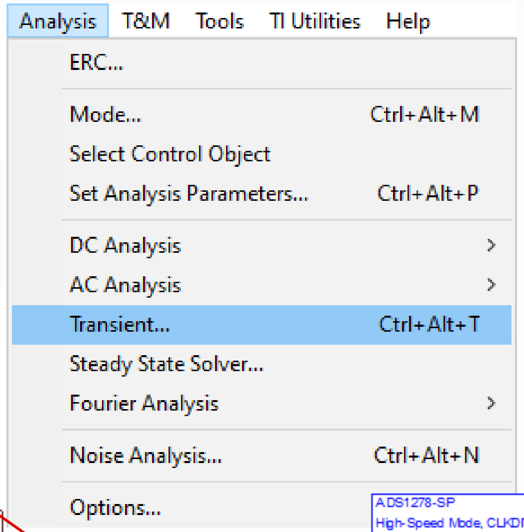


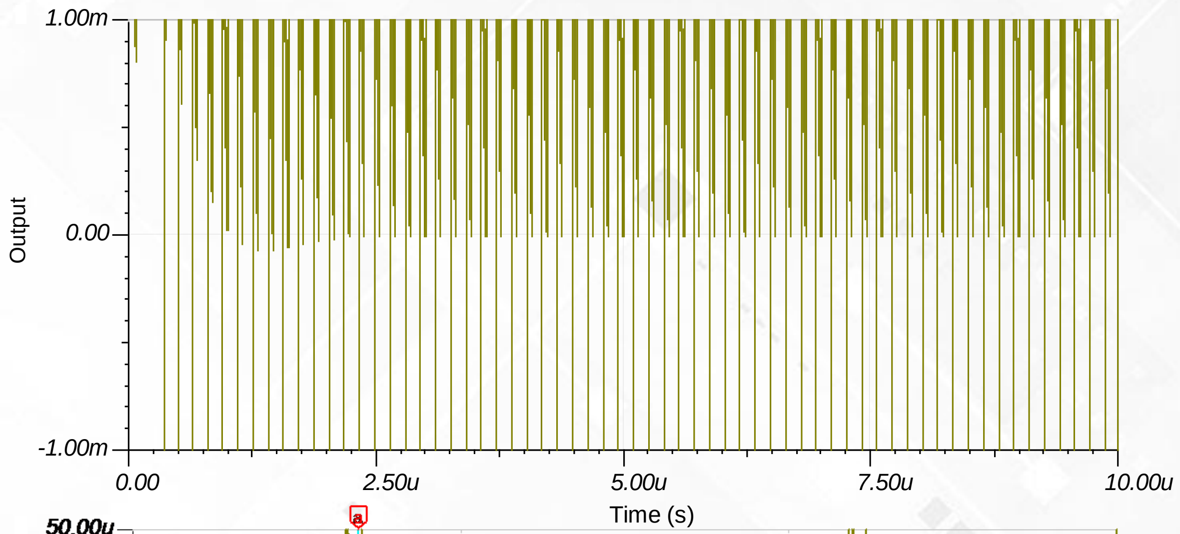


- Phase Margin for Ain+ and Ain- Amplifier paths, 68.99 Deg @ cross-over point
- Dip in phase margin at ~150KHz might allow for some ringing...

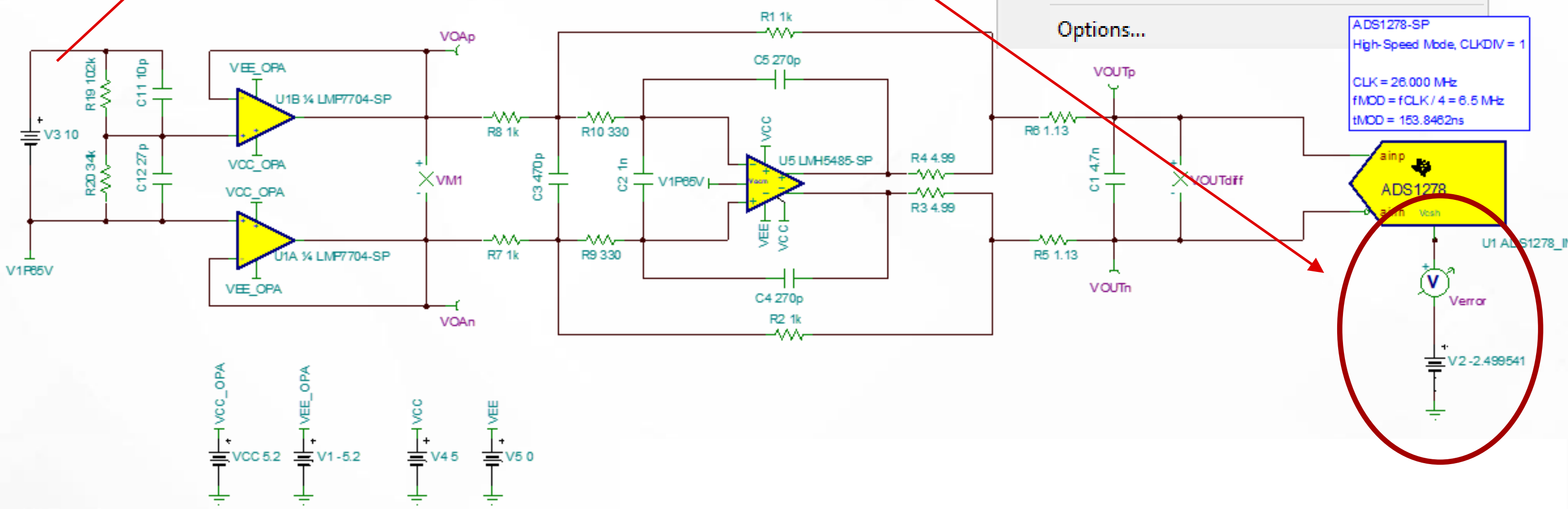
Settling time driving ADC input

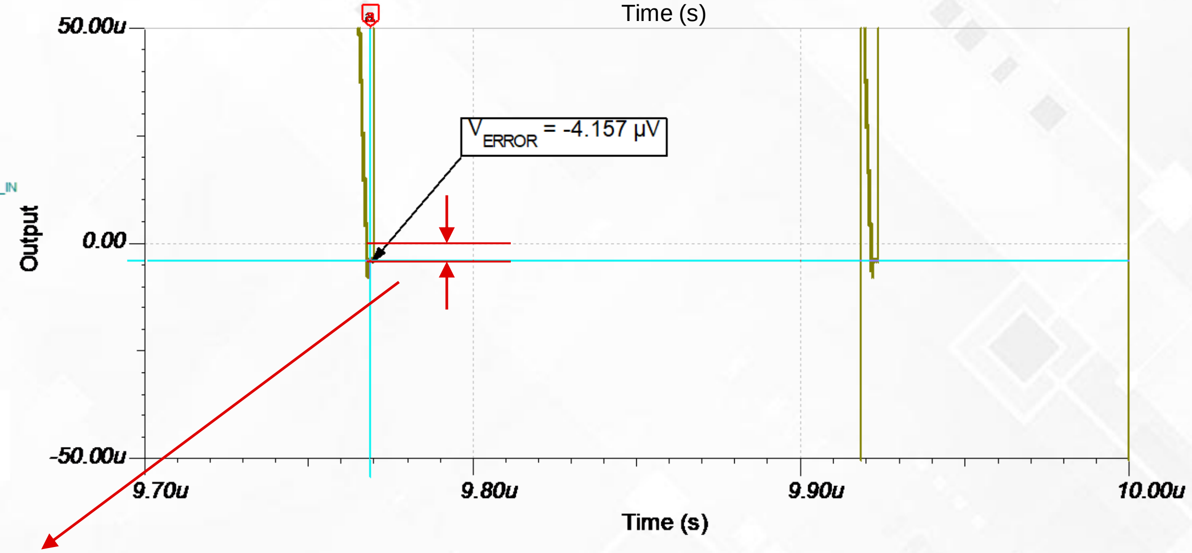
Use Analysis → Transient…





Take advantage of ADS1278 model’s Vcsh output to analyze voltage on sampling capacitor for max DC input (10V at input generate Vdiff -2.499541V).





- ➢ Sampled output voltage error of ADS1278 is -4.157 uV after full settling of step input.
- ➢ This error appears as a gain error, and reduces to approximately 0V at 0V input.
- ➢ Gain Error ~[(2.5V- 4.157e-6V)/2.5V-1]*100 = -0.00016628% = -1.6628 ppm (~20bit resolution)

Agenda

Analog Front End design for data acquisition systems with TI's tooling landscape

- Data acquisition system design goals & challenges
- Component & topology selection with Analog Engineer's Calculator
- Design iterations with TINA-TI simulator
  - Basic functionality
  - Noise analysis / ENOBs
  - Linearity / frequency response
  - Stability (Phase- & gain margin)
  - Settling time
- Summary

Summary

- Designing the analog front end is a multi-dimensional challenge and does typically require an iterative development process.

- TI products, available simulation models and tools enable designers:
    - to identify a good starting point quickly

    - quick and easy validation of several system aspects such as frequency response, stability, noise levels, settling times, etc.:
        - Quick understanding of the design behavior
        - Fast design iterations
        - High confidence into design success prior start of actual hardware design

- Tools are downloadable for free

- Technical support available via e2e forum or your local TI representatives

- All details of this presentation are described in the application note:

  Analog Front-End Design With Texas Instruments' Tooling Landscape

ADS1278-SP AFE Test Board

In development

Performance vs. power of four different AFE architectures

Features

- Multiple configuration options for power, clocking, V_{REF} & V_{OCM}
- Dual channel inputs with four different AFE topologies:
  - Direct FDA
  - Instrumentation Amplifier: Direct or + MFB FDA
  - SE Input Buffer + MFB FDA

Benefits

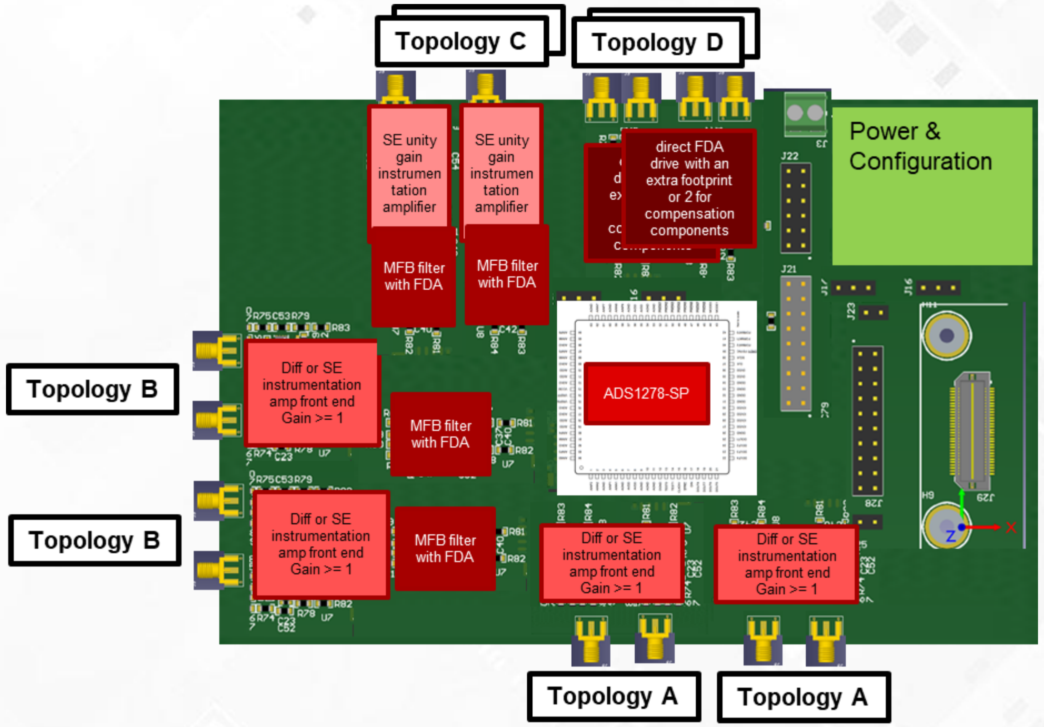
- High resolution of up to 18 ENOB across wide temperature range
- High PSRR and rail-to-rail capabilities enable simplified power supply design (Unipolar supply, no LDO)
- Low power consumption & board size per channel

Target Applications

- Satellite precision data acquisition systems:
- Thermal control of optical instruments / camera systems
- Linear displacement (position) sensing / motion control
- Gyro sensors
- Atomic clock

Devices

- ADS1278-SP — 24-Bit 8-Ch Simultaneous-Sampling Delta-Sigma ADC
- LMH5485-SP — 850-MHz fully differential amplifier
- LMP7704-SP — precision, low-input bias, RRIO, wide supply range amplifiers
- LMH6628QML-SP — Dual Wideband, Low Noise, Voltage Feedback Op Amp
- LM4050QML-SP — 2.5-V or 5-V shunt voltage reference
- TPS7H1101A-SP — 1.5-V to 7-V input, 3-A low-noise low-dropout (LDO) regulator
- TPS50601A-SP — 3-V to 7-V input, 6-A synchronous step-down converter

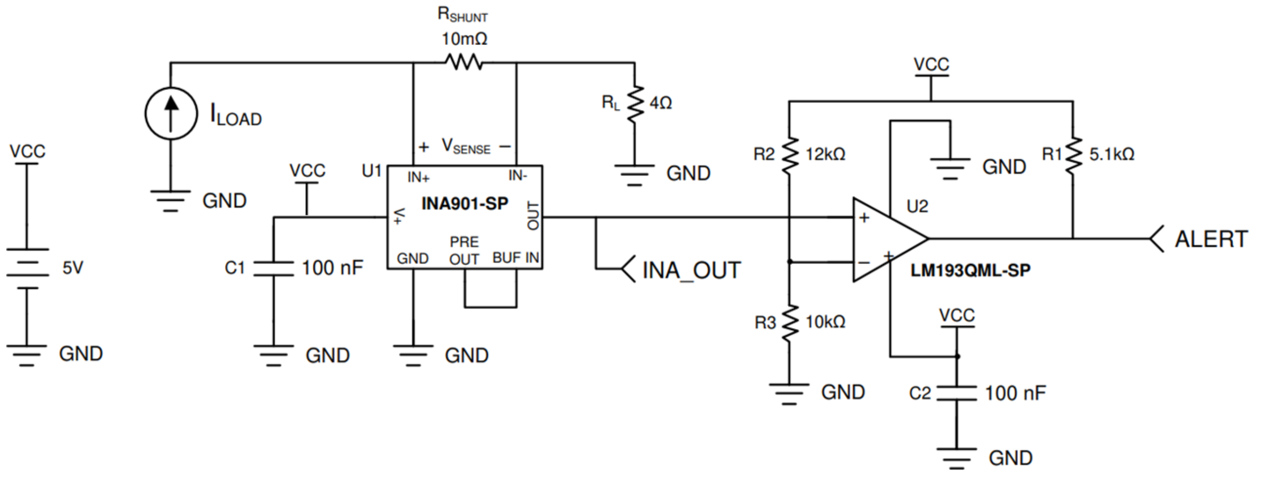


Space-grade, 50-krad, overcurrent event-detection circuit

Example from TI's "Spacecraft Circuit Design Handbook"

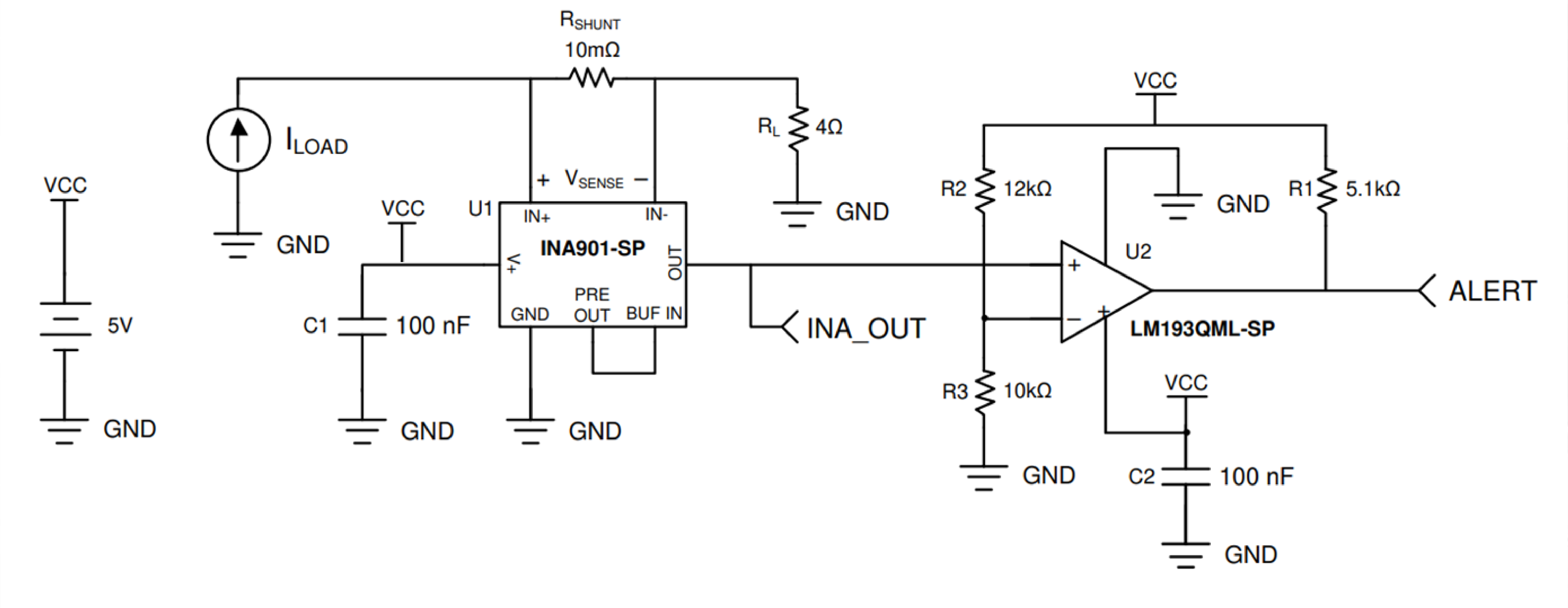
Web Address with more collateral:
https://www.ti.com/applications/industrial/aerospace-defense/space/overview.html

Problem and proposal



- Space radiation can lead to latch-up
  - Parasitic SCR triggers
  - Steep current rise
  - Component death by overheat
- Detected “quickly” -> no problem
  - Unidirectional current sense can detect abnormal behavior
  - Over current events could then trigger power cycling
- This circuit example shows high side current sense
  - Nominal currents from 5A to 10A
  - Sense resistor of only 10 mΩ (P_{max} < 1W)
  - Comparator triggers ALERT at I > 11A (V_{OC} > 2.2 V)

Circuit diagram



Comments

- INA901-SP is a space grade precise current sense amplifier
- INA901 generates in this circuit 200 mV / A
- LM193QML-SP works as voltage comparator for immediate action
  - Threshold set to 2.2 V (11 A)
- Signal could be further processed in ADC and MCU (FFT, fast fourier transform)
- Unusual power pattern could then trigger actions as well
  - Transmit to ground station
  - Ground station could decide what to do

Design process

- Steps of circuit design shown in “Spacecraft Circuit Design Handbook”
- Calculation of shunt R1
- Calculation of R2 and R3 for correct trigger
- Calculation of trigger (offset) error depending on
  - Set threshold
  - Input current

- Find the book here: https://www.ti.com/lit/eb/slyy214/slyy214.pdf

Linear Thermoelectric Cooler (TEC) Driver Circuit with high accuracy and stability and minimized noise emissions

Space-grade, 100-krad, linear thermoelectric cooler (TEC) driver circuit

- Star tracker systems
- Temperature regulation CCD-based Infrared Camera
- Laser Communication Systems
- Wide Field Planetary Camera

Design challenge/problem statement
• Survive **100-krad** (Si) total dose, high immunity to SEL **≥ 75MeV-cm2 /mg** • Bi-directional current control (**+/- 2.5A**) • Avoid any hard switching to **avoid EMI** • Keep **board area** requirements as low as possible • High accuracy (**1mA**)

Target End Equipment:

- Laser communications payload
- Optical imaging payload
- Star tracker
- Satellite motor & actuator drive

Solution description

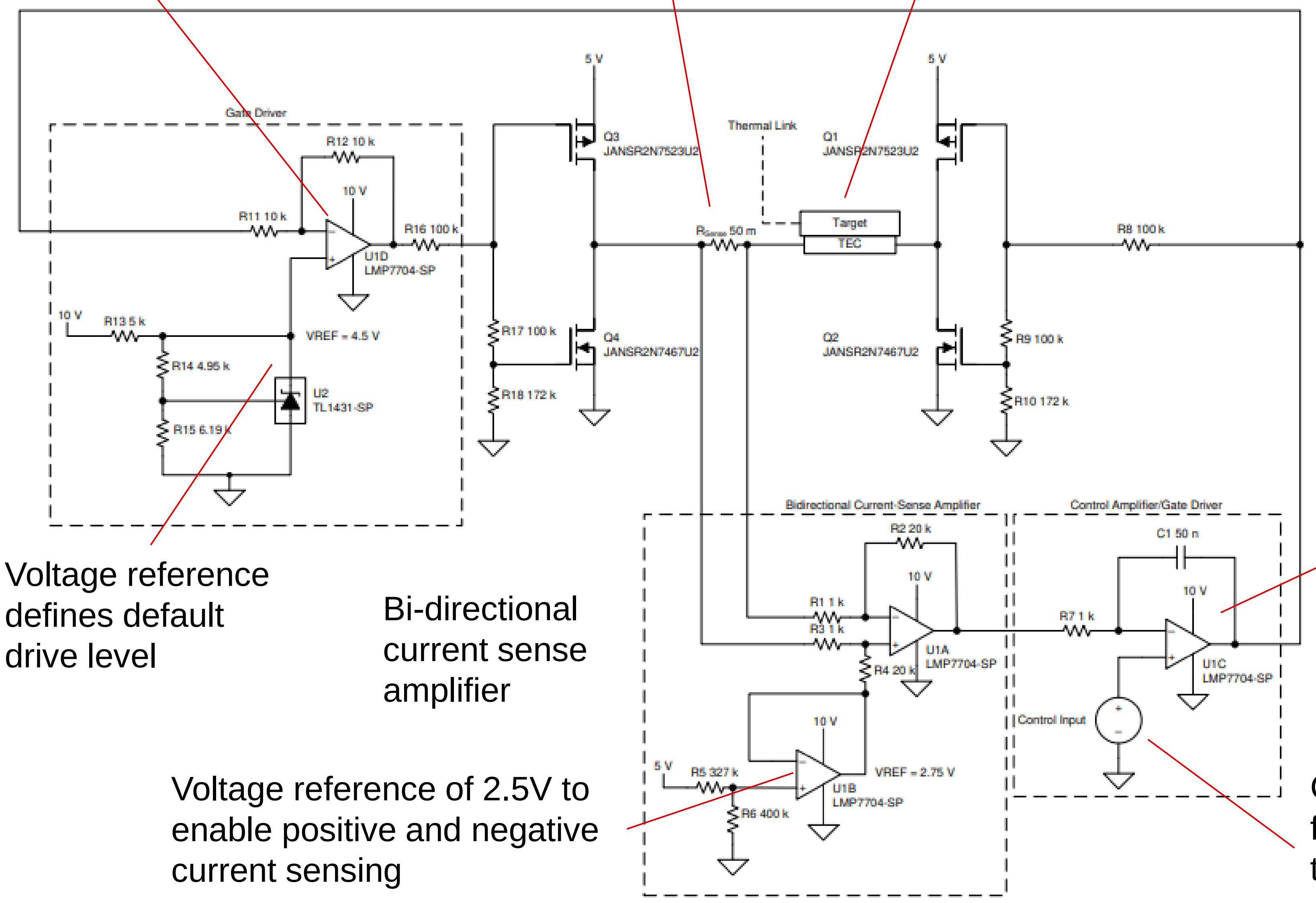
A **Linear H-Bridge** driver provides:

1. **Low noise:** TECs are usually used in high accuracy imaging systems.
   - No EMI is induced since there is no switching
2. **High accuracy:**
   - Current control error within 1mA
3. **Low design complexity:**
   - No MCU, only non-complex components

Driver for the left half bridge

Current shunt resistor

TEC Element



Voltage reference defines default drive level

Bi-directional current sense amplifier

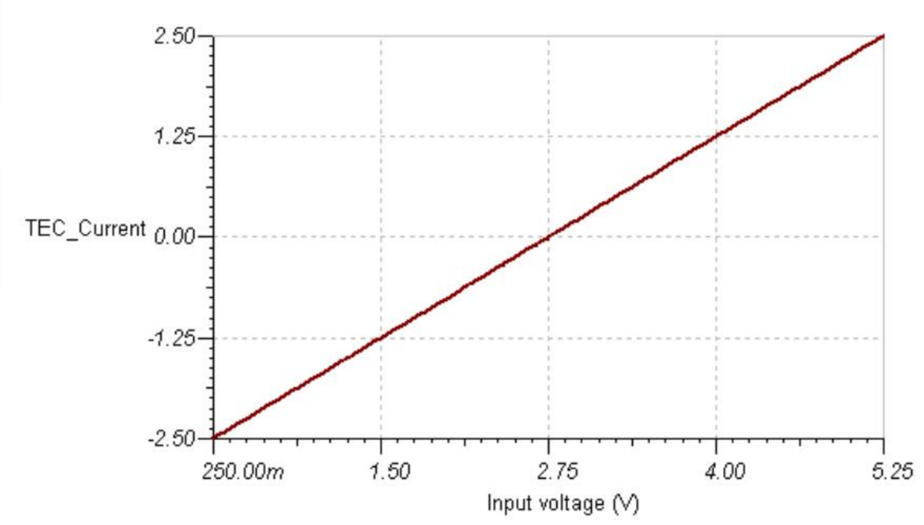
Voltage reference of 2.5V to enable positive and negative current sensing

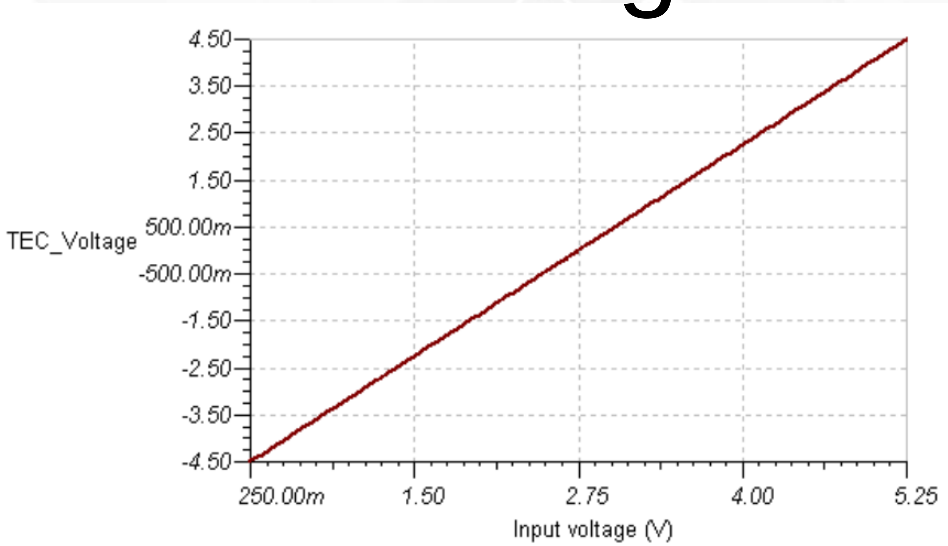
- Control amplifier handles the feedback from the current sense amplifier
- Drives the right half bridge directly

Control input from outer temperature control loop

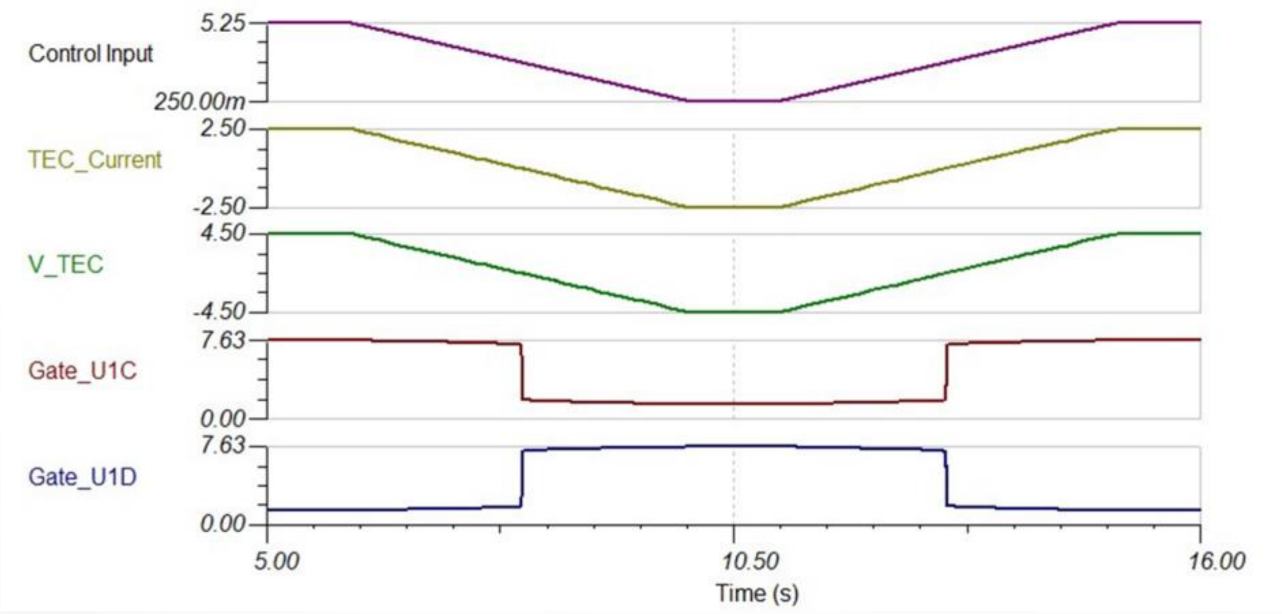
Validation results

TEC Element Ratings

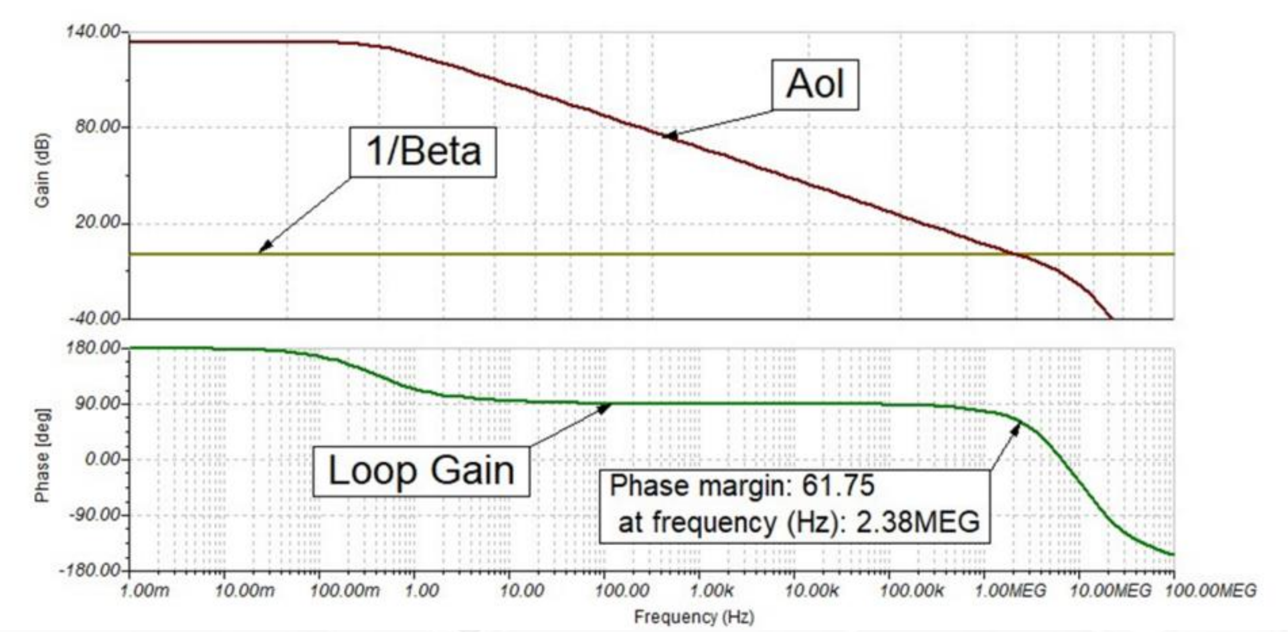




Transient Simulation



System Stability



Space-grade, 100-krad, linear thermoelectric cooler (TEC) driver circuit

Summary

- The design meets all design criteria in terms of max **current rating** and **voltage rating** of the TEC, **high accuracy, stability** and **radiation hardness**
- The linear driver avoids any switching and keeps **EMI low**
- **Low complexity** with very small board space requirements (e.g. the four OpAmps are integrated in a single package). Only two voltage rails required.
- Application brief with design steps under Space-Grade, 100-krad, Linear Thermoelectric Cooler (TEC) Driver Circuit

Rad-Hard and Rad-Tolerant Current Measurement Solutions

Released

INA901-SP

Very Wide Common Voltage Current Sense Amplifier with Split Stage for Filtering

Features

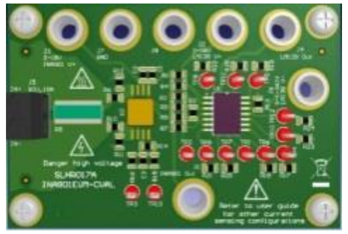
- Radiation: TID 50krad RHA, SEL 85 MeV.cm²/mg (125 C)
- -15V to 65V common-mode range independent of supply
- 2.7V to 16V supply
- Split stages for filtering
- Bandwidth up to 130kHz
- Gain: 20V/V
- Package: Ceramic 8-lead HKX 6.5mm x 6.5mm
- Option for KGD

Applications

- Current Monitor for current mode control DC-DC Convertor
- Current Measurement in an H-Bridge for Motor Control
- Latching Current Limiters on High common mode bus
- Current sensing on GaN modules for increased efficiency

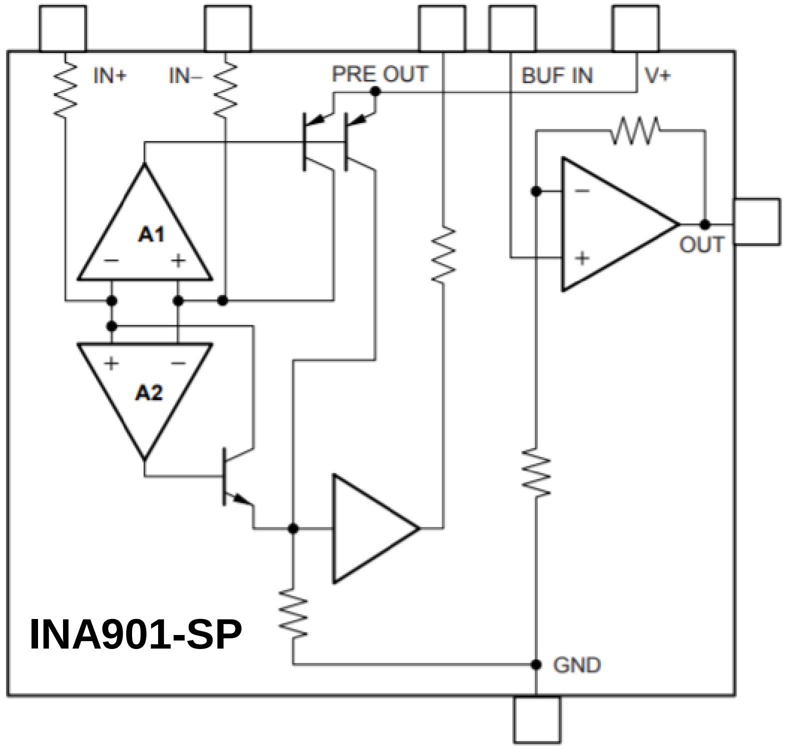
Tools and Resources

- Product folder: LINK
- SMD datasheet: LINK
- Evaluation board (EVM): LINK
- Radiation reports: LINK



Benefits

- Eliminates need for additional protective components in the event of CMR reversals
- Preserves buffered voltage output and saves using an additional op amp
- Simplifies design of current control loops
- Enables a flexible circuit design
- QMLV Qualified 5962-1821001VXC



Released

INA240-SEP

-4V to 80V Bi-Directional with PWM Rejection CSA For Large Common-Mode Transients

Features

- TID Characterization (ELDRS Free) to **30 krad(Si)**
- SEL Immune to LET = **43 MeV·cm²/mg** at 125°C
- High Accuracy
  - –Input Offset Voltage: **25 µV (max)** with **250 nV/°C Max. Drift**
  - –Gain Error: **±0.25% (max)** with **2.5 ppm/°C Max. Drift**
- Available in Military) Temperature Range **-55°C to 125°C**
- Fixed Gain: **20 V/V**
- Package: 8-Pin TSSOP (3.0 × 4.4 mm)

Applications

- Low Earth Orbit Space Applications
- Power Supervision
- Overcurrent and Undercurrent Detection
- Satellites Telemetry
- Motor Control Loops

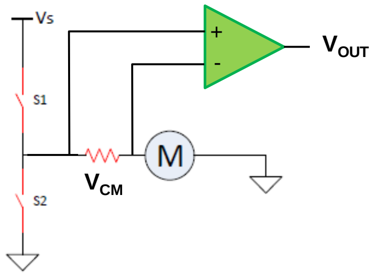
Tools and Resources

- Product folder: LINK
- Military Datasheet (VID): LINK
- Reliability & Radiation Reports: LINK

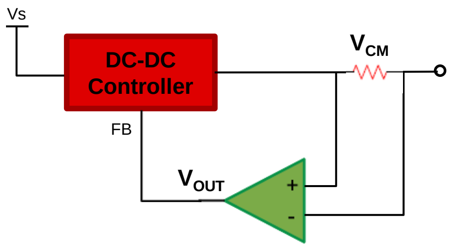
Benefits

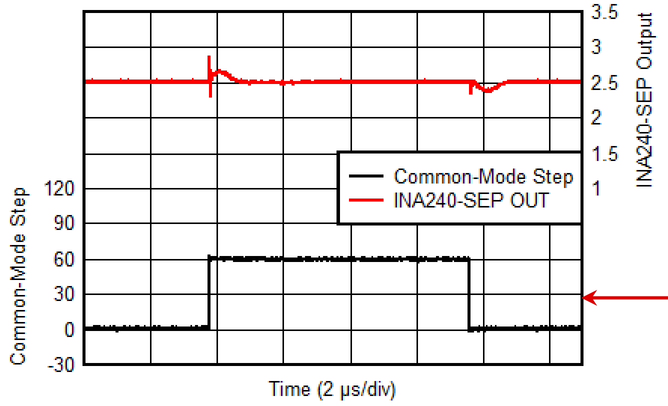
- Radiation Lot Acceptance Testing (RLAT) to 20 krad(Si)
- Vendor Item Drawing (VID) V62/18615
- Large input range to integrate into increasing common-mode voltage applications
- High accuracy minimizes system margins
- High CMRR allows for direct in-line motor current sensing

In-Line Motor Current Sensing



High-Side DC-DC Current Sensing





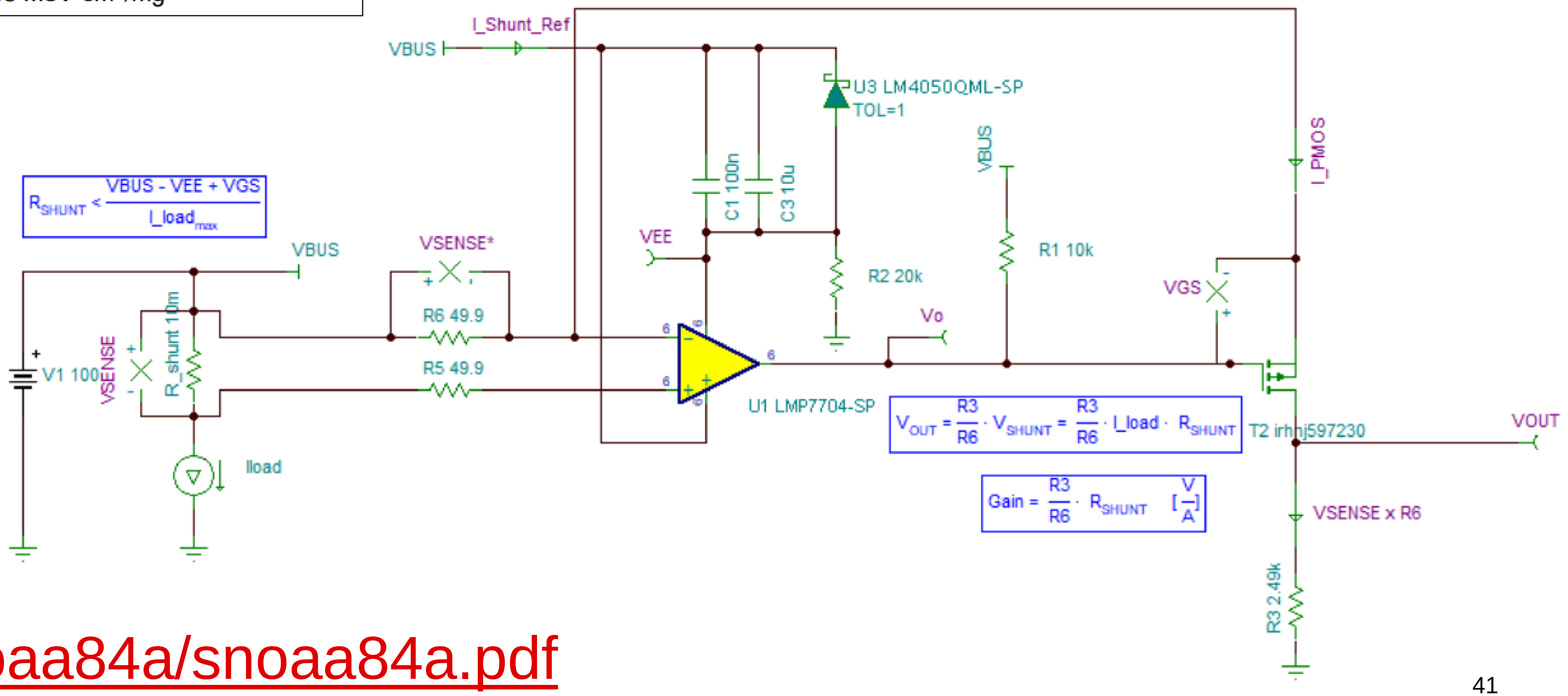
Stable V_{OUT}!

Large, high slew rate input V_{CM}

Texas Instruments

High Common Mode Current Measurement

Parameter	Value
Common-Mode Voltage (VCM)	100 V
Load Current (I_{load} or I_{shunt})	1 A to 10A
Output Voltage (V_{out})	0.5 V to 5 V
Output Voltage Error	< 0.7%
Power Consumption	< 700 mW
Total Ionizing Dose (TID)	100-krad (Si)
Single Event Latch-up (SEL) Immunity	85 MeV·cm^2/mg



- https://www.ti.com/lit/an/snoaa84a/snoaa84a.pdf

Space Grade Satellite Telemetry Reference Design

TIDA-010197

Benefits

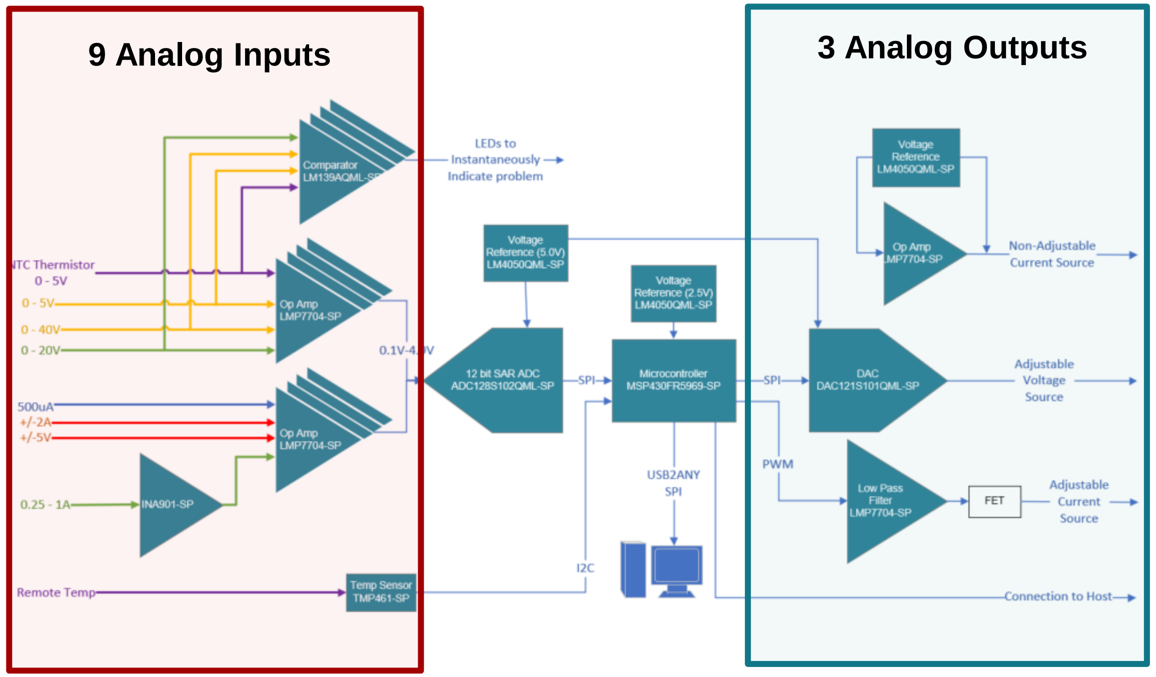
- All inclusive telemetry module to monitor a variety of measurements:
  - Voltage, Current, Temperature, Sensors (Current Output)
- Options for “5 V Rail” or“ 5 V and 12V Rails”
- Multiple integration options for different size, cost, and accuracy needs
  - Integrated MCU ADC (50~75 krad and 72 MeV)
  - ADC128S102QML-SP 12-Bit ADC (100 krad and 75 MeV)

Target Applications

- Satellites
  - Health Monitoring / Telemetry
  - Power Monitoring on Busses
  - RF PA Biasing
  - TEC Monitor
  - Attitude & Orbit Control System (AOCS)

Devices

- ADC128S102QML-SP 8-Ch, 12-bit ADC
- MSP430FR5969-SP FRAM Mixed-Signal Microcontroller
- LMP7704-SP Precision Quad Op Amp
- LM158QML-SP GP Dual Op Amp
- DAC121S101QML-SP 12-Bit DAC
- LM4050QML-SP Shunt Voltage Reference
- TMP461-SP Digital Output (I2C) Temp Sensor
- INA901-SP Current Sense Amp
- LM139QML-SP Quad Comparator



Web address with more collateral:
https://www.ti.com/applications/industrial/aerospace-defense/space/overview.html
The “Spacecraft Circuit Design Handbook”:
https://www.ti.com/lit/eb/slyy214/slyy214.pdf

Thanks