TECH DAYS
Texas Instruments

Design & Protection of Analog Outputs for Industrial Automation

ASC > DC > DAC

Kevin Duke

TI Training - Summary

Design, Protection, and Technologies for Analog Outputs in Industrial Automation:

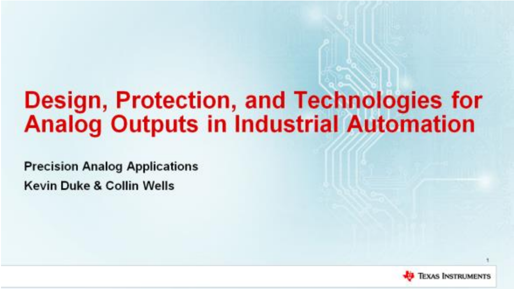
Analog outputs in industrial automation come in a variety of configurations that each must deliver strong precision while passing stringent EMI / EMC certification tests. This session will address these systems and their challenges by explaining each configuration, walking through example designs for analog outputs, and a discussion of immunity tests and the design of protection circuits for these tests. We will also take a look at the HART communication protocol, which is growing in popularity world-wide, and the benefits that it provides to these systems. The presentation will include a look at existing and roadmap TI components that are intended to service analog outputs in industrial automation.

What you'll learn:

- Common Architectures
- Current / Voltage Output Design
- Intro / Benefits of HART
- Internal ESD Structures
- IEC61000-4 Test Standard
- Design of Protection Circuits

Course Details:

Type: In Person / Webinar
Format: PPT / PDF
Duration: 60 – 90 Minutes
Language: English
Cost: Free
Audience: Customers, Field Applications Engineers, Design Engineers, Test & Characterization Engineers



Available Online

About Presenter – Kevin “The Duke of DACs” Duke

Systems Engineer – Digital-to-Analog Converters - Dallas, Texas USA

Background

- ➢ B.S.E.E., Texas Tech University 2010
- ➢ 8 years of Analog and Mixed Signal Experience
  - – 3 years SW / FW data converter demonstration platform development
  - – 3 years dedicated Analog Applications Engineering for catalog and industrial automation DAC products
  - – 2 years product definition / business development for industrial automation DAC products

Expertise

- – Industrial transient and other miscellaneous immunity standards
- – PLC & Sensor Transmitter architectures
- – HART, Foundation Fieldbus, and other “Smart Transmitter” Protocols
- – Troubleshooting complex board/system level problems

Agenda

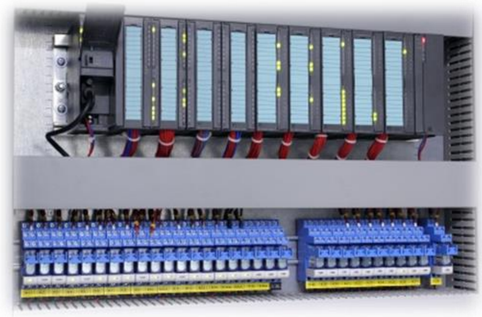
- Overview
  - Where/how are analog outputs used in industrial automation?
  - What are the standard configurations for analog outputs?
- Designing 3-wire Transmitters
  - Theory of Operation
  - Design Examples
- Designing 2-wire Transmitters
  - Theory of Operation
  - Design Examples
- HART
  - What is it? Why should I care?
- Designing Protection Solutions
  - How does a device get damaged?
  - How do customers test for industrial transient immunity?
  - How do I stop these transients from damaging my design?

Overview

Where are analog outputs used in Industrial Automation? What do they look like?

How are Analog Outputs used in Industrial Automation?

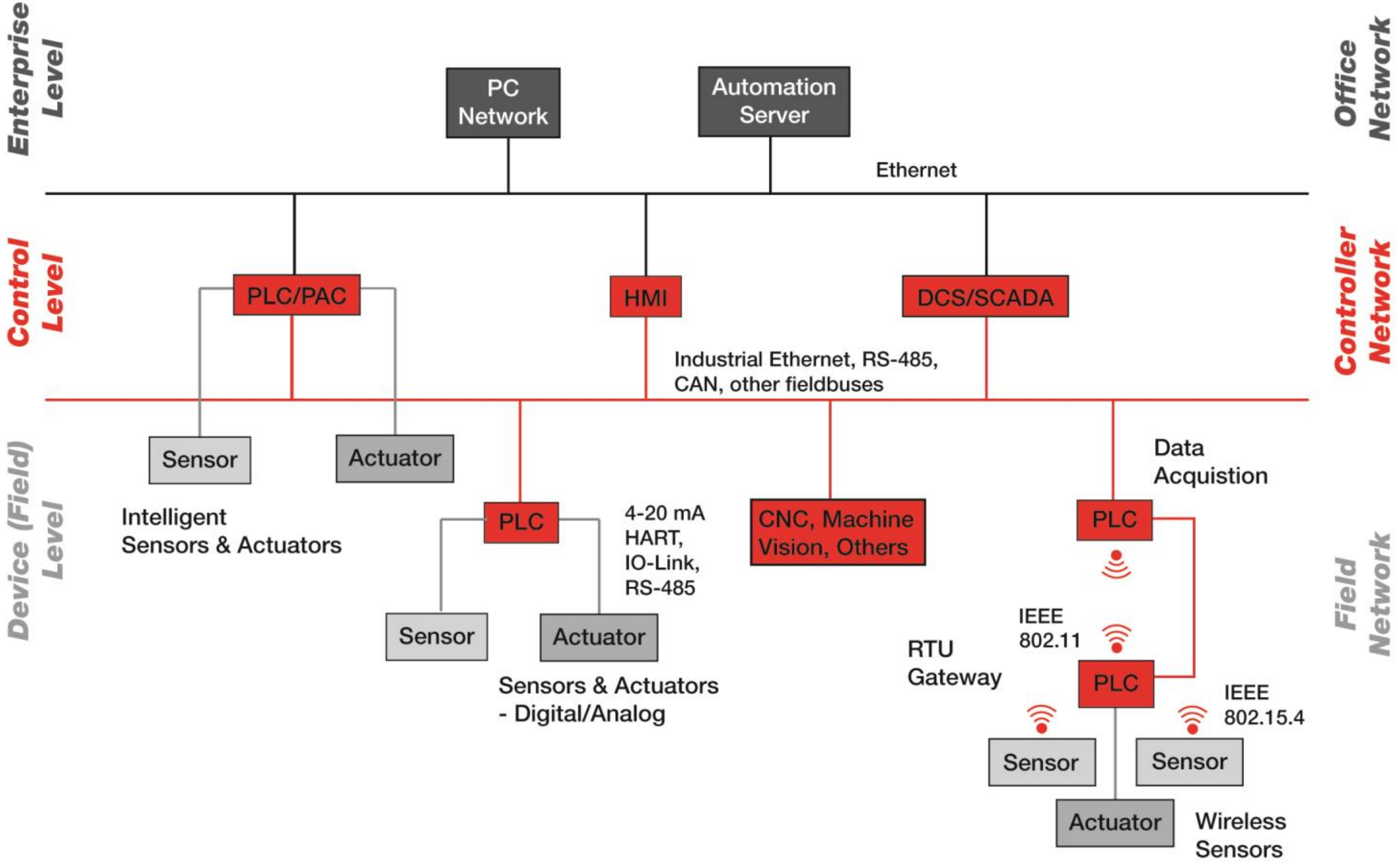
- Programmable Logic Controllers
  - Analog output modules that control something placed in the field
    - Movement of robotic arm, position of linear actuator, etc.
  - Analog output module is powered by PLC back-plane
    - Primarily 3-wire systems



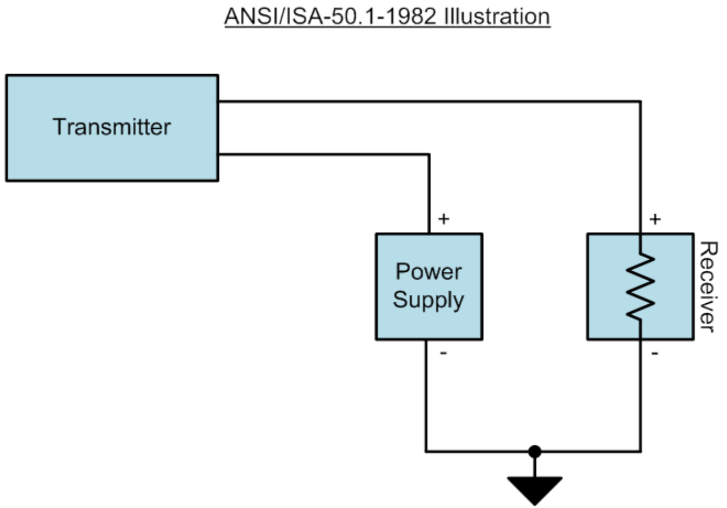
- Field Elements
  - Analog outputs paired with sensors, placed remotely in the field
  - Comprise a majority of the market for industrial analog outputs
  - Most often 2-wire, or loop-powered, 4-20mA sensor transmitters
  - Some transmitter current requirements are greater than 4mA
    - Use 3-wire configuration

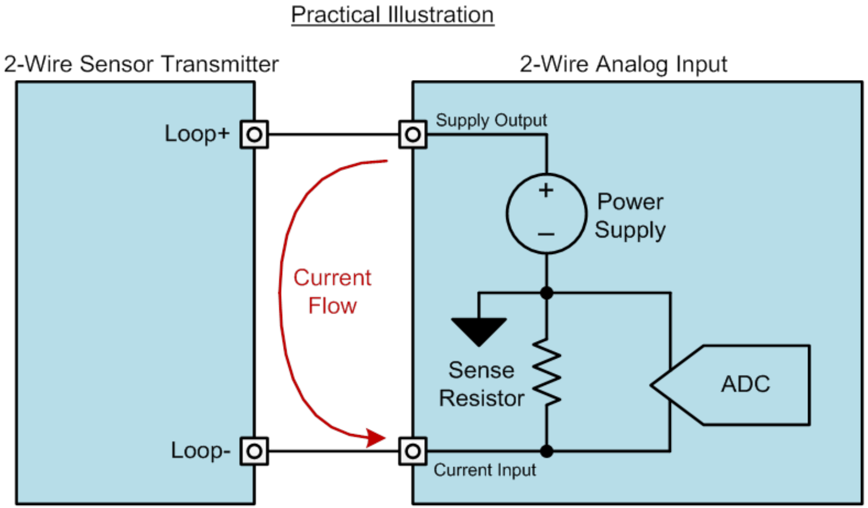
- Is isolation required? Why? Is isolation provided by the receiver or the transmitter?
  - There are isolated variants of 2-wire and 3-wire analog outputs
  - Power isolation, at least, is implied in all 4-wire analog outputs

Industrial Automation Overview



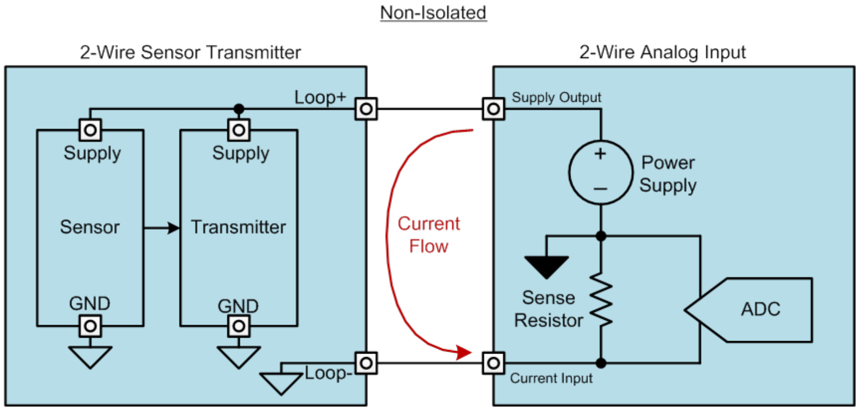
2-wire Configuration

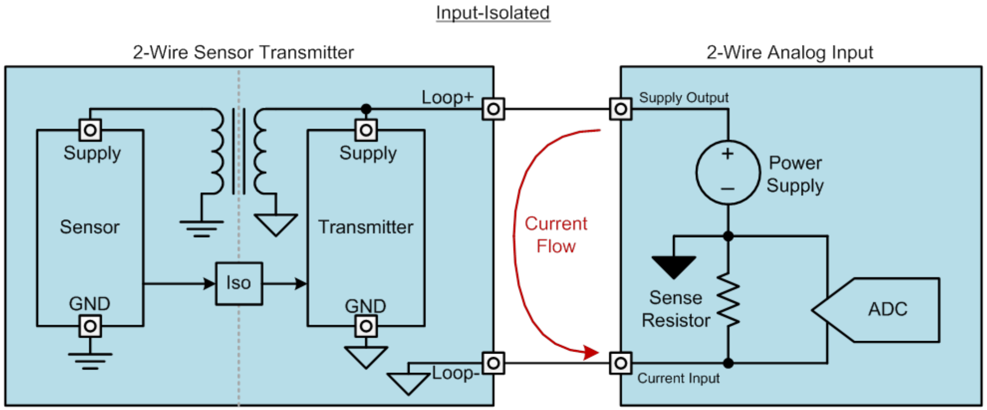




- Supply, transmitter, and receiver are in series – power & signal are in the same loop
- Transmitter communicates with receiver through return current (4-20mA)
- Transmitter must be powered on ≤4mA of supply current
- Long cable lengths between supply and transmitter, transmitter and receiver, and large sense resistors can reduce voltage available for transmitter

2-wire Isolation





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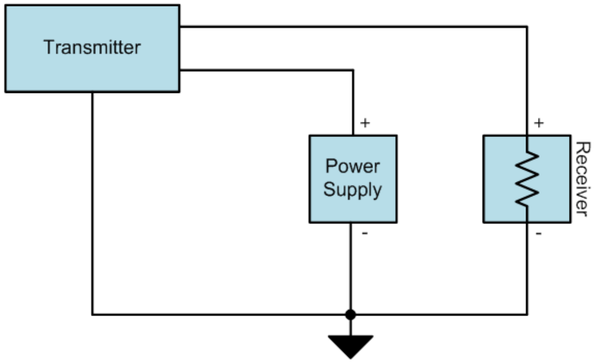
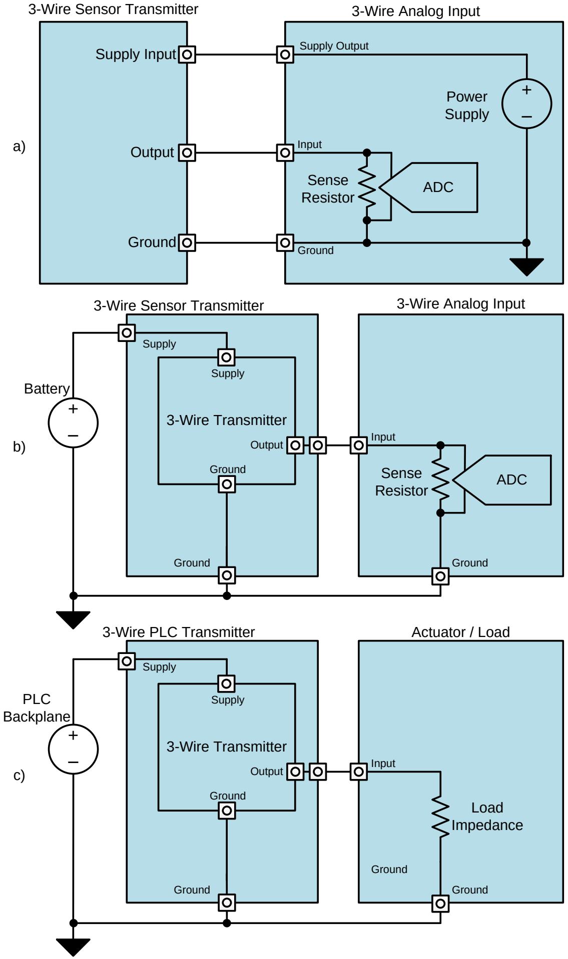
3-wire Configuration

ANSI/ISA-50.1-1982 Illustration



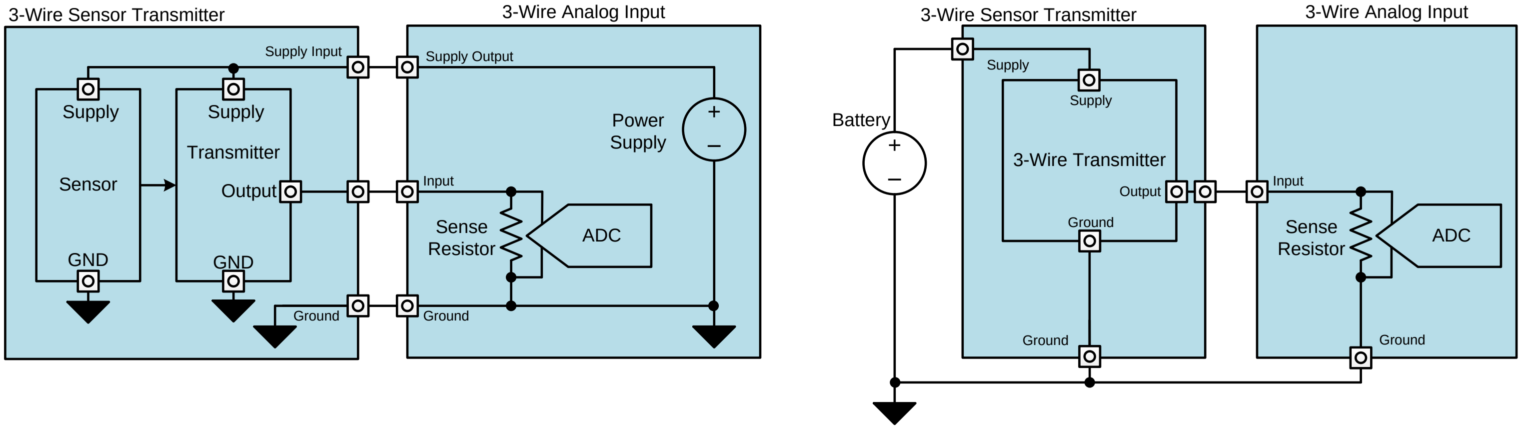
- Transmitter has separate loops for power and for analog output
  - Output current can reach 0mA
- Grouping of power supply, transmitter, and receiver may vary
  a) >4mA supply current available for transmitter
  b) Similar to a) but with local supply to remove cable impedance voltage drop
  c) Typical implementation for PLC transmitter, battery from b) replaced by PLC backplane

Practical Illustrations

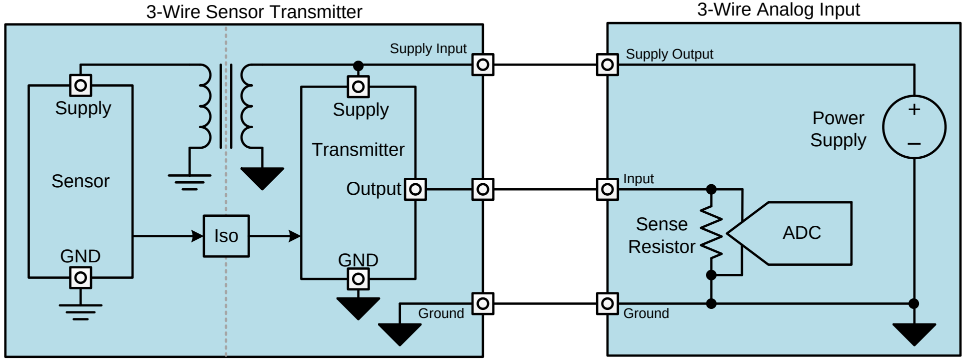


3-wire Isolation

Non-Isolated

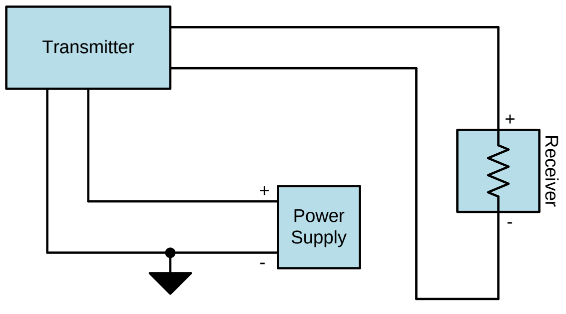


Input-Isolated

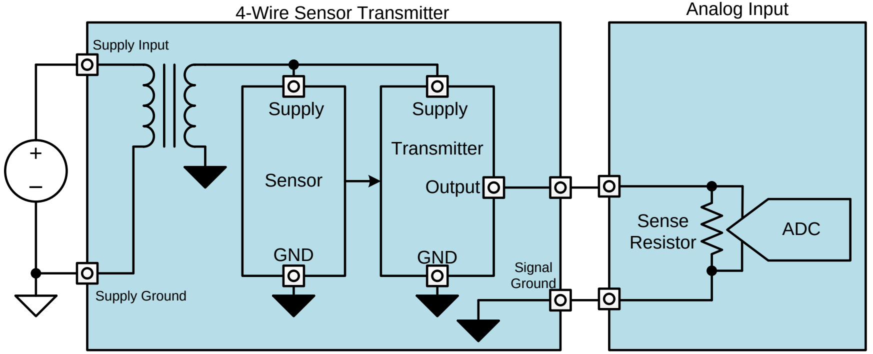


4-wire Configuration & Isolation

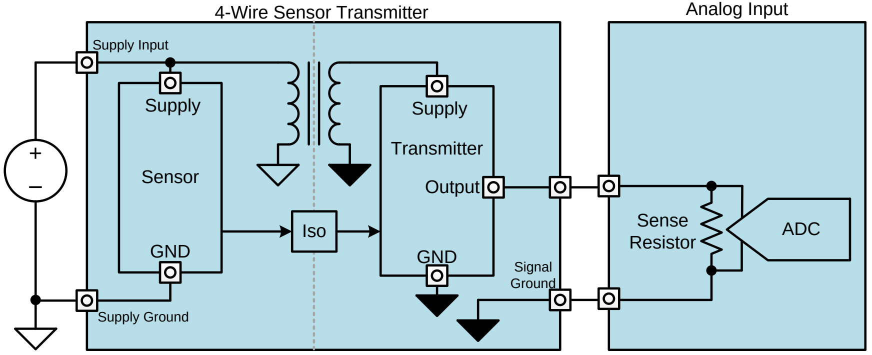
ANSI/ISA-50.1-1982 Illustration



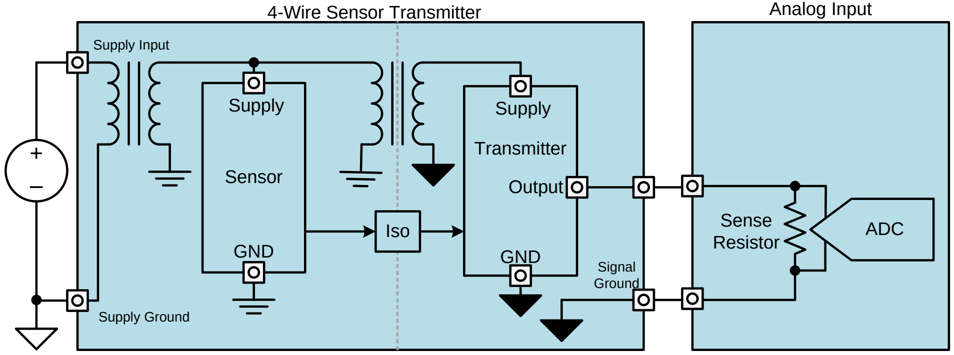
Power-Isolated



Output-Isolated



Fully-Isolated



Designing 3-wire Transmitters

Theory of Operation & Design Examples

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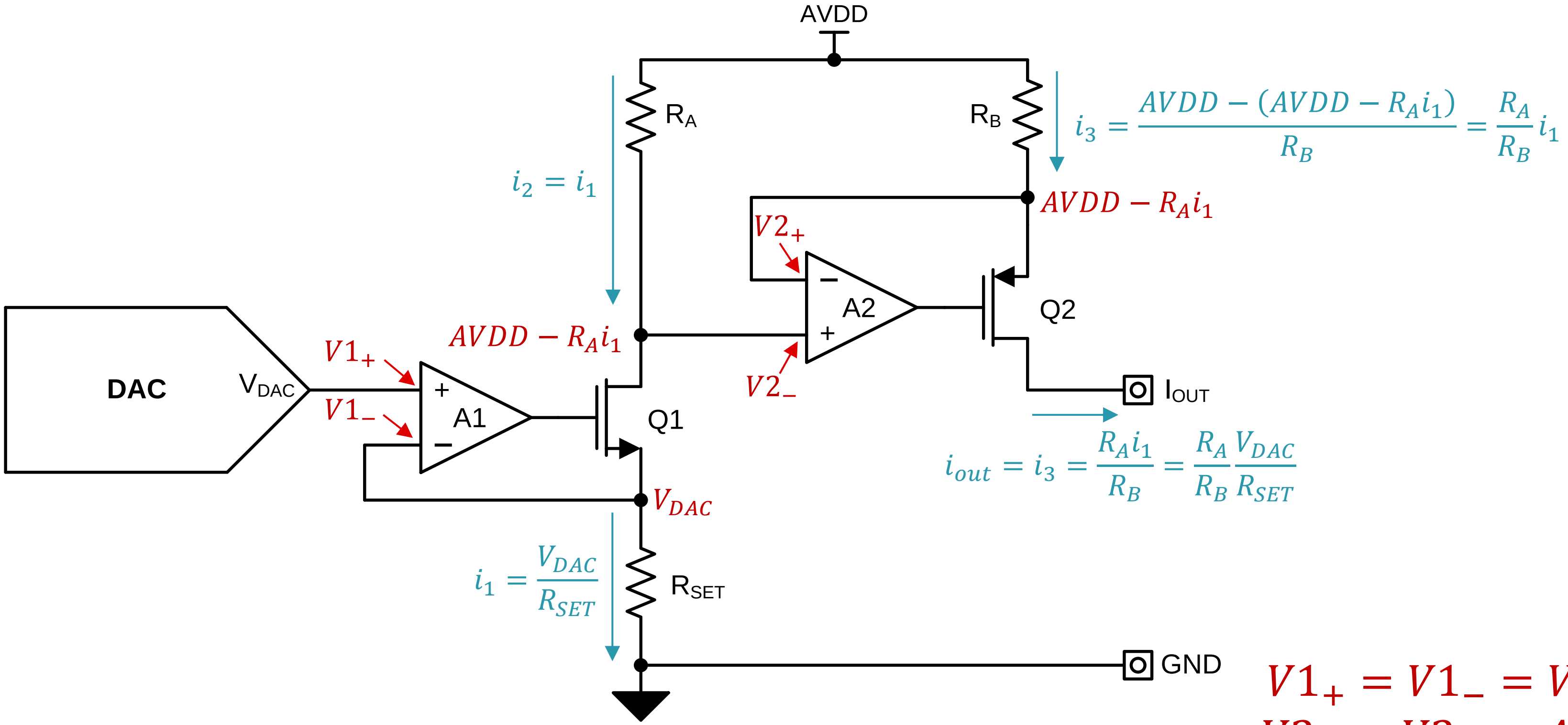
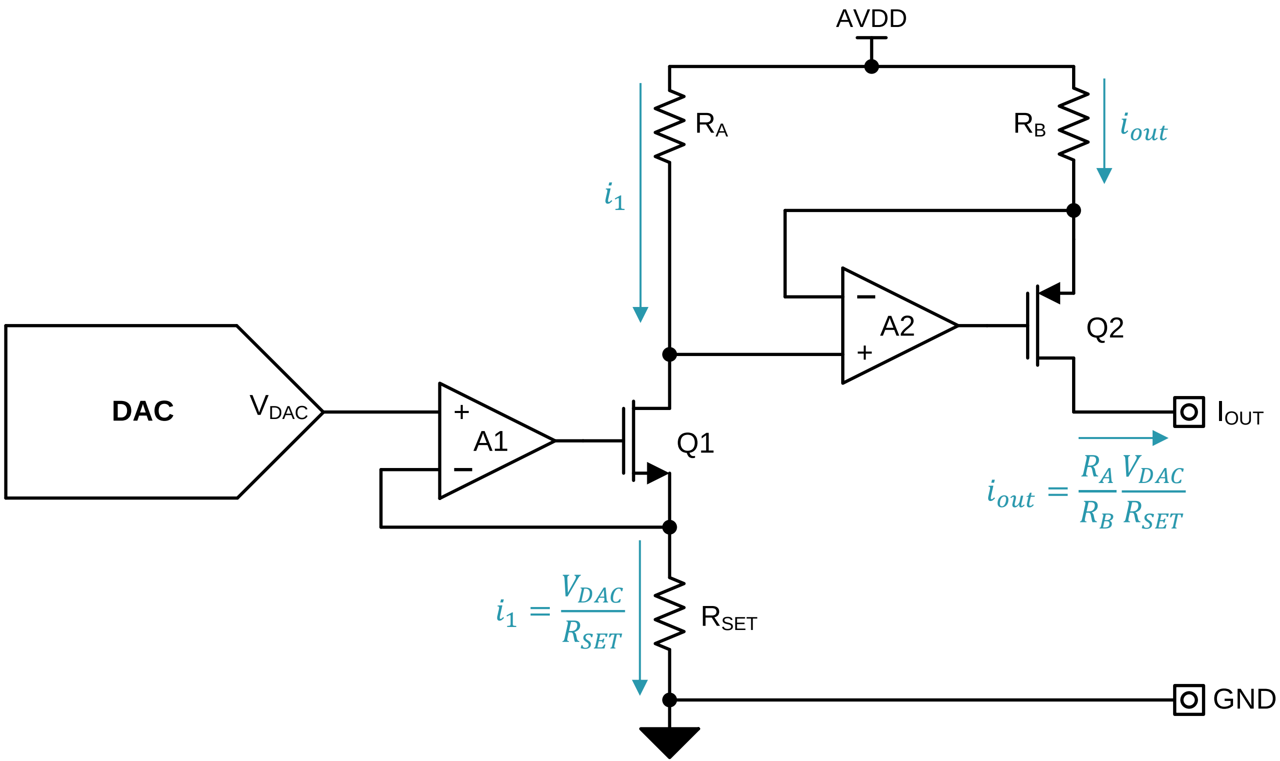
Current Output: Theory of Operation



$$V1_+ = V1_- = V_{DAC}$$
$$V2_+ = V2_- = AVDD - R_A i_1$$

Texas Instruments

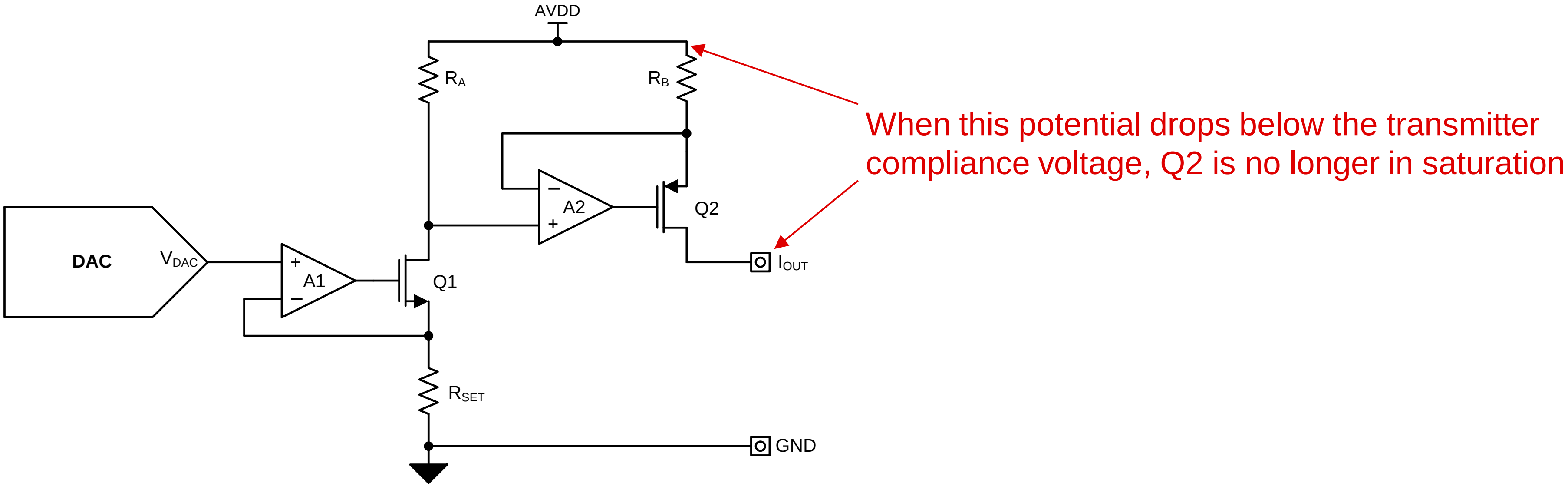
Current Output: Considerations



- i_1 current is wasted power
  - All of this current goes straight to ground
- Large i_1 current creates heating / drift of Q1 & R_{SET}
- Ratio of R_A:R_B sets current gain from first stage to output stage
- At full-scale output & low impedance load, Q2 power / heat dissipation rises
  - In layout, keep away from other sensitive components

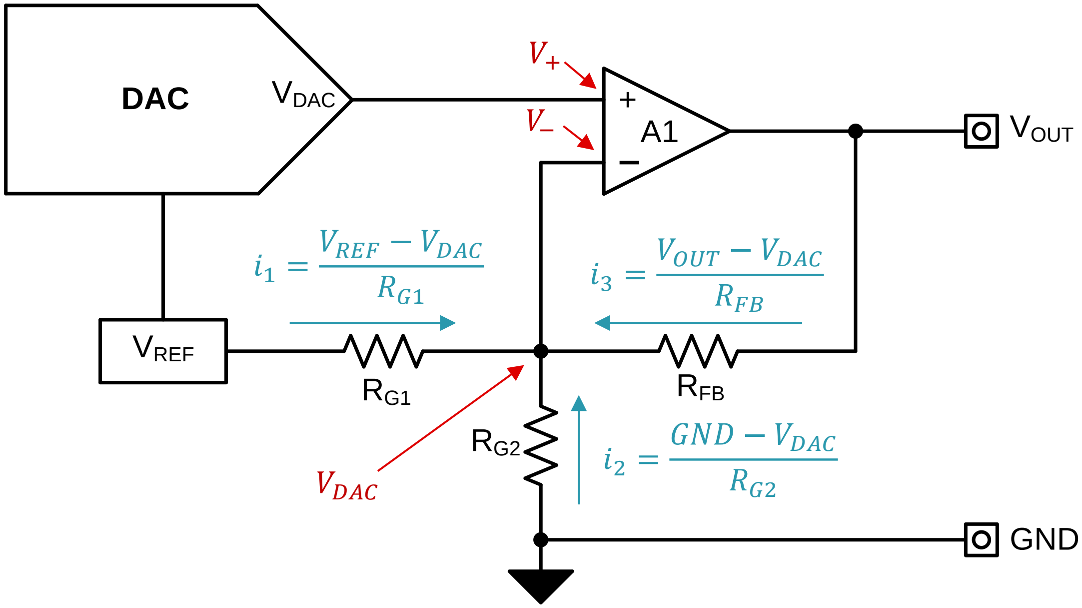
Texas Instruments

Current Output: Compliance Voltage



- Compliance voltage is the point at which the voltage potential at the point of load is too high for the voltage to current converter to maintain linear operation
- To accommodate for compliance voltage:
  - Understand the maximum current output
  - Understand the maximum load impedance
  - Ensure that AVDD > MaxCurrent*MaxLoad + Compliance Voltage

Voltage Output: Theory of Operation



$$\frac{-V_{DAC}}{R_{G2}} + \frac{V_{REF} - V_{DAC}}{R_{G1}} + \frac{V_{OUT} - V_{DAC}}{R_{FB}} = 0$$

$$\frac{-V_{DAC}}{R_{G2}} + \frac{V_{REF}}{R_{G1}} - \frac{V_{DAC}}{R_{G1}} + \frac{V_{OUT}}{R_{FB}} - \frac{V_{DAC}}{R_{FB}} = 0$$

$$\frac{V_{OUT}}{R_{FB}} = \frac{V_{DAC}}{R_{FB}} + \frac{V_{DAC}}{R_{G1}} + \frac{V_{DAC}}{R_{FB}} - \frac{V_{REF}}{R_{G1}}$$

$$V_{OUT} = \left(1 + \frac{R_{FB}}{R_{G1}} + \frac{R_{FB}}{R_{G2}}\right) V_{DAC} - \frac{R_{FB}}{R_{G1}} V_{REF}$$

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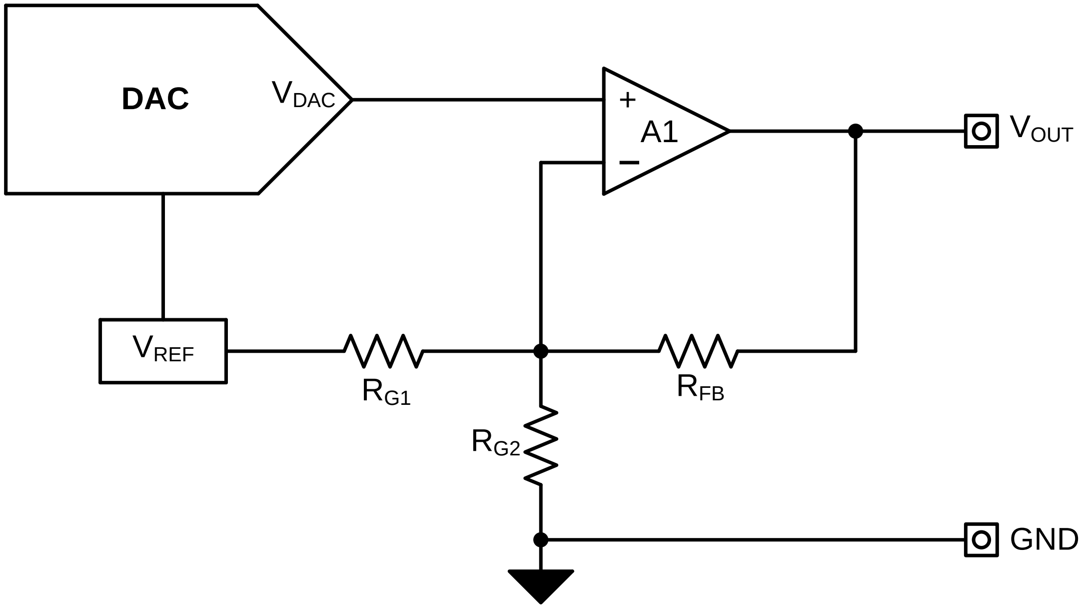
Voltage Output: Consideration



- Select offset gain to set negative full-scale end point

$$V_{NegativeFS} = -\frac{R_{FB}}{R_{G1}} V_{REF}$$

- Modify full-scale range gain

$$V_{FSR} = \left(1 + \frac{R_{FB}}{R_{G1}} + \frac{R_{FB}}{R_{G2}}\right) V_{DAC}$$

- Check full-scale output

$$V_{Positive\ FS} = V_{FSR} - V_{NegativeFS}$$

$$V_{OUT} = \left(1 + \frac{R_{FB}}{R_{G1}} + \frac{R_{FB}}{R_{G2}}\right) V_{DAC} - \frac{R_{FB}}{R_{G1}} V_{REF}$$

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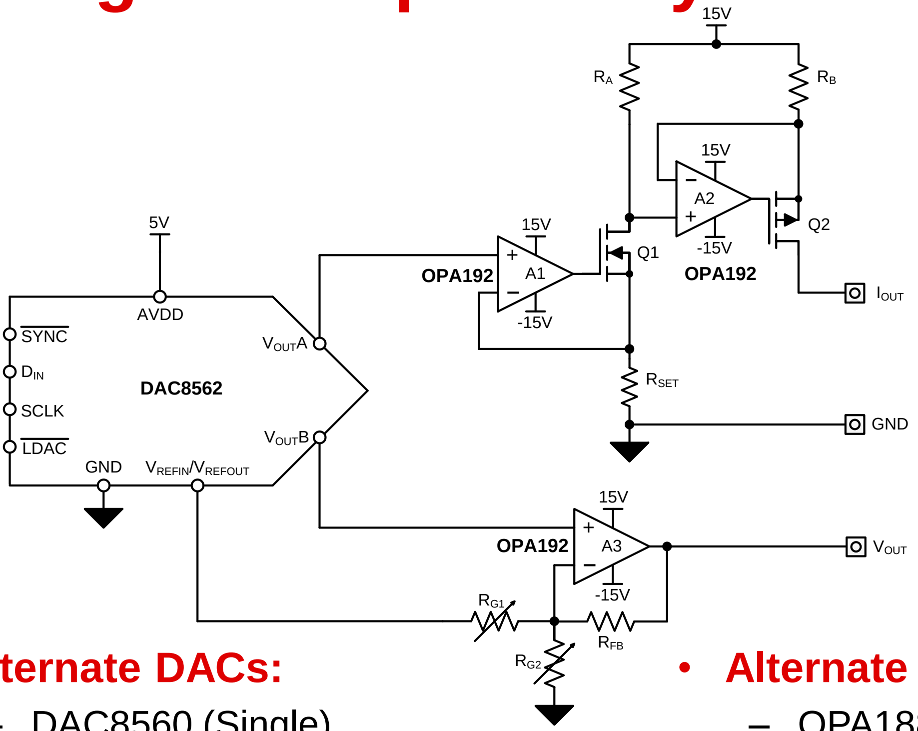
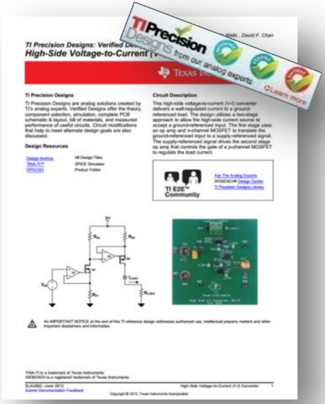
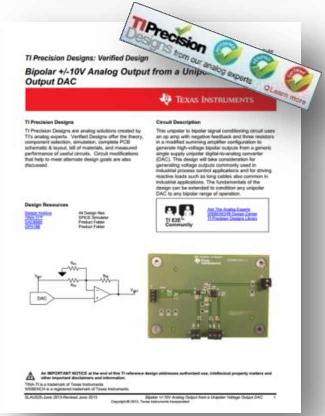
Design Example: Fully Discrete



- **Alternate DACs:**
  - DAC8560 (Single)
  - DAC8564/8 (Quad/Octal)
  - DAC8811/2 (Improved Single/Dual)
- **Alternate Amplifiers:**
  - OPA188
  - OPA277
  - OPA170/OPA172



TIPD102



TIPD125

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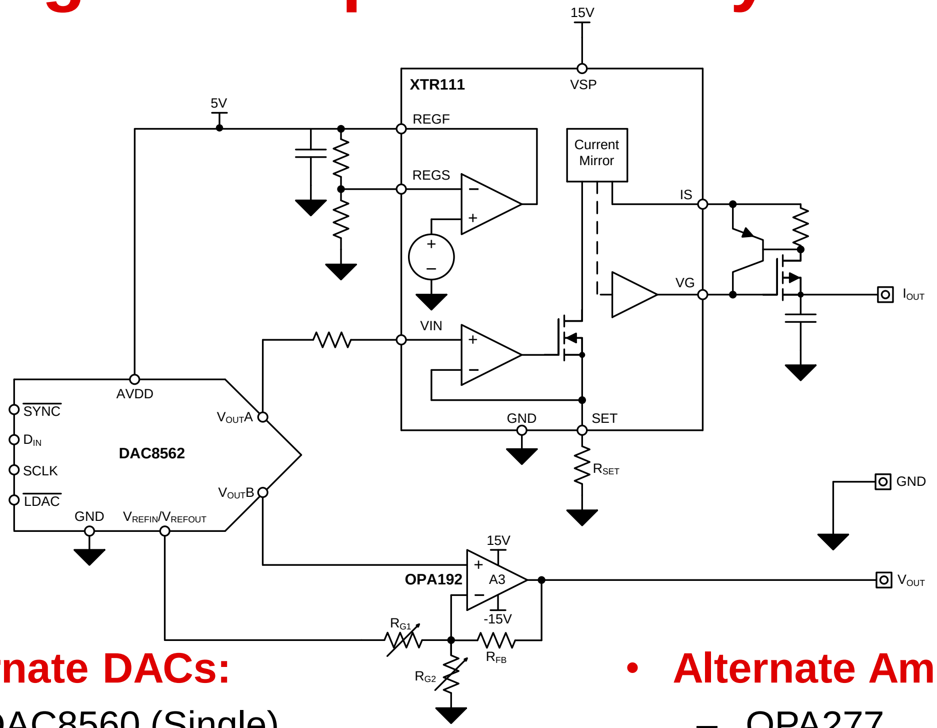
Design Example: Partially Discrete



- Alternate XTRs:
  - XTR110 (Internal R_{SET})
  - XTR300 (Source/Sink)

- **Alternate DACs:**
  - DAC8560 (Single)
  - DAC8564/8 (Quad/Octal)
  - DAC8811/2 (Improved Single/Dual)

- **Alternate Amplifiers:**
  - OPA277
  - OPA170/OPA172
  - OPA188

TIPD in Test

DAC8760/7760

16-/12-bit DACs with Voltage and 4-20mA Current Outputs

RELEASED
A GRADE IN TEST

Features

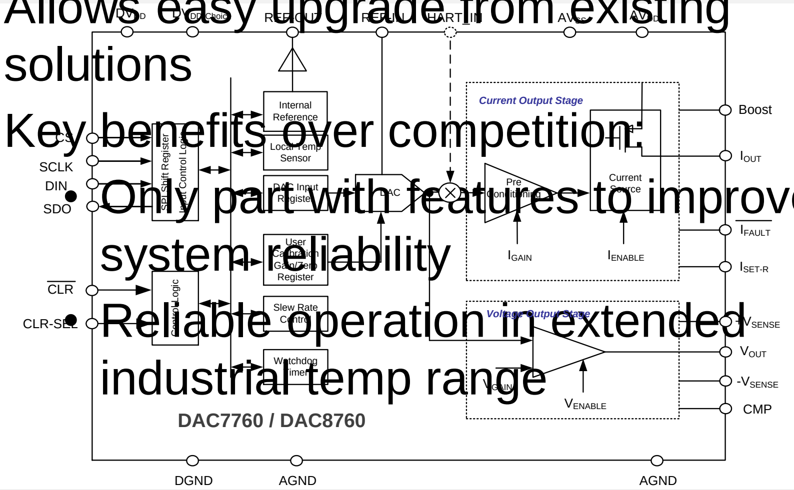
- DAC with Current & Voltage Outputs
- Selectable Ranges
  - Current: 0-20mA; 4-20mA; 0-24mA
  - Voltage: 0-5V; 0-10V; +/-5V; +/-10V (10% over-range)
- TUE: 0.1% FSR max
- Internal Reference (10ppm/^{0}C max)
- Wide Temp Range: -40°C to +125°C
- Reliability: Short-Circuit limit, CRC, Watchdog timer

Applications

- PLC I/O modules
- Sensor Transmitters
- Industrial Automation
- Building Automation

Benefits

- Integrates 3 different components on board to help save board space, cost and reduce design time
- Higher accuracy than competition
- Allows easy upgrade from existing solutions
- Key benefits over competition:
  - Only part with features to improve system reliability
  - Reliable operation in extended industrial temp range



TEXAS INSTRUMENTS

DAC8750/7750

16-/12-bit DACs with 4-20mA Current Outputs

RELEASED
A GRADE IN TEST

Features

- DAC with Current Outputs
- Selectable Ranges
  - Current: 0-20mA; 4-20mA; 0-24mA
- TUE: 0.1% FSR max
- Internal Reference (10ppm/^{0}C max)
- Wide Temp Range: -40°C to +125°C
- Fault Detect: Open-Circuit of I-Out, thermal alarm, compliance voltage

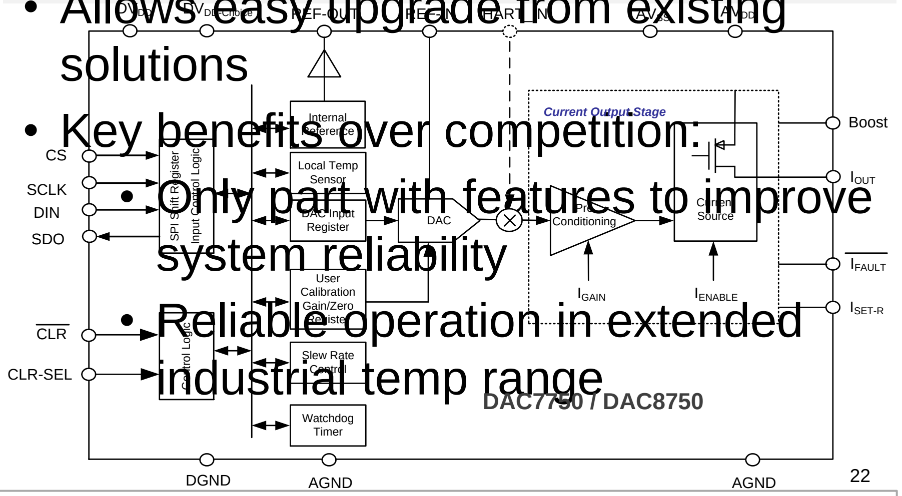
Applications

- PLC I/O modules
- Sensor Transmitters
- Industrial Automation
- Building Automation

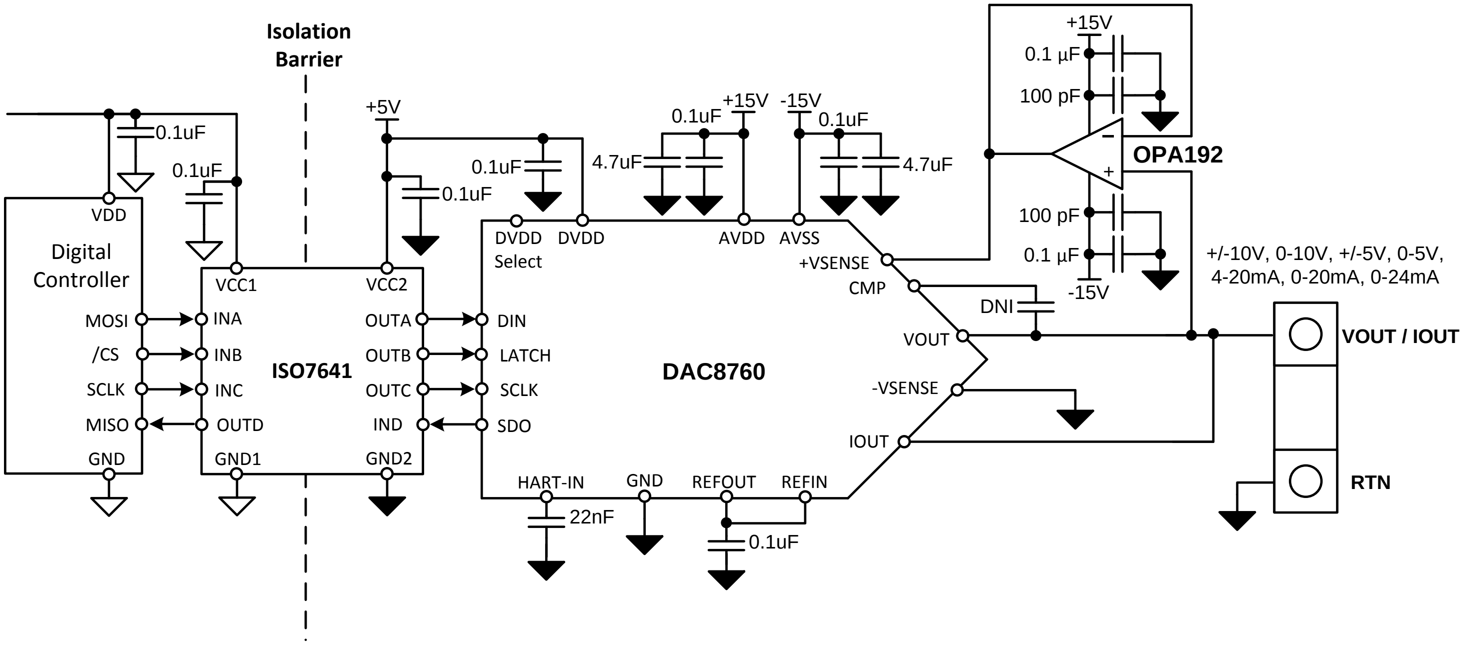
QFN / 24-QSSOP

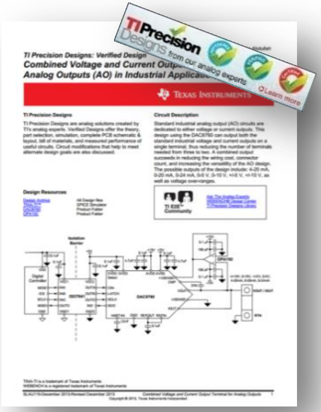
Benefits

- Integrates 3 different components on board to help save board space, cost and reduce design time
- Higher accuracy than competition
- Allows easy upgrade from existing solutions
- Key benefits over competition:
  - Only part with features to improve system reliability
  - Reliable operation in extended industrial temp range



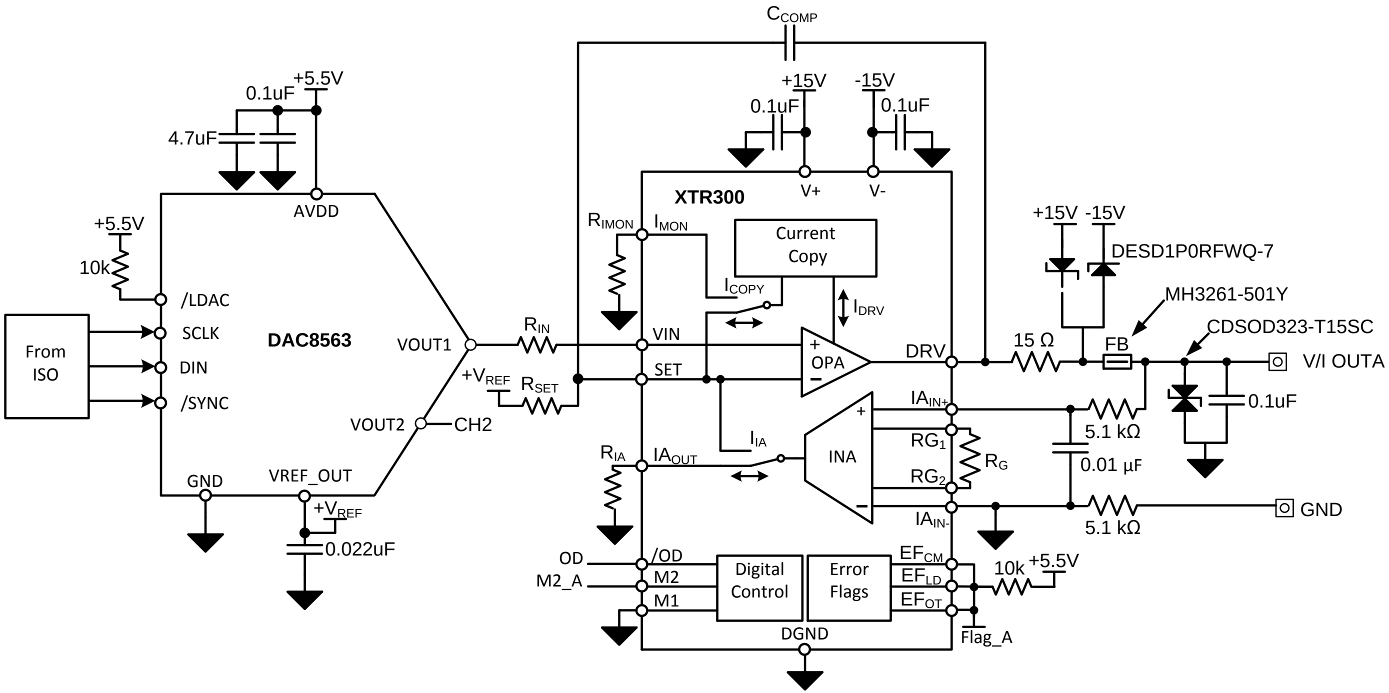
Design Example: Single Channel Universal Analog Output

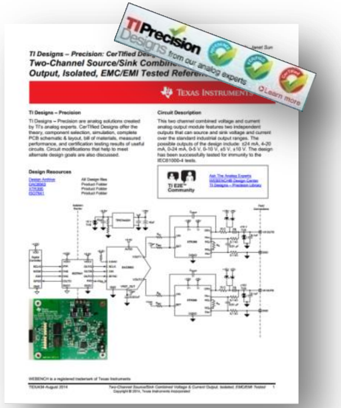




TIPD119

Design Example: Dual Channel Universal Analog Output w/Bipolar Current Outputs

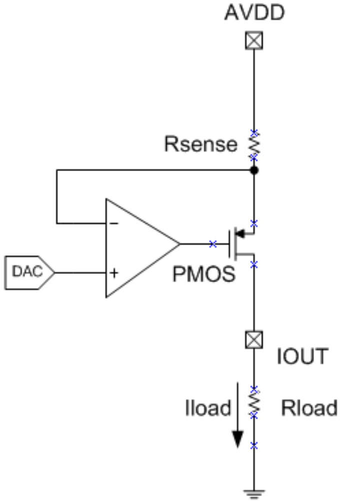




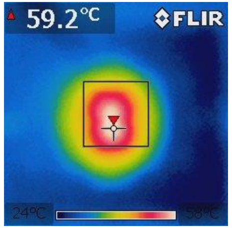
TIPD155

Power Dissipation for PLC AO Modules

Analog Current Output Circuit
(No Power Management)



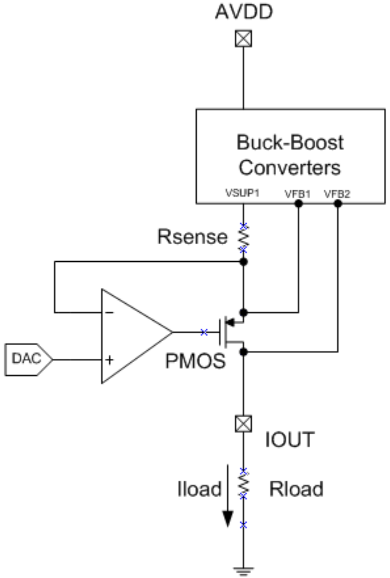
AVDD = 24V
Rload = 1Ω
IOUT = 24mA



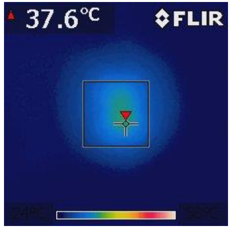
High Power dissipation

	Rload	Chip
Power Dissipation	0.6mW	576mW

Analog Current Output Circuit
(Adaptive Power Management)



AVDD = 24V
Rload = 1Ω
IOUT = 24mA
70% Efficiency



Low Power dissipation

	Rload	Chip
Power Dissipation	0.6mW	185mW

DAC8775

Quad-Channel 16-bit DACs with Voltage/Current Outputs & Adaptive Power

RELEASED

Features

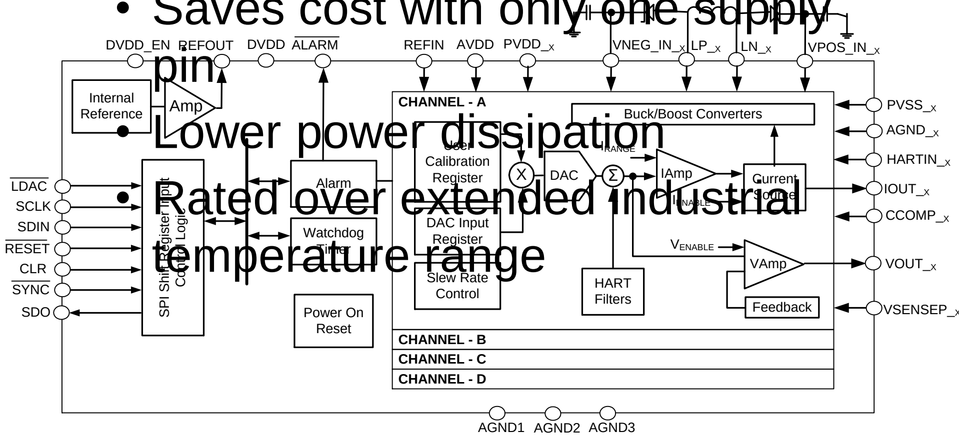
- Integrated DAC and selectable voltage/current ranges
  - Iout: 0-20mA; 4-20mA; 3.5-23.5mA; 0-24mA ; ±24mA
  - Vout: 0-5V; 0-10V; +/-5V; +/-10V (20% over-range)
  - TUE: 0.1% FSR max; 5V reference: 10 ppm/°C max
- Adaptive Power Management
  - Single supply pin for full chip (12-36V)
  - Single Inductor buck-boost converter generates
    - Current out supply: 4-32V
    - Voltage out supply: +/-15V
    - Auto learn mode
- Integrated LDO for digital supply: 5V
- Enhanced Reliability: Open-Circuit of I-Out, thermal alarm, compliance voltage, Watchdog timer
- Enhanced safety features
- Wide Temp Range: -40°C to +125°C
- Package QFN-72 (10x10 mm)

Applications

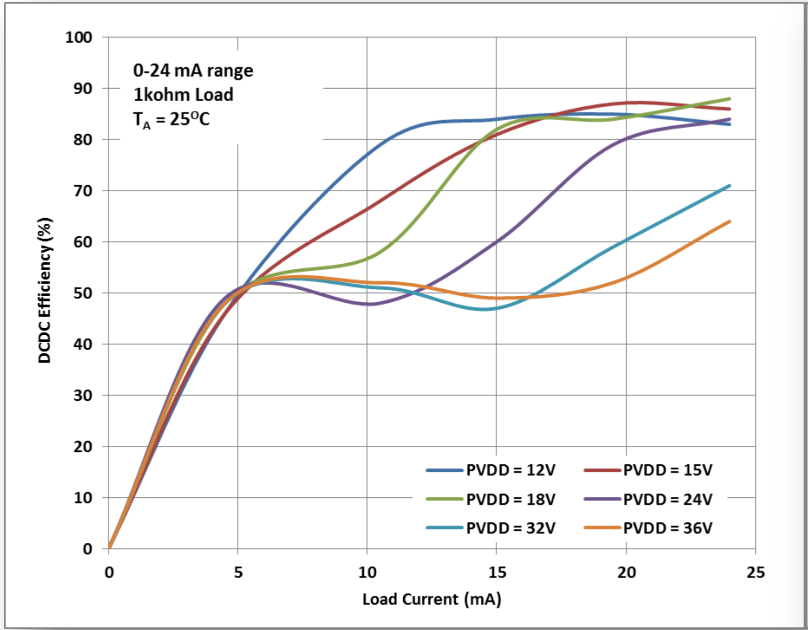
- PLC I/O modules
- Sensor Transmitters
- Industrial Automation
- Building Automation

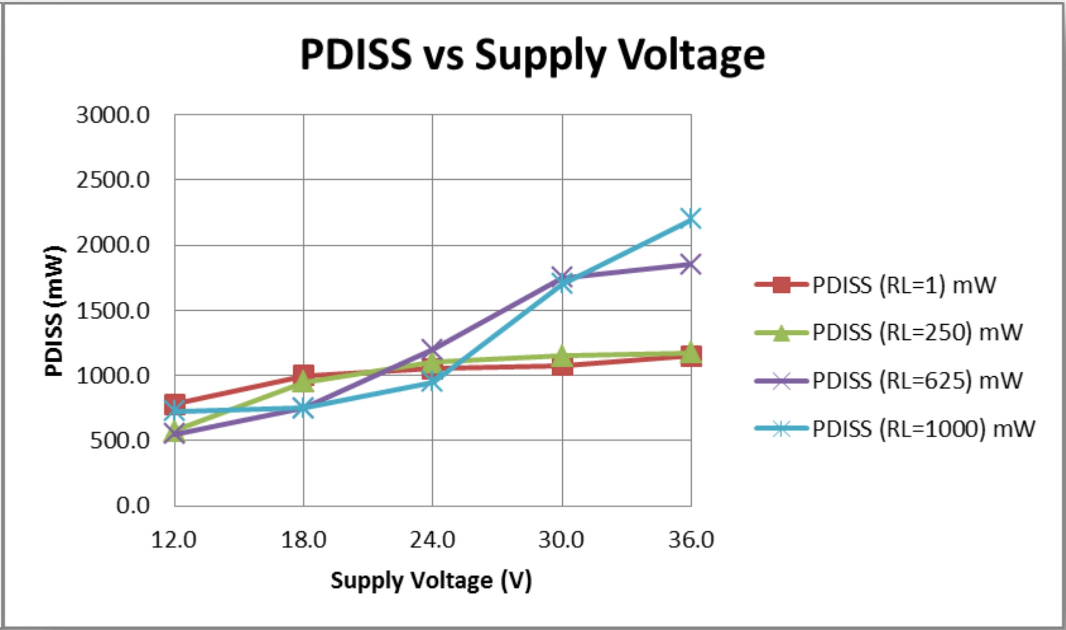
Benefits

- Reduce thermal stress and module size
- Simple power supply scheme
- Overall solution compared to others
  - Saves cost with only one supply pin
  - Lower power dissipation
  - Rated over extended industrial temperature range



DAC8775 DC/DC Efficiency, Power Dissipation





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TIPD215: Less than 1W, Quad Channel, Analog Output Module with Adaptive Power Management

TIDesigns

Features

- Integrated DAC and selectable voltage/current ranges
  - TUE: 0.1% FSR max; 5V reference: 10 ppm/°C max
- DAC8775 Adaptive Power Management
  - Single supply pin for full chip (12-36V)
  - Single Inductor buck-boost converter generates all supplies
- LM5166 high efficiency light load buck-converter accepts wide industrial supply inputs (12-66V) at >95% efficiency
- Enhanced Reliability: Open-Circuit of I-Out, thermal alarm, compliance voltage, Watchdog timer
- Wide Temp Range: -40°C to +125°C

Applications

- Factory Automation & Control
- Building Automation
- Motor Drives

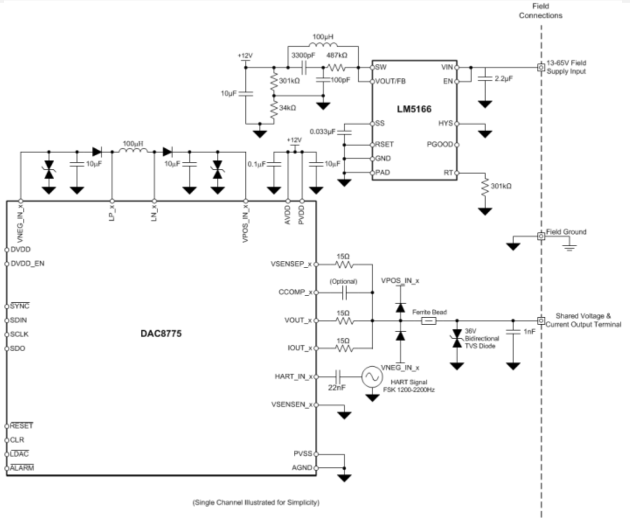
Tools & Resources

- **TIPD215 Folder**
- **Design Guide**
- **Design Files:** Schematics, BOM, Gerbers, Software, etc.

- **Device Datasheets:**
  - DAC8775
  - LM5166

Benefits

- Reduce thermal stress and module size
- Simple power supply scheme
- Overall solution compared to others
  - Saves cost with only one supply pin
  - Lower power dissipation
  - Rated over extended industrial temperature range



TIPD216: Quad-Channel Industrial Voltage and Current Output Driver, EMI/EMC Tested

TIDesigns

Features

- Integrated DAC and selectable voltage/current ranges
  - TUE: 0.1% FSR max; 5V reference: 10 ppm/°C max
- DAC8775 Adaptive Power Management
  - Single supply pin for full chip (12-36V)
  - Single Inductor buck-boost converter generates all supplies
- External protection circuitry for passing common IEC61000-4 transient compliance testing
- Enhanced Reliability: Open-Circuit of I-Out, thermal alarm, compliance voltage, Watchdog timer
- Wide Temp Range: -40°C to +125°C

Benefits

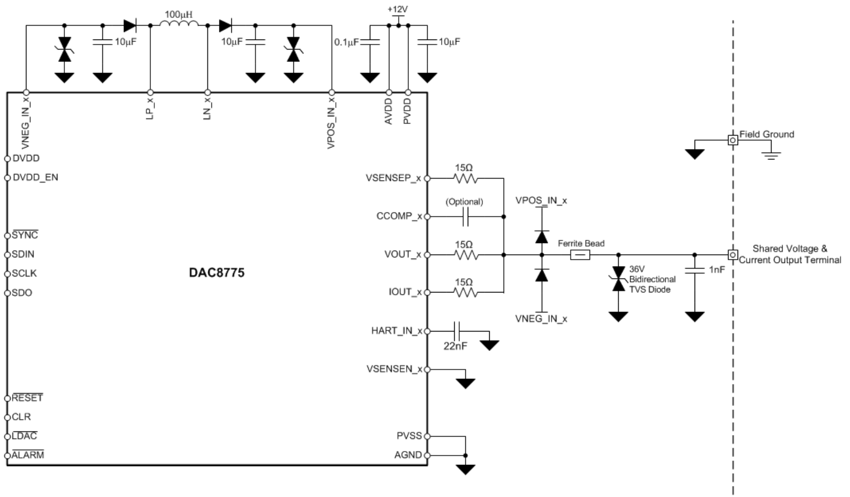
- Reduce thermal stress and module size
- Simple power supply scheme
- Overall solution compared to others
  - Saves cost with only one supply pin
  - Excellent EMI/EMC immunity
  - Rated over extended industrial temperature range

Applications

- PLC I/O Modules
- Sensor Transmitters
- Industrial Automation

Tools & Resources

- **TIPD216 Folder**
- **Design Guide**
- **Design Files:** Schematics, BOM, Gerbers, Software, etc.
- **Device Datasheets:**
  - DAC8775



(Single Channel Illustrated for Simplicity)

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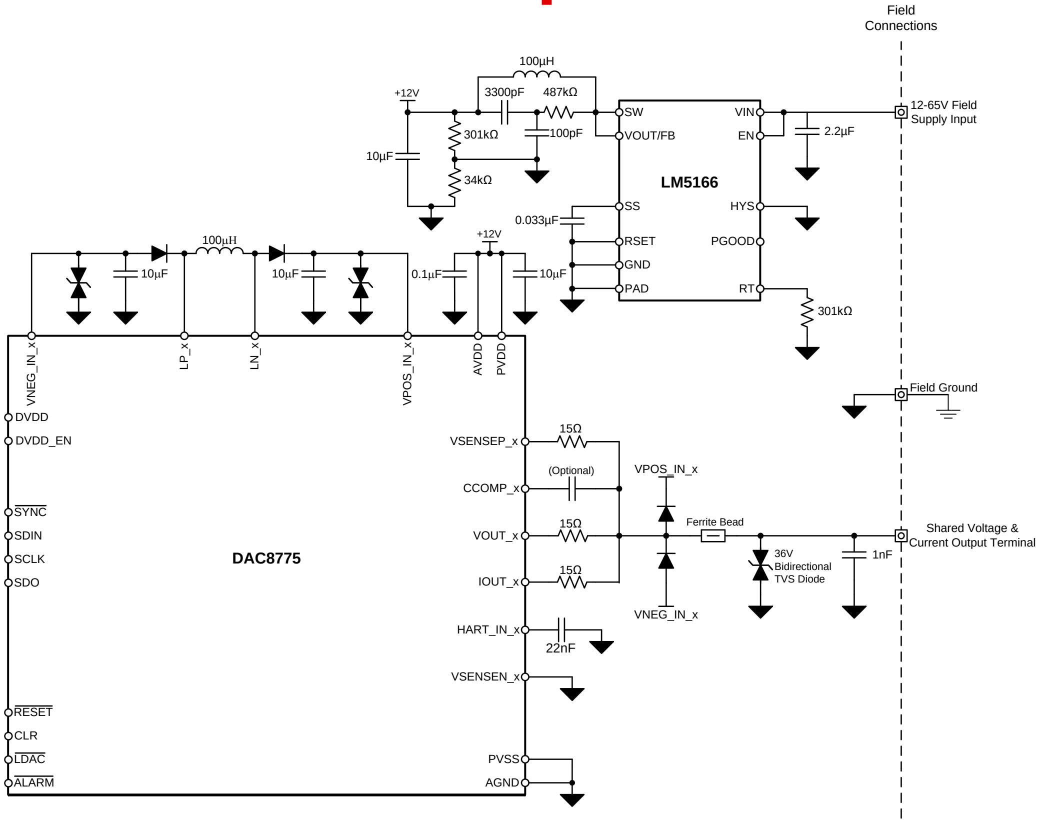
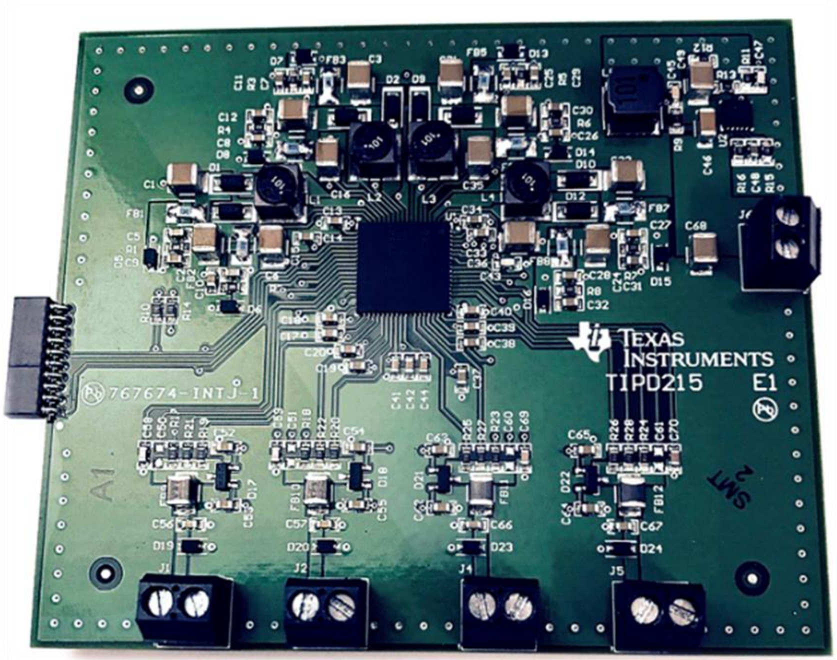
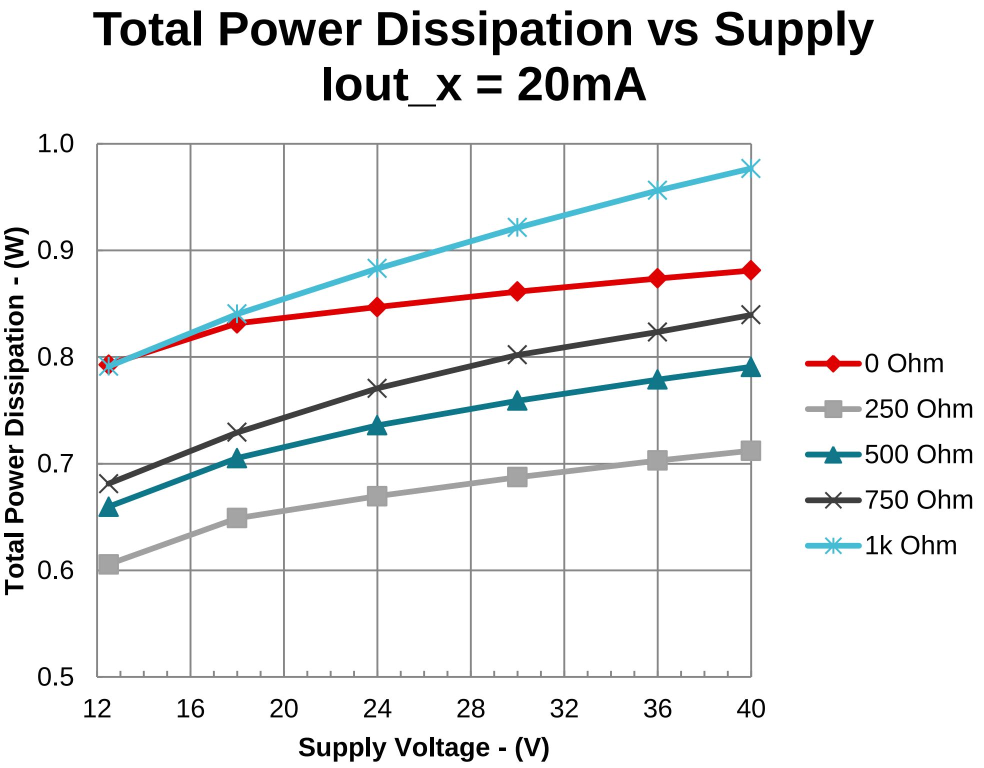
Generic Example Circuit



(Single Channel Illustrated for Simplicity)



Power Dissipation Measured Results



Results Summary

PARAMETER	GOAL	MEASURED
Channels / Resolution	Quad Channel / 16-bit	Quad Channel / 16-bit
Voltage Range, Current Range	±10V, 4-20mA	±10V, 4-20mA
Total Power Dissipation (1)	<1W (MAX)	0.98W (MAX)
Current Output: Total Unadjusted Error	≤0.1% FSR (MAX)	0.090%FSR (MAX)
Voltage Output: Total Unadjusted Error	≤0.1% FSR (MAX)	0.015%FSR (MAX)
Current Output: Peak-to-Peak Ripple	8µA (TYP)	8.1µA (TYP)
Voltage Output: Peak-to-Peak Ripple	2mV (TYP)	0.176mV
IEC61000-4 Immunity	Pass (2)	Pass, Class A all test except RI & CI (Class B)

(1) Worst case power dissipation, all channels enabled at 20mA output driving 0Ω load
(2) Pass with Class A or Class B performance, Class A threshold defined as 0.1% FSR

Designing 2-wire Transmitters

Theory of Operation & Design Examples

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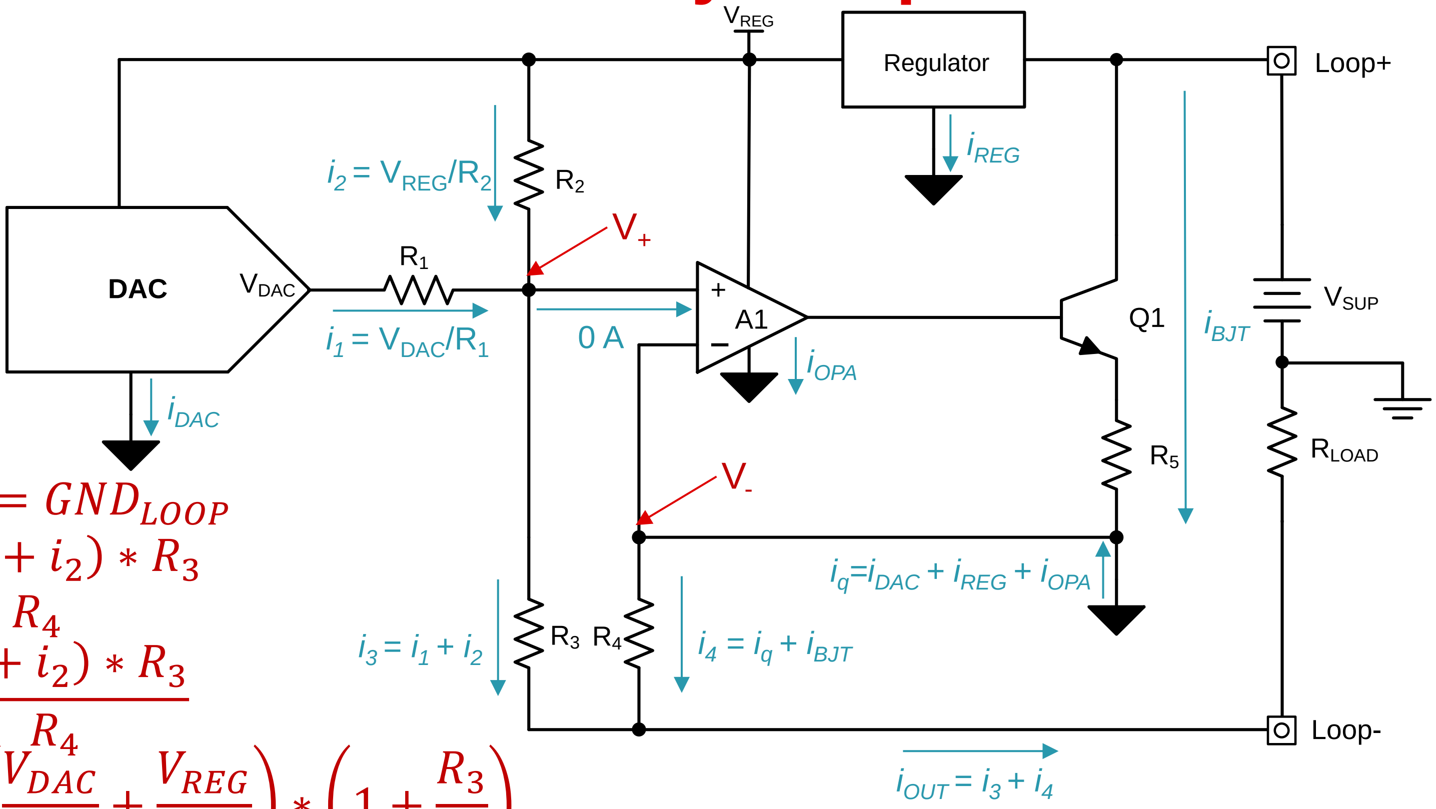
2-Wire Transmitter: Theory of Operation



$$V_+ = V_- = GND_{LOOP}$$

$$V_+ = (i_1 + i_2) * R_3$$

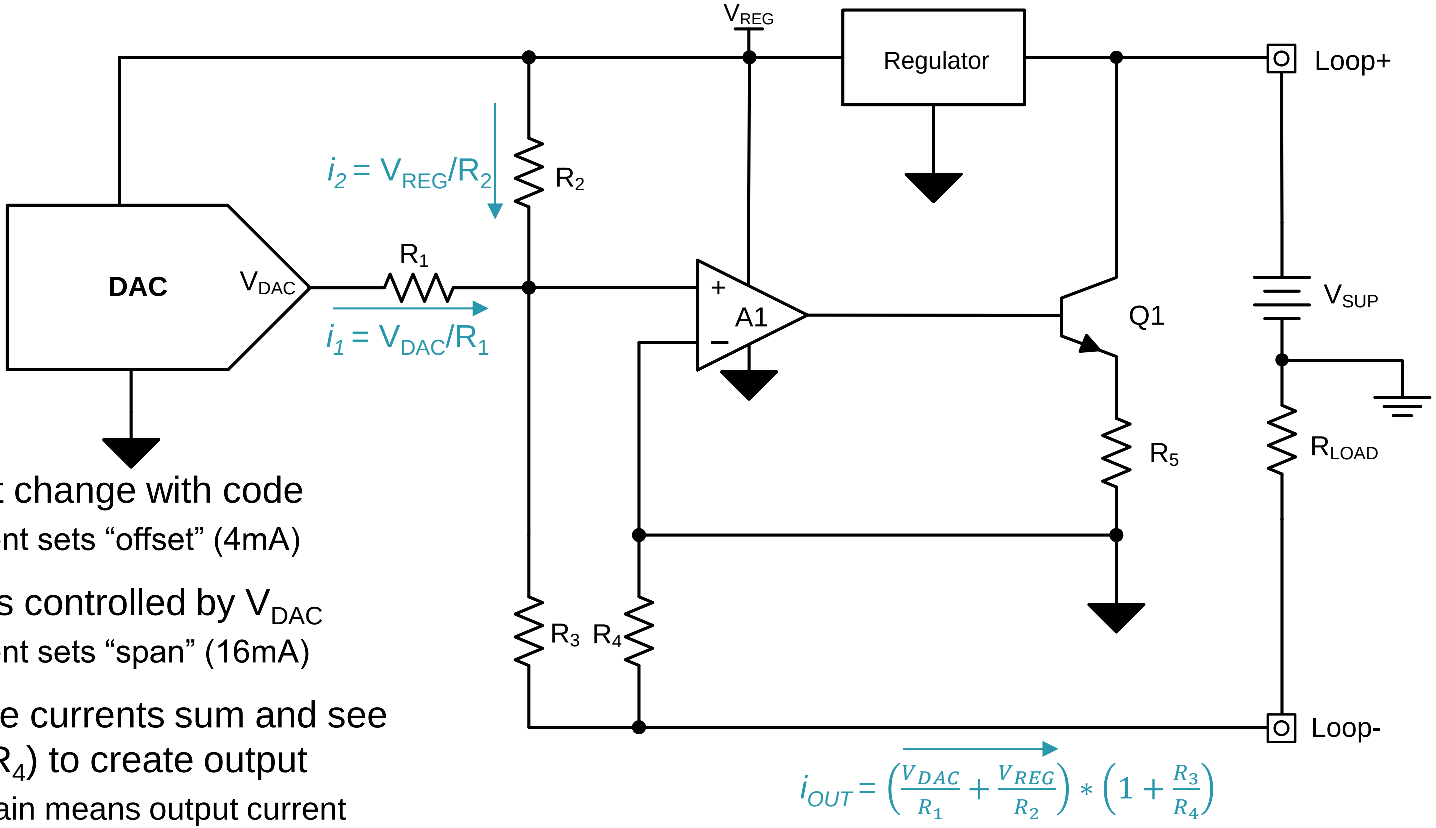
$$V_- = i_4 * R_4$$

$$i_4 = \frac{(i_1 + i_2) * R_3}{R_4}$$

$$i_{OUT} = \left(\frac{V_{DAC}}{R_1} + \frac{V_{REG}}{R_2}\right) * \left(1 + \frac{R_3}{R_4}\right)$$

Texas Instruments

2-Wire Transmitter: Considerations



- i_2 does not change with code
  - i_2 current sets "offset" (4mA)
- i_1 current is controlled by V_{DAC}
  - i_1 current sets "span" (16mA)
- i_1 and i_2 are currents sum and see G=1+(R_3/R_4) to create output
  - High gain means output current primarily flows from loop through BJT

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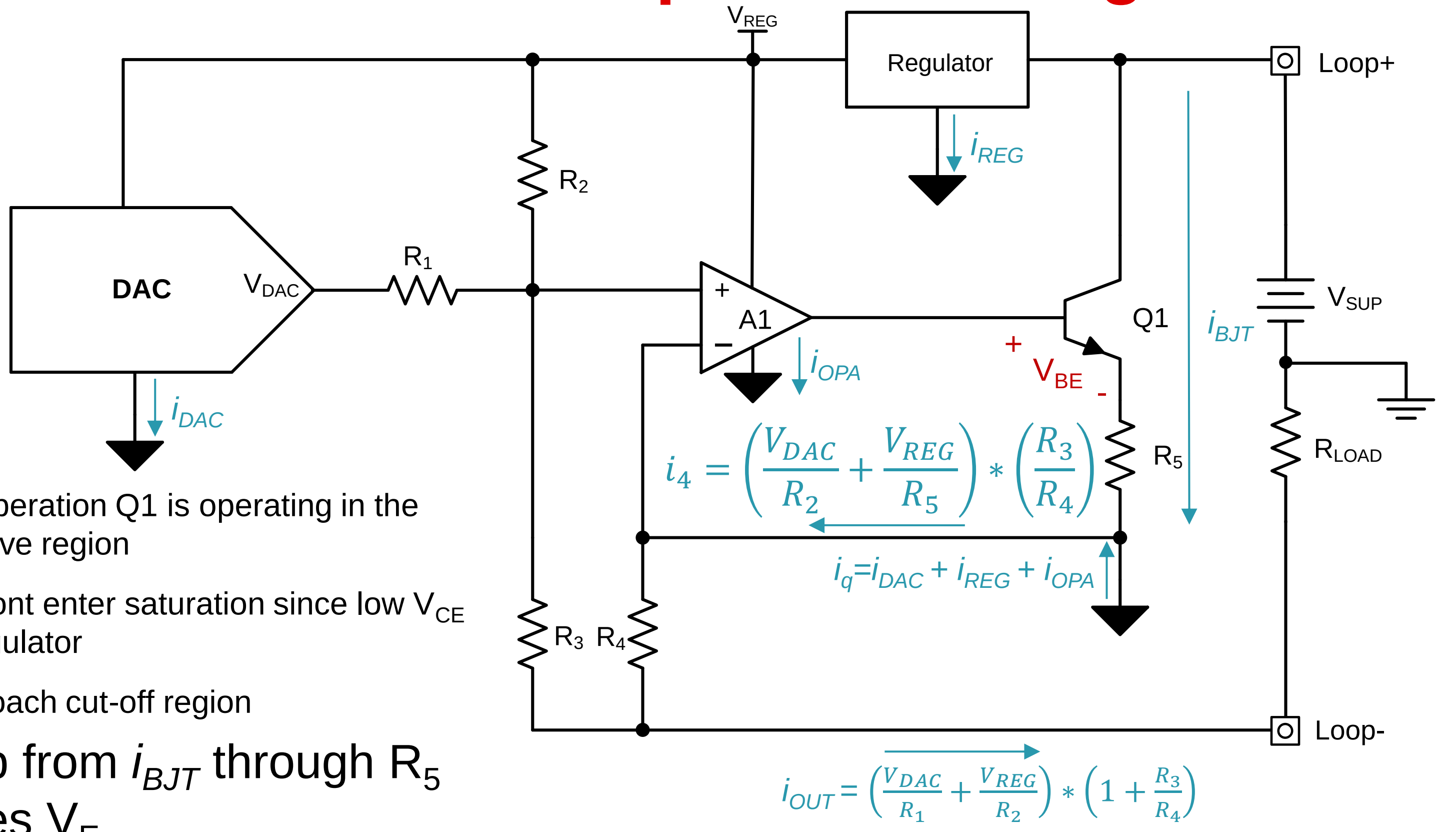
2-Wire Transmitter: Compliance Voltage



- In normal operation Q1 is operating in the forward-active region
- Probably wont enter saturation since low V_{CE} turns off regulator
- Could approach cut-off region
  - Drop from i_{BJT} through R_5 raises V_E
  - To maintain V_{BE}, V_B must rise with V_E

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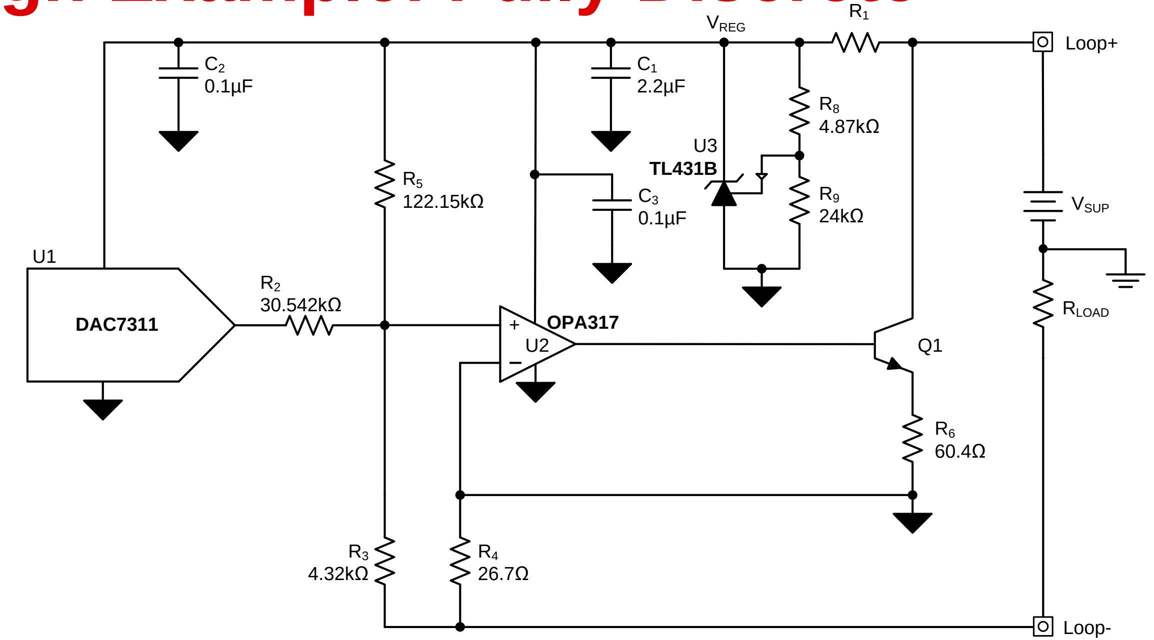
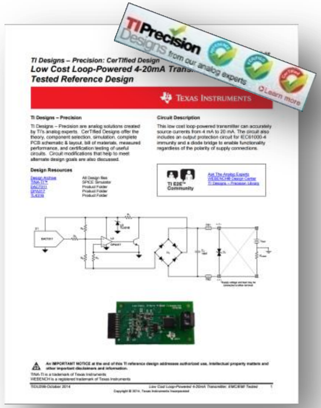
Design Example: Fully Discrete





TIPD158

- **Alternate DACs:**
  - DAC5311, DAC6311, DAC7311, DAC8311, DAC8411
  - DAC8550/DAC8551 (16-bit, Buffered Output)
  - DAC8830 (16-bit, Very High Accuracy)
- **Alternate Amplifiers:**
  - OPA316
  - OPA170
  - OPA333

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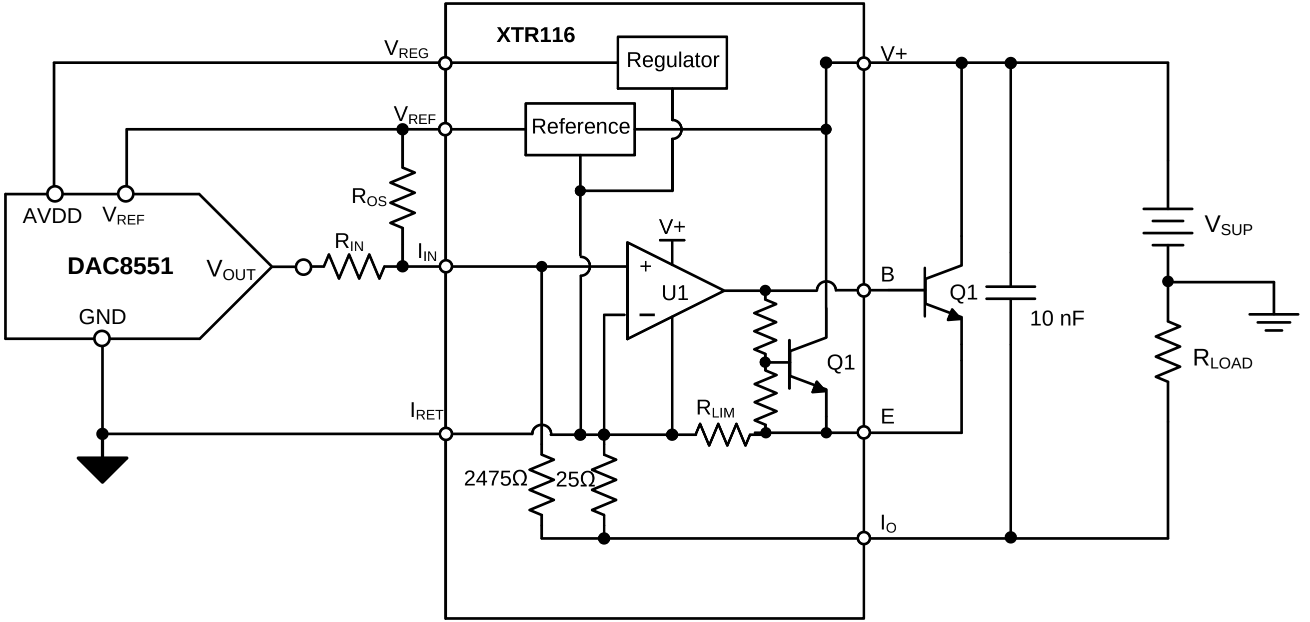
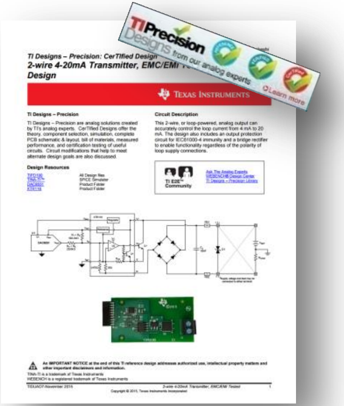
Design Example: Partially Discrete





TIPD190

- **Alternate DACs:**
  - DAC5311, DAC6311, DAC7311, DAC8311, DAC8411
  - DAC8550/DAC8551 (16-bit, Buffered Output)
  - DAC8830 (16-bit, Very High Accuracy)
- **Alternate XTRs:**
  - XTR115
  - XTR117

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DAC161S997 / DAC161P997

16-bit 2-wire Current Output DACs with SPI or 1-Wire Interfaces

RELEASED

Features

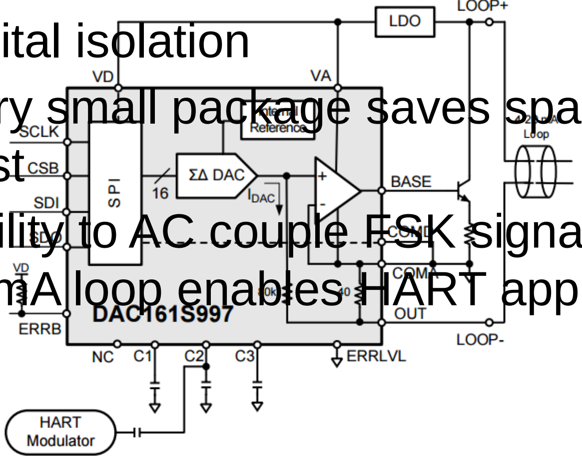
- 16-bit ΣΔ DAC
- 2-wire Current Output
  - 0-24mA output range
  - Pin-Programmable Power-Up Current
  - Programmable NAMUR Output Current Levels
- TUE: 0.1% FSR max

Applications

- Sensor Transmitters
- Industrial Automation
- Building Automation
- HART Interface

Benefits

- Integrates DAC, reference, loop amplifier, and gain setting resistors required for 2-wire transmitter applications
- 1-wire interface relaxes needs from digital isolation
- Very small package saves space / cost
- Ability to AC couple FSK signals to 4-20mA loop enables HART applications



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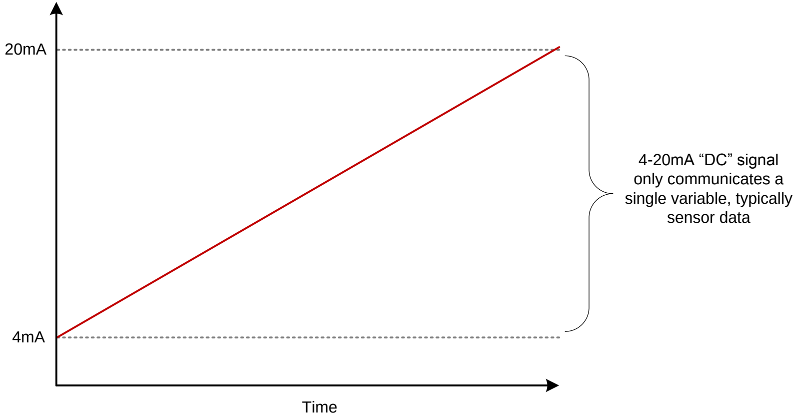
HART

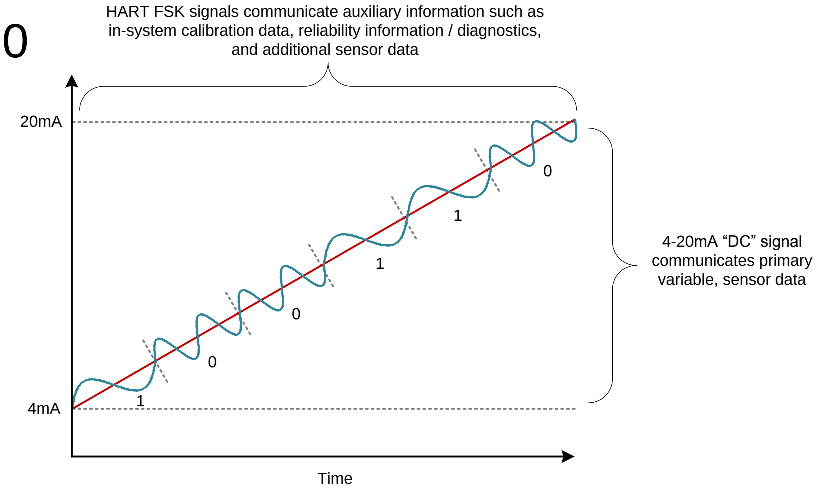
What is it? What benefit does it provide?

HART – What is it? Why is it useful?

- HART – Highway Addressable Remote Transducer
  - Bell 202 Frequency Shift Keying Standard at 1200 bps
- “Mark” and “Space” Symbols (1mApp)
  - Mark: 1200 Hz sinusoid, represents 1
  - Space: 2200 Hz sinusoid, represents 0



“Simple” Sensor Transmitter



“Smart” Sensor Transmitter

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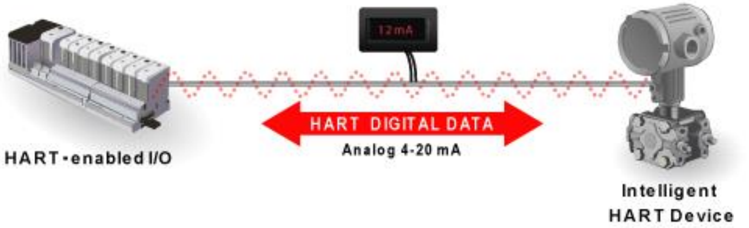
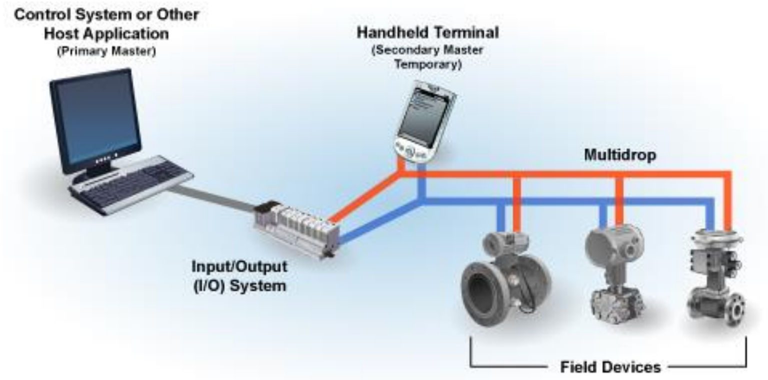
HART – What is it? Why is it useful?

Multi-drop: Multiple Masters, Multiple Slaves

Point to Point: Master AI, Slave AO / Sensor





Voltage FSK ⟶ ⟵ Current FSK

Slaves are not allowed to use 4-20mA for communication, all transmitters set for 4mA DC. HART FSK communication only. Maximum 16 slaves on the bus.

DAC8740H, DAC8741H, DAC8742H

HART, Foundation Fieldbus, & Profibus PA Modems

RTM 4Q17

Features

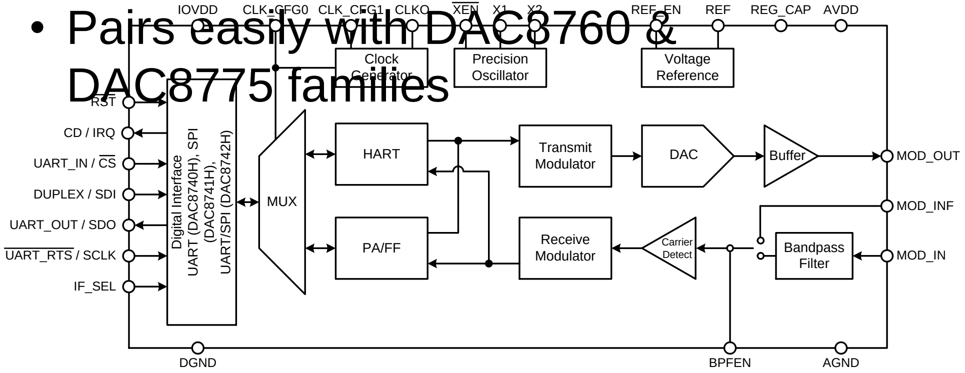
- HART/FF/PA compliant FSK Modem
- 1.8-5.5V operation
- Low Quiescent Current
  - Modulator/Demodulator: 150uA (target max)
  - Internal Oscillator: TBD uA
- Flexible Clocking Options
  - Internal Oscillator
  - External Crystal Oscillator
  - External CMOS clock input
- Integrated Receive band-pass filter, optional external filter
- Buffered Voltage Output
- Interface Options
  - SPI with extended features (DAC8741H / DAC8742H)
  - Simple UART "feedthrough" (DAC8740H / DAC8742H)
- Wide Temp Range: -55°C to +125°C

Applications

- Industrial Process Control and Automation
- PLC I/O Modules
- 4 to 20mA, loop powered transmitters

Benefits

- Minimal power consumption
- HART modem and oscillator eases processing burden
- Reliable operation to extended industrial temp range
- Pairs easily with DAC8760 & DAC8775 families



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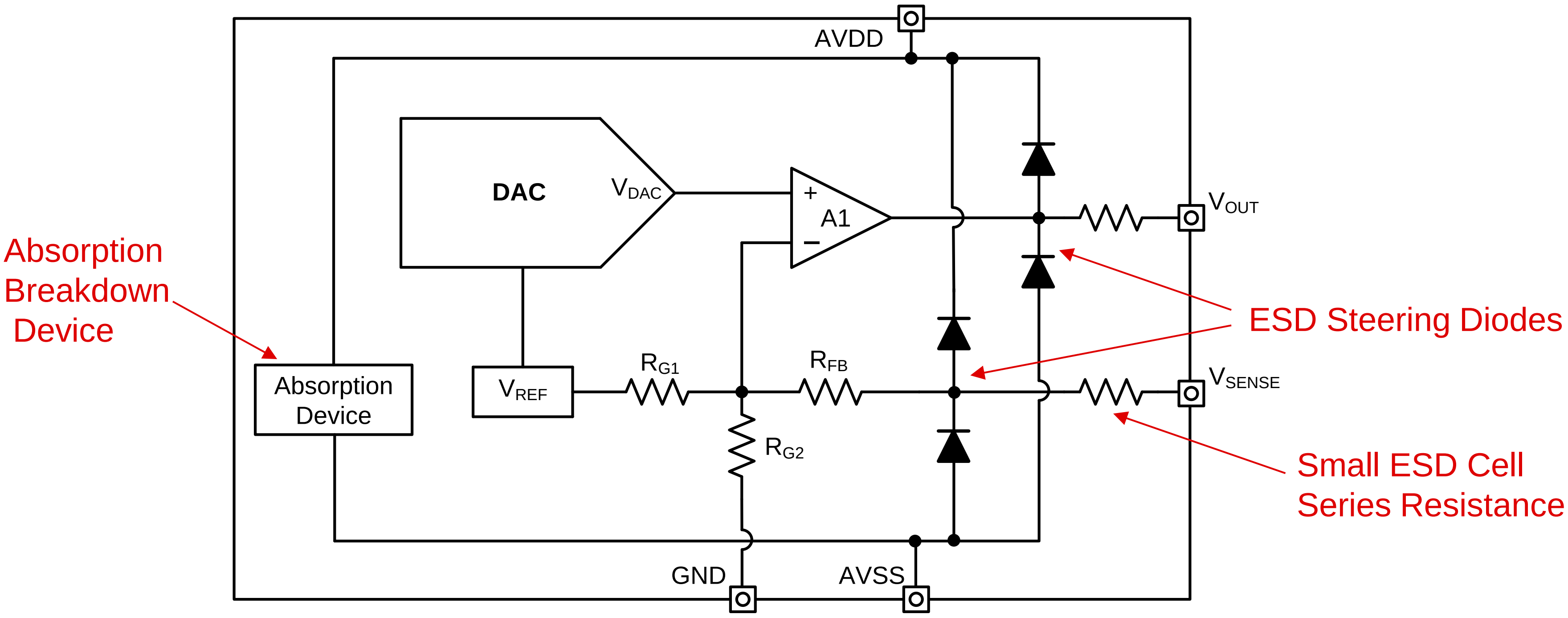
Designing Protection Solutions

How do parts get damaged? How is this tested? How do we prevent designs from damage?

ESD Protection Inside an IC



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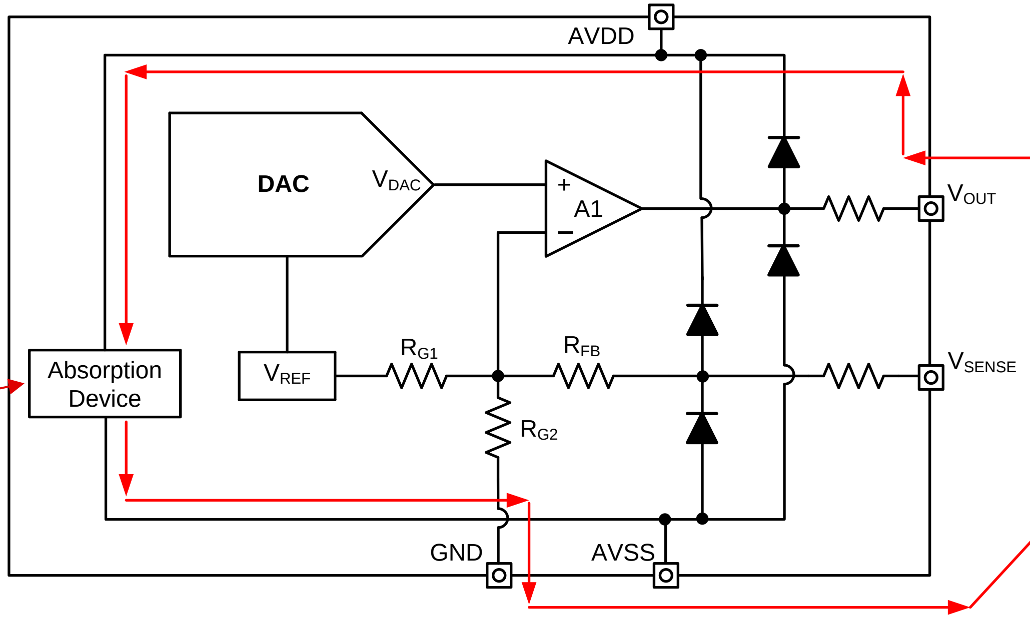
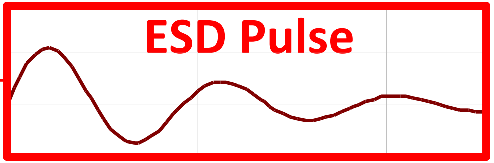
ESD Protection Circuit with ESD Pulse Applied

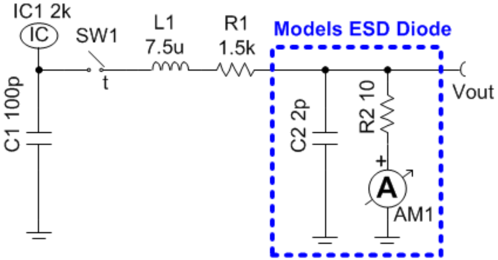
ESD diodes direct ESD pulse to absorption device

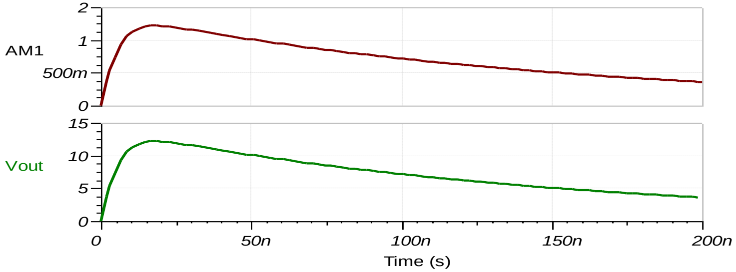




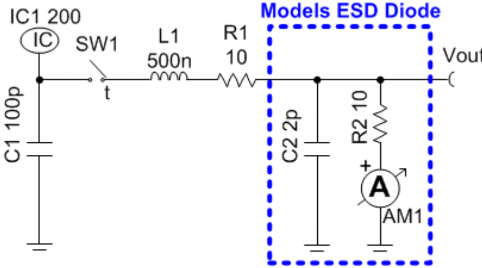
Types of ESD Simulator Pulses

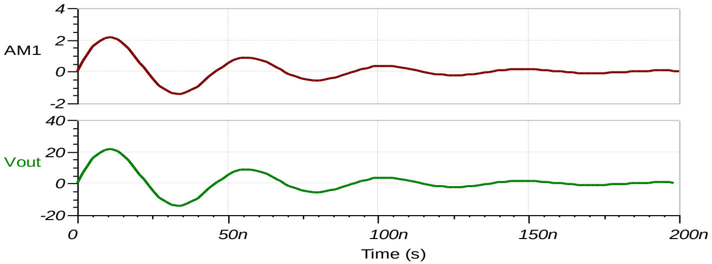
Human Body Model (HBM)



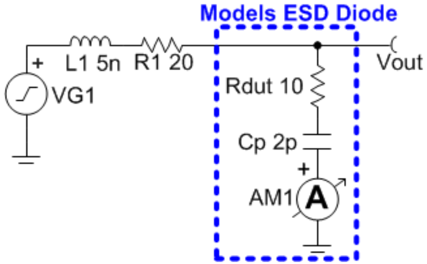


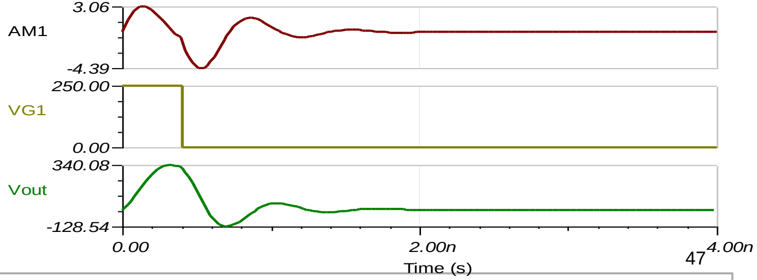
Machine Model (MM)





Charged Device Model (CDM)





Electrostatic Discharge vs. Electrical Overstress

ESD

- Short duration event (1-100ns)
- High voltage (kV)
- Fast edges
- Low Energy
- Both “in-circuit” and “out-of-circuit”

EOS

- Can be a short or longer duration event
  - Nanoseconds to Milliseconds or more
  - Can be continuous
- High or Lower voltage
  - May be kVs or only a few volts beyond absolute maximum ratings
- High Energy
- “In-circuit” event only

IEC61000-4 Test Suite

- IEC61000-4 contains 35 different immunity test standards
- Most commonly applied immunity tests:
  - Electrostatic Discharges
    - **IEC61000-4-2: Electrostatic Discharge Immunity**
  - HF Conducted Disturbances
    - **IEC61000-4-4: Electrically Fast Transient Immunity**
    - **IEC61000-4-5: Surge Immunity**
    - **IEC61000-4-6: Conducted Immunity Tests**
  - HF Radiated Disturbances
    - **IEC61000-4-3: Radiated Immunity**
    - IEC61000-4-9: Pulse Magnetic Field Tests
  - LF Radiated Disturbances
    - IEC61000-4-8: Power Frequency Magnetic Field Immunity

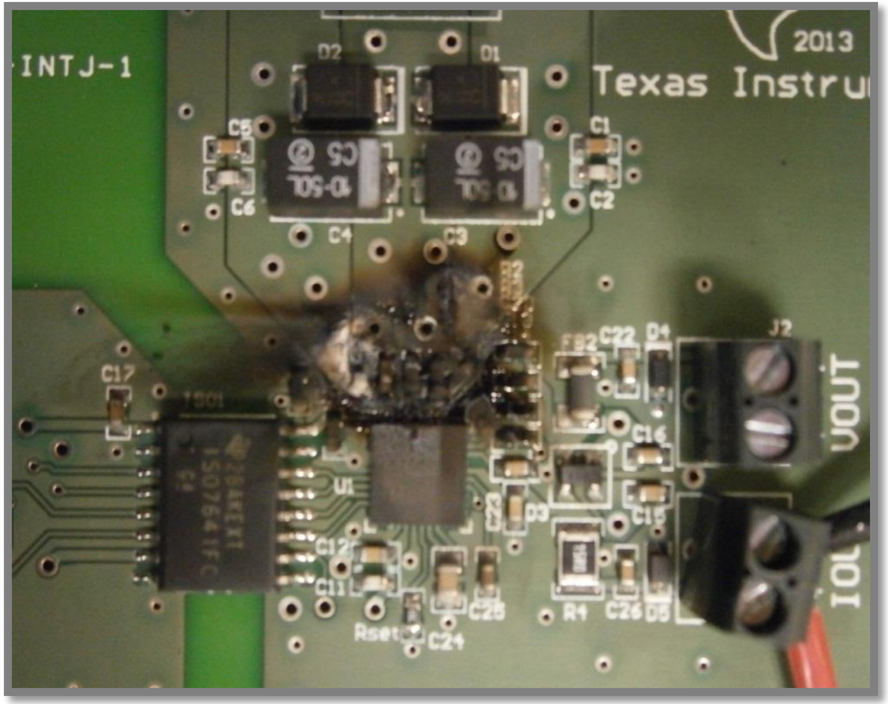
IEC61000-4 Classifications

- Two Components for each test
  I. Threat Level
  II. Class

Classification of results for IEC61000-4 Immunity

Grade	Description
Class A	Normal performance within an error band specified by the manufacturer.
Class B	Temporary loss of function or degradation of performance which ceases after the disturbance is removed. The equipment under test recovers its normal performance without operator interference.
Class C	Temporary loss of function or degradation of performance, correction of performance requires operator intervention.
Class D	Loss of function or degradation of performance which is not recoverable, permanent damage to hardware or software, or loss of data.

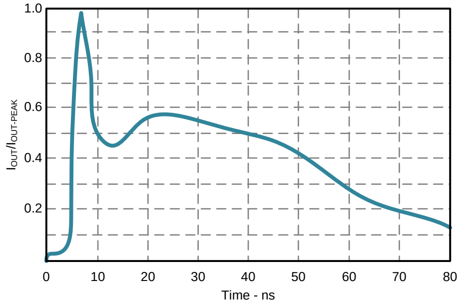
Example of Class D Results



IEC61000-4 Test

- IEC61000-4-2: Electrostatic Discharge Immunity (2kV to 15kV)
  - Simulates the electrostatic discharge of an operator directly onto an electrical component

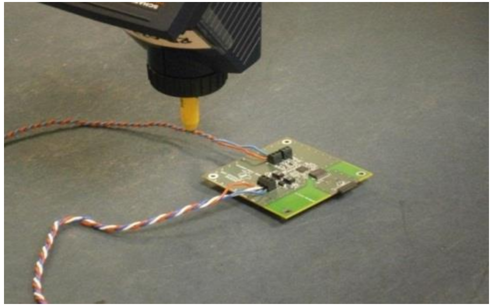
ESD Test Pulse



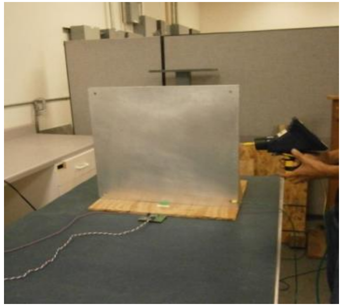
- This is system level immunity
- This ***is not*** JEDEC HBM/CDM/MM device level immunity!!
- Read article for more information:

Understanding and Comparing the differences in ESD Testing
– T. Kugelstadt & D. Byrd on EDN, Oct 6, 2011

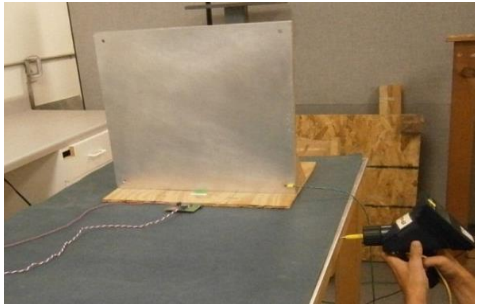
Air Discharge



Vertical Coupling



Horizontal Coupling



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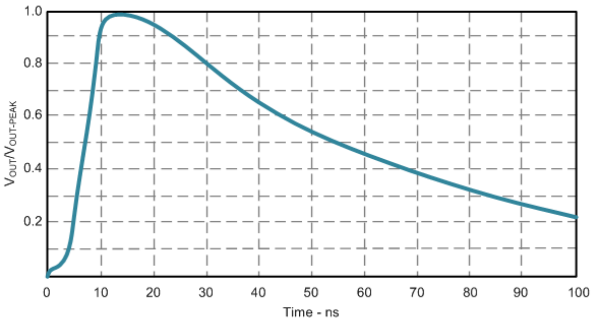
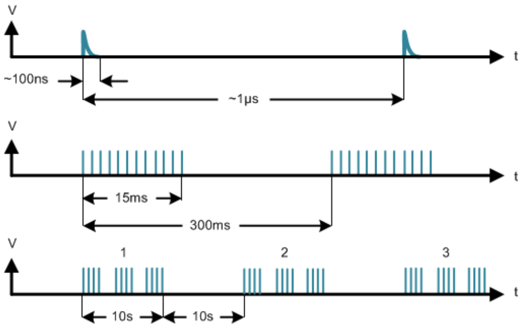
IEC61000-4 Testing

- IEC61000-4-4: Electrically Fast Transient Immunity (0.5kV to 4kV)
  - Simulates every day switching transients common in industrial applications

EFT Test Pulse



EFT Pulse Train



EFT Test Setup

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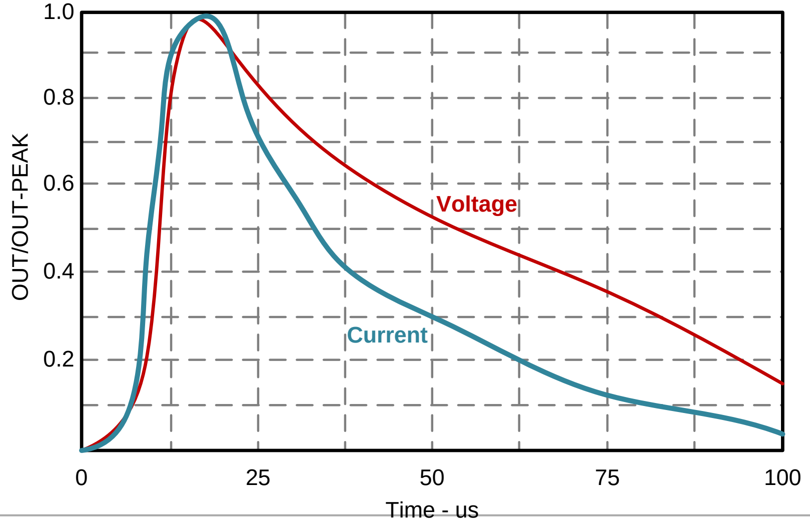
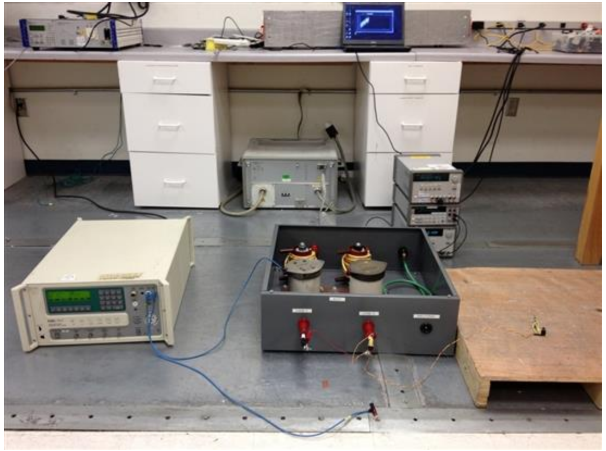
IEC61000-4 Testing

- IEC61000-4-5: Surge Immunity (0.5kV to 4kV)
  - Simulates very severe transients such as lightning strikes
- Output impedance for Surge Immunity tests varies
  - Energy content of test pulse could be very large, protection solution will vary

Surge Test Pulse



EFT Test Setup



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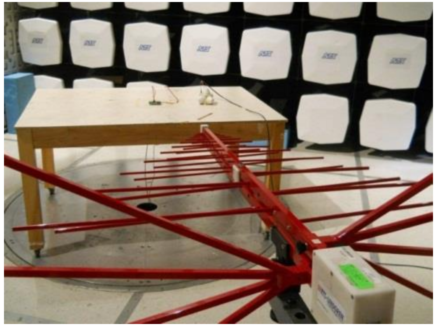
IEC61000-4 Testing

- IEC61000-4-3: Radiated Immunity (1V/m to 30V/m)
  - Simulates exposure to high frequency radiated emissions in the range of 80MHz to 1GHz
- IEC61000-4-6: Conducted Immunity (3V/m to 10V/m)
  - Simulates exposure to radio frequency emissions in the range of 150kHz to 80MHz

RI Horizontal Setup



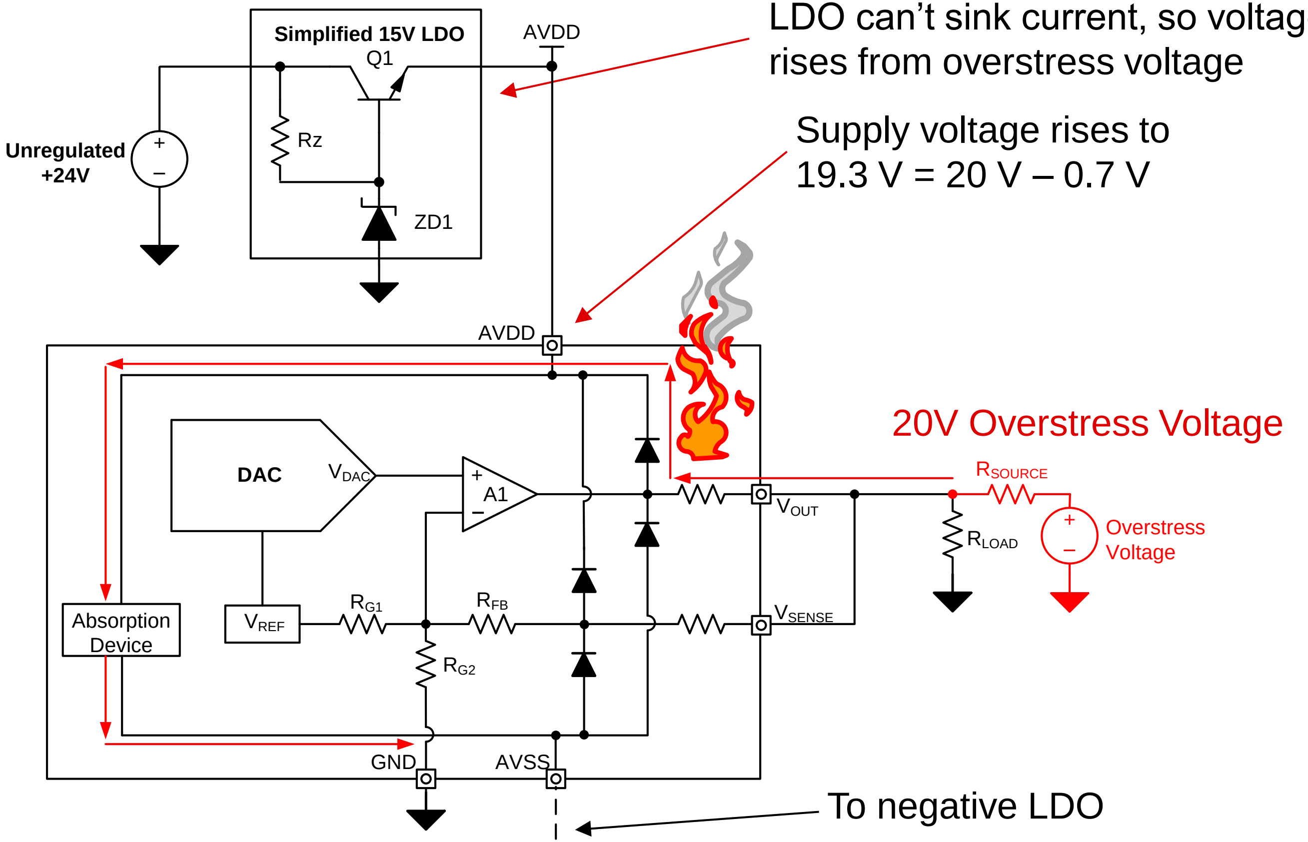
RI Vertical Setup

CI Test Setup

Continuous Electrical Overstress on Output

LDO can't sink current, so voltage rises from overstress voltage

Supply voltage rises to 19.3 V = 20 V – 0.7 V



To negative LDO

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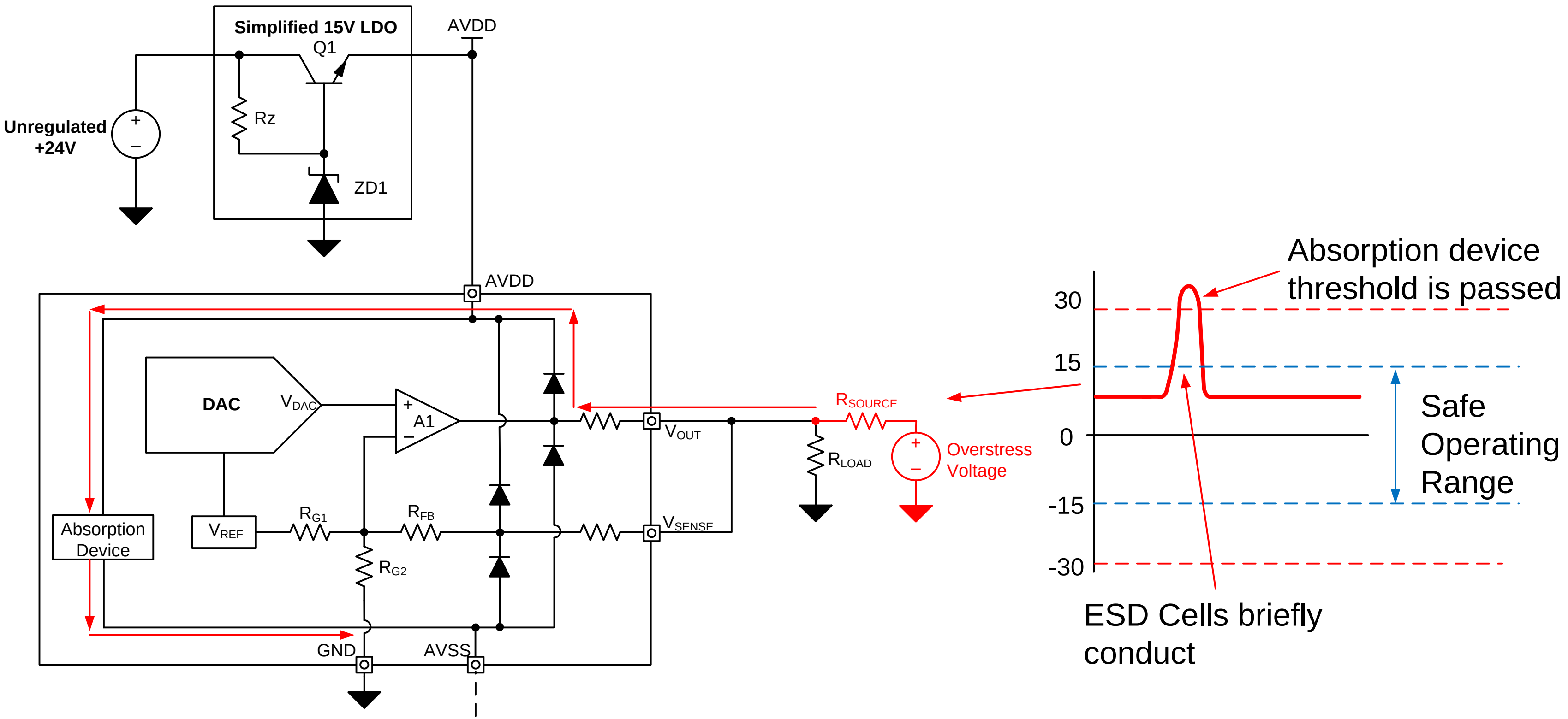
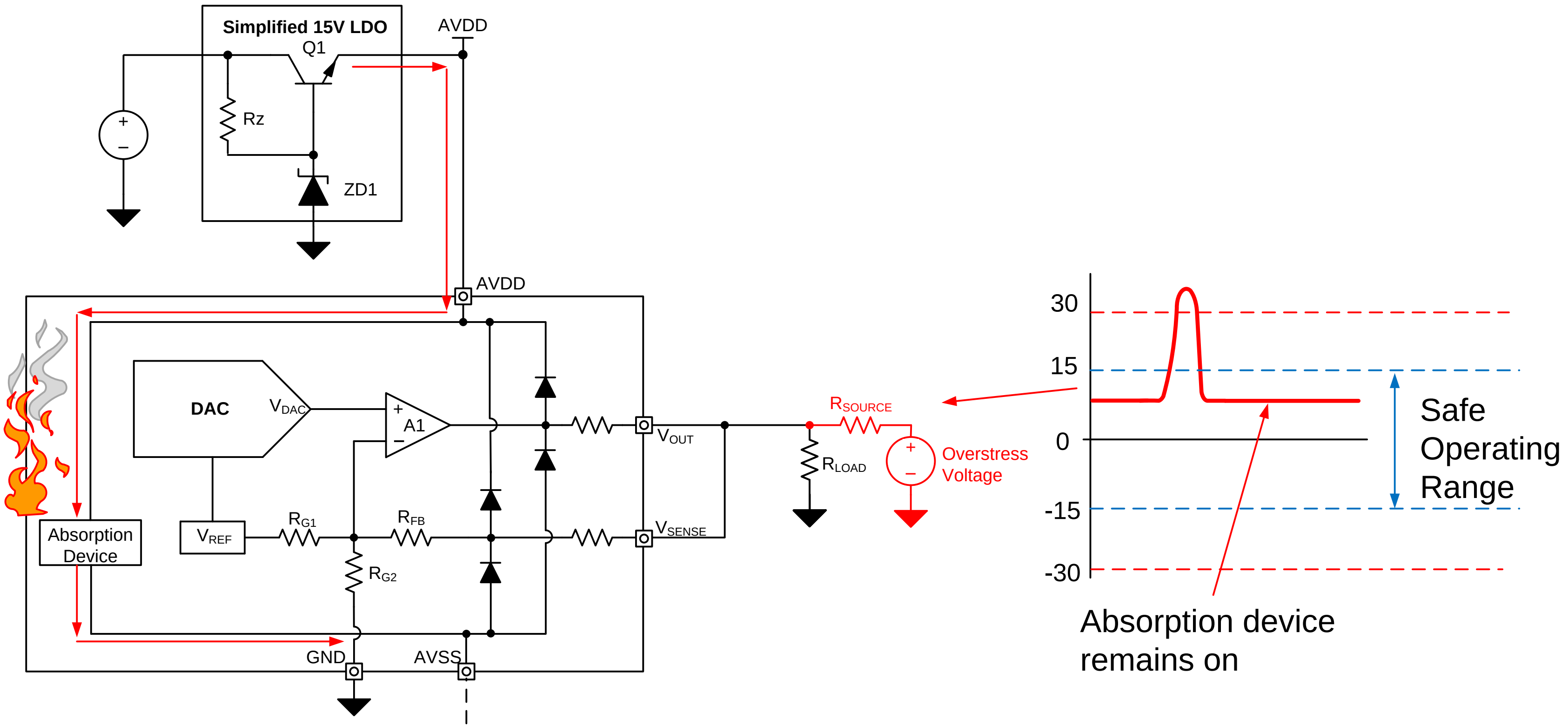
Fast Electrical Overstress on Output



Texas Instruments

Fast Electrical Overstress on Output



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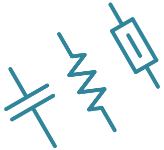
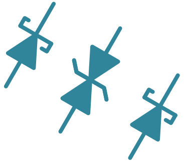
EMC/EMI Tested Analog Output





Attenuation

- This method uses passives (resistors, capacitors, ferrite beads) to *attenuate* sudden voltage changes and limit current
- Level of protection depends on ability to anticipate input signal magnitude, frequency and shape
- IR drops skew DC accuracy
- Excessive capacitance limits bandwidth

Diversion

- This method uses voltage clamps (TVS diodes, Schottky diodes)
- These devices *clamp* the input voltage and divert the energy away from the IC
- *Does not limit current*
- Parasitic capacitance, current leakage and response time can complicate design

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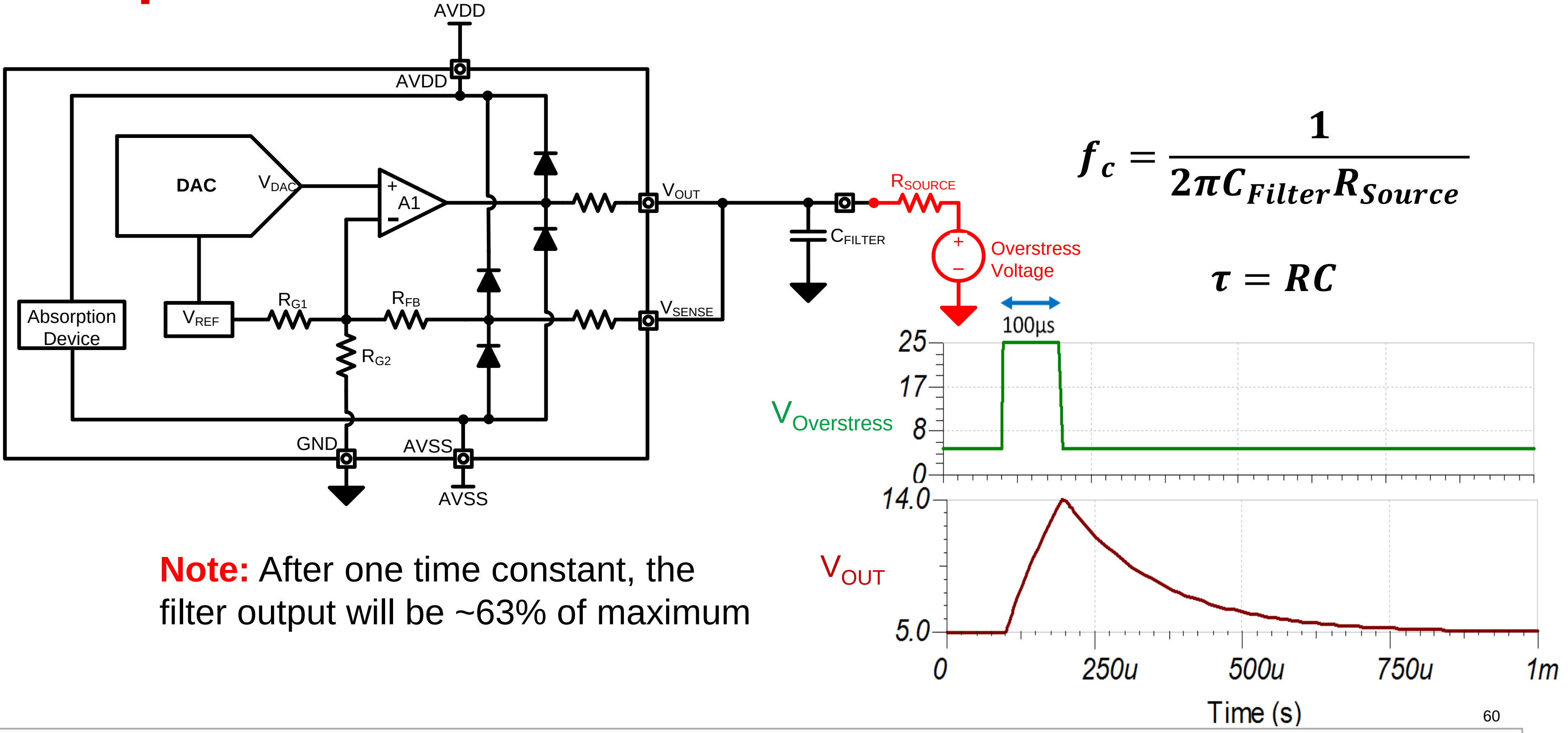
Simple RC Filter Can Reduce Transients



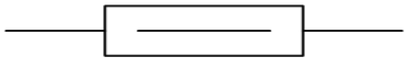
$$f_c = \frac{1}{2\pi C_{Filter} R_{Source}}$$

$$\tau = RC$$

Note: After one time constant, the filter output will be ~63% of maximum

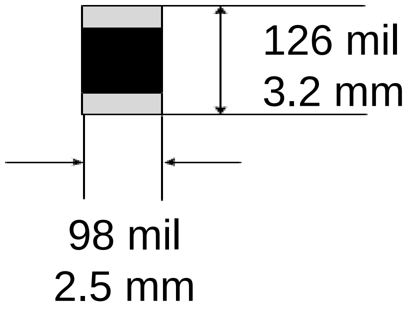
Ferrite Bead/Ferrite Chip

Schematic Symbol

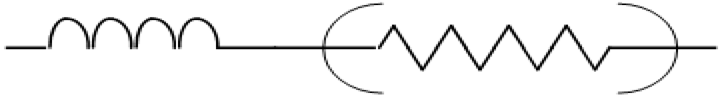


42 mΩ at DC
600 Ω at 600 MHz
3 A rated current

1210 Package (3225 Metric)



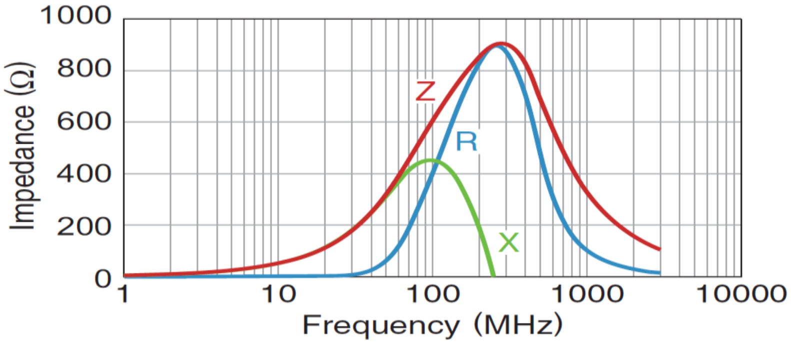
Model



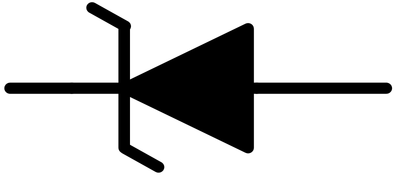
Inductance

Frequency-variable resistance

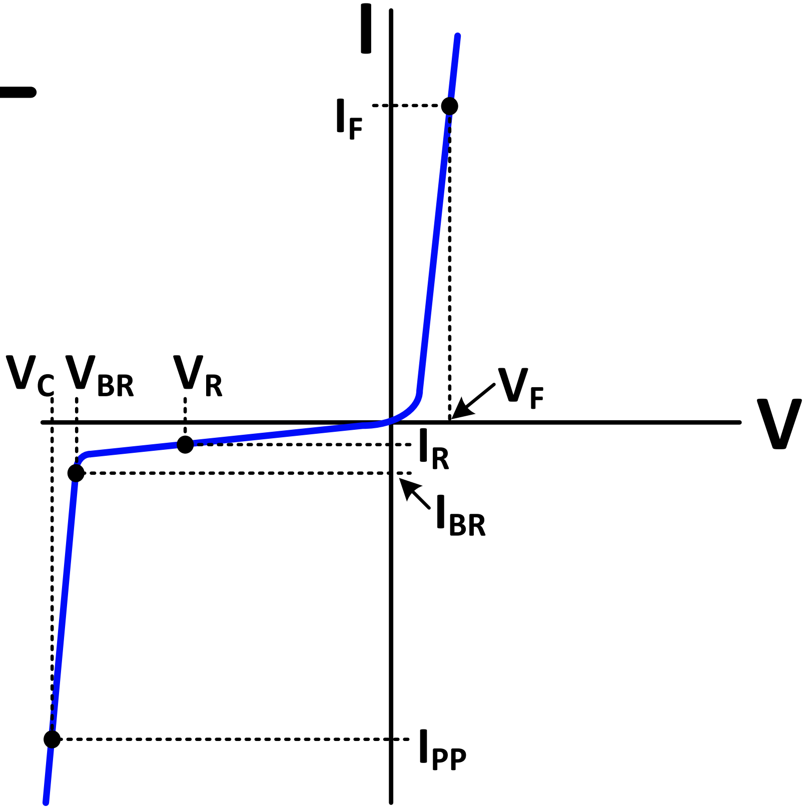
Characteristic



Unidirectional Transient Voltage Suppressor (TVS) Diode



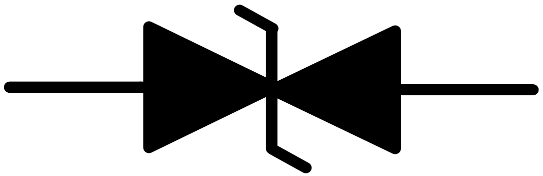
Symbol	Parameter
V_{BR}	Breakdown voltage
V_R	Stand-off voltage
V_C	Clamping voltage
V_F	Forward voltage drop
I_{BR}	Breakdown Current @ V_{BR}
I_R	Reverse Leakage @ V_R
I_F	Forward Current @ V_F
I_{PP}	Peak Pulse current @ V_C



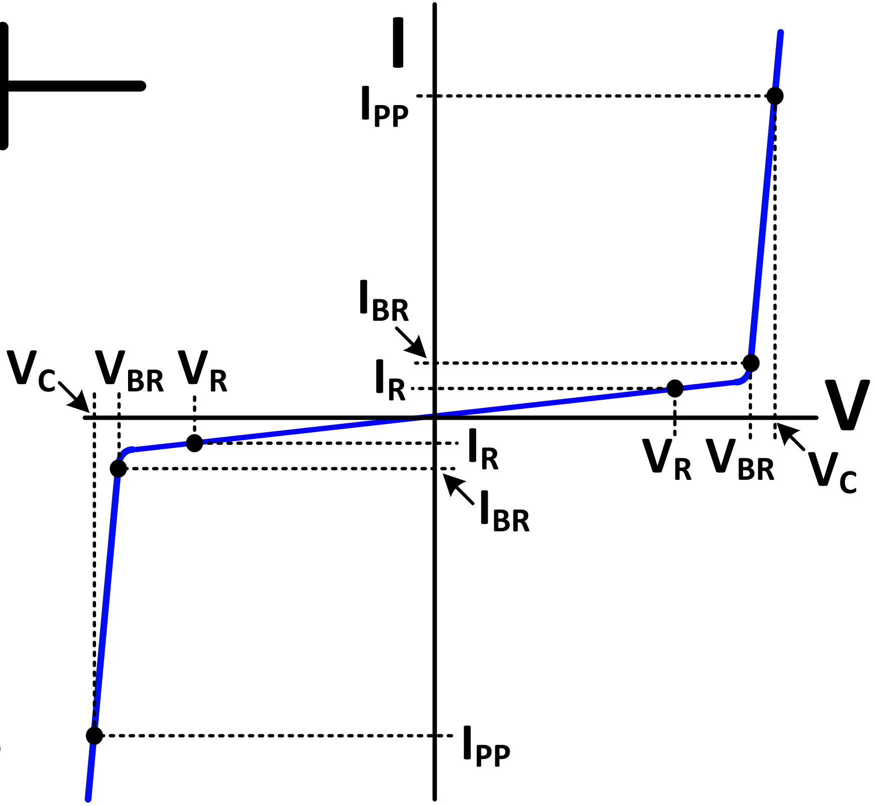
Set **V_R** = maximum operating supply voltage

Note: leakage current I_R is specified at V_R

Bidirectional Transient Voltage Suppressor (TVS) Diode



Symbol	Parameter
V_{BR}	Breakdown voltage
V_R	Stand-off voltage
V_C	Clamping voltage
V_F	Forward voltage drop
I_{BR}	Breakdown Current @ V_{BR}
I_R	Reverse Leakage @ V_R



Set $\mathbf{V_R}$ = maximum operating supply voltage

Note: leakage current I_R is specified at V_R

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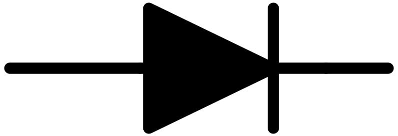
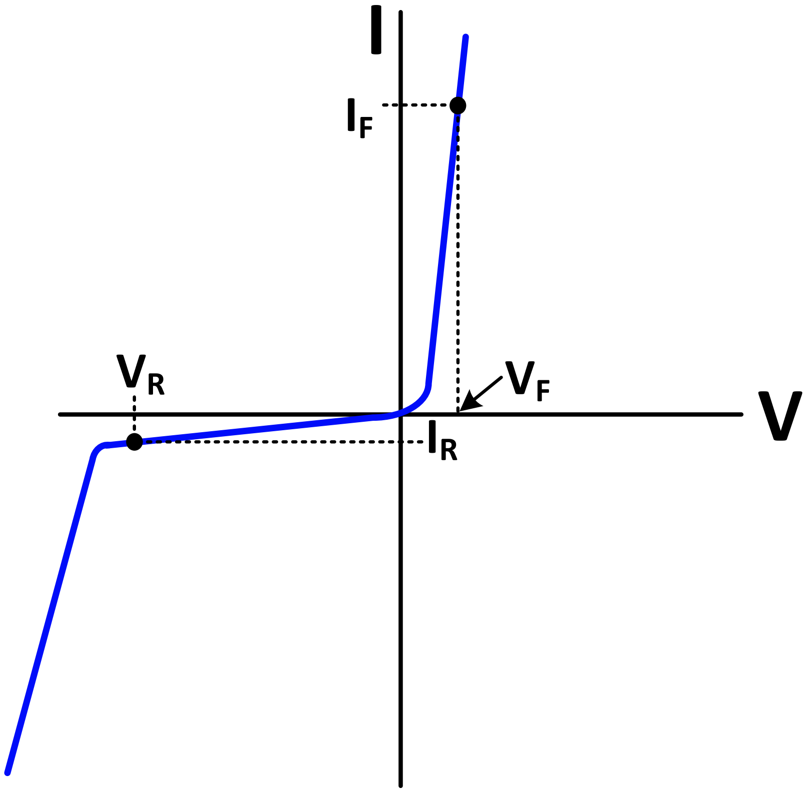
Low Forward Voltage Diodes (may be Schottky)



Symbol	Parameter
V_R	Max reverse voltage
V_F	Forward voltage drop
I_R	Reverse Leakage @ V_R
I_F	Forward Current @ V_F
I_{PP}	Peak Pulse current @ V_C



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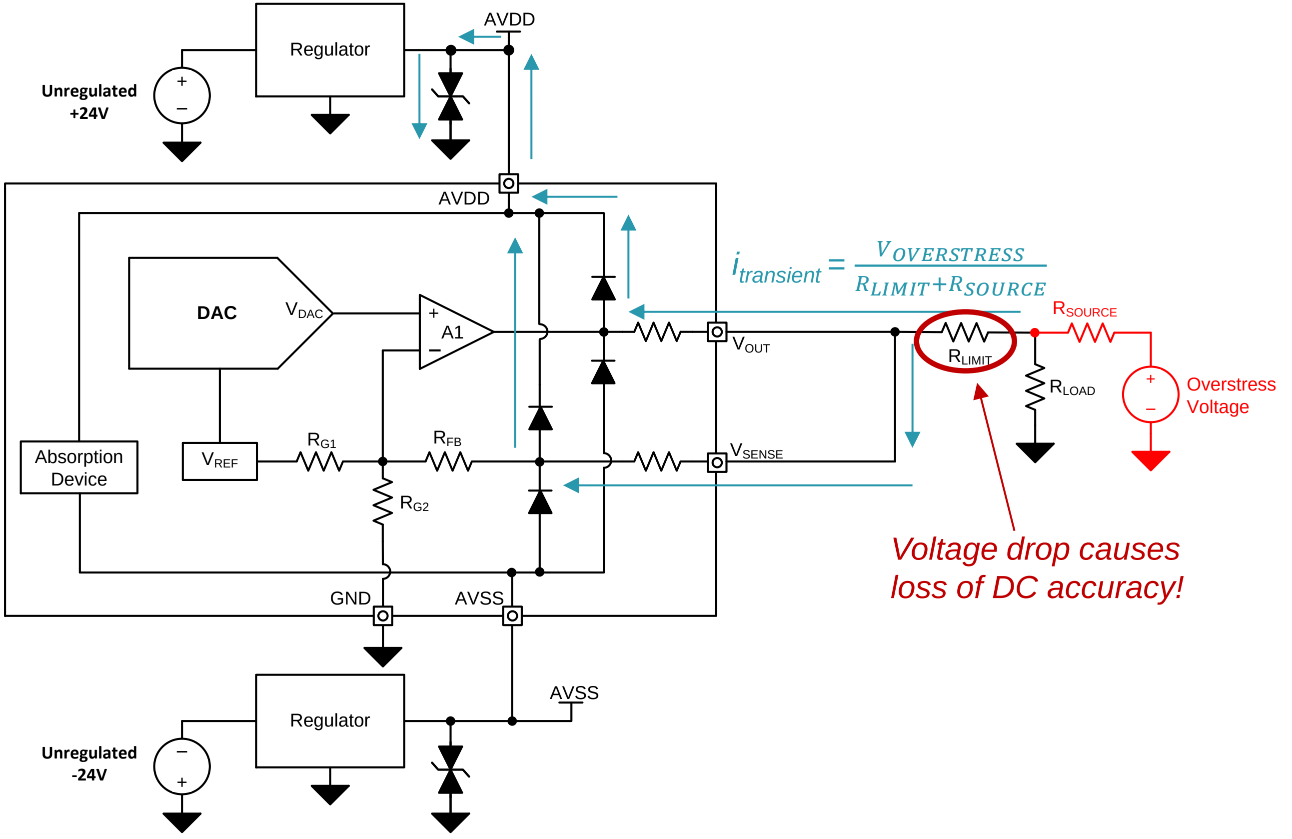
TVS Diodes on Supplies, Pass Element



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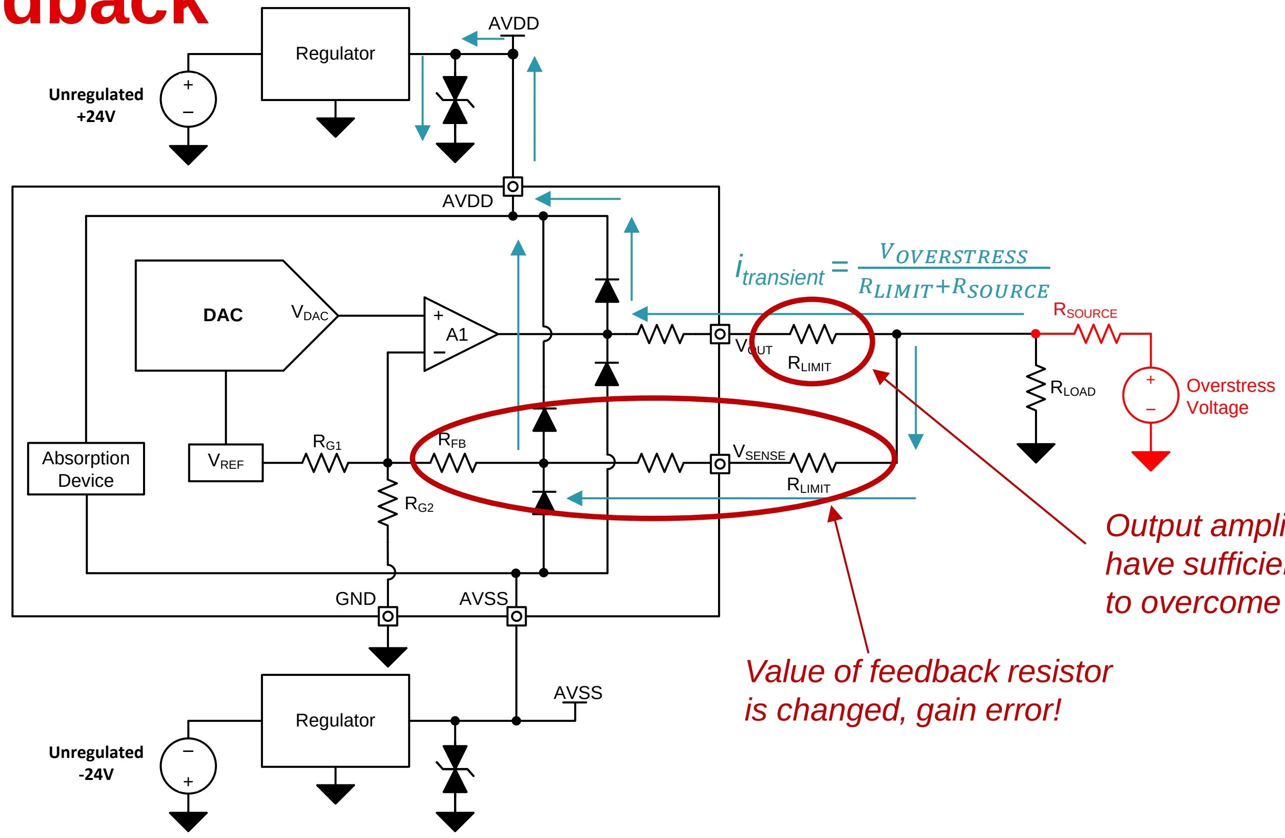
TVS Diodes on Supplies, Pass Elements inside Feedback



Output amplifier may not have sufficient headroom to overcome voltage drop!

Value of feedback resistor is changed, gain error!

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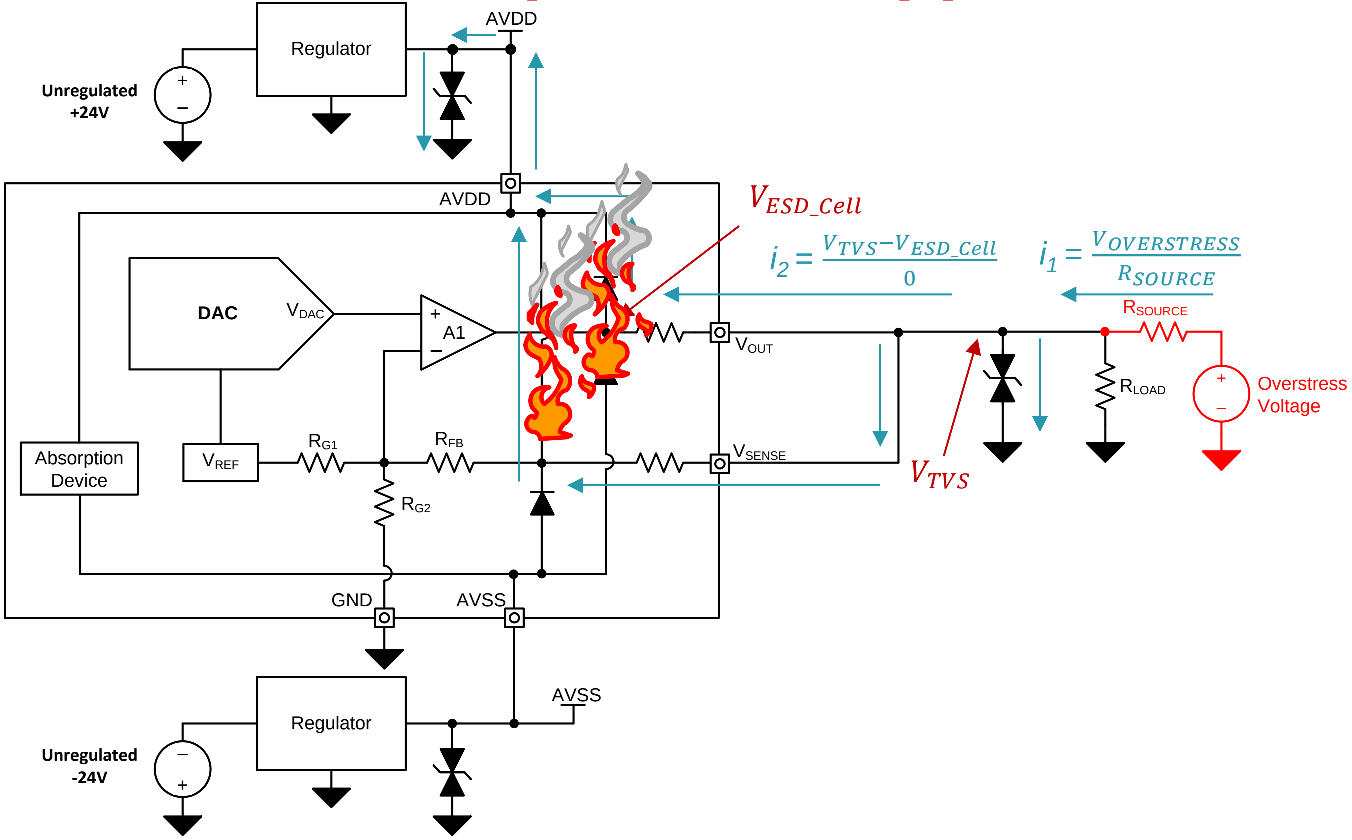
TVS Diodes on Output and Supplies



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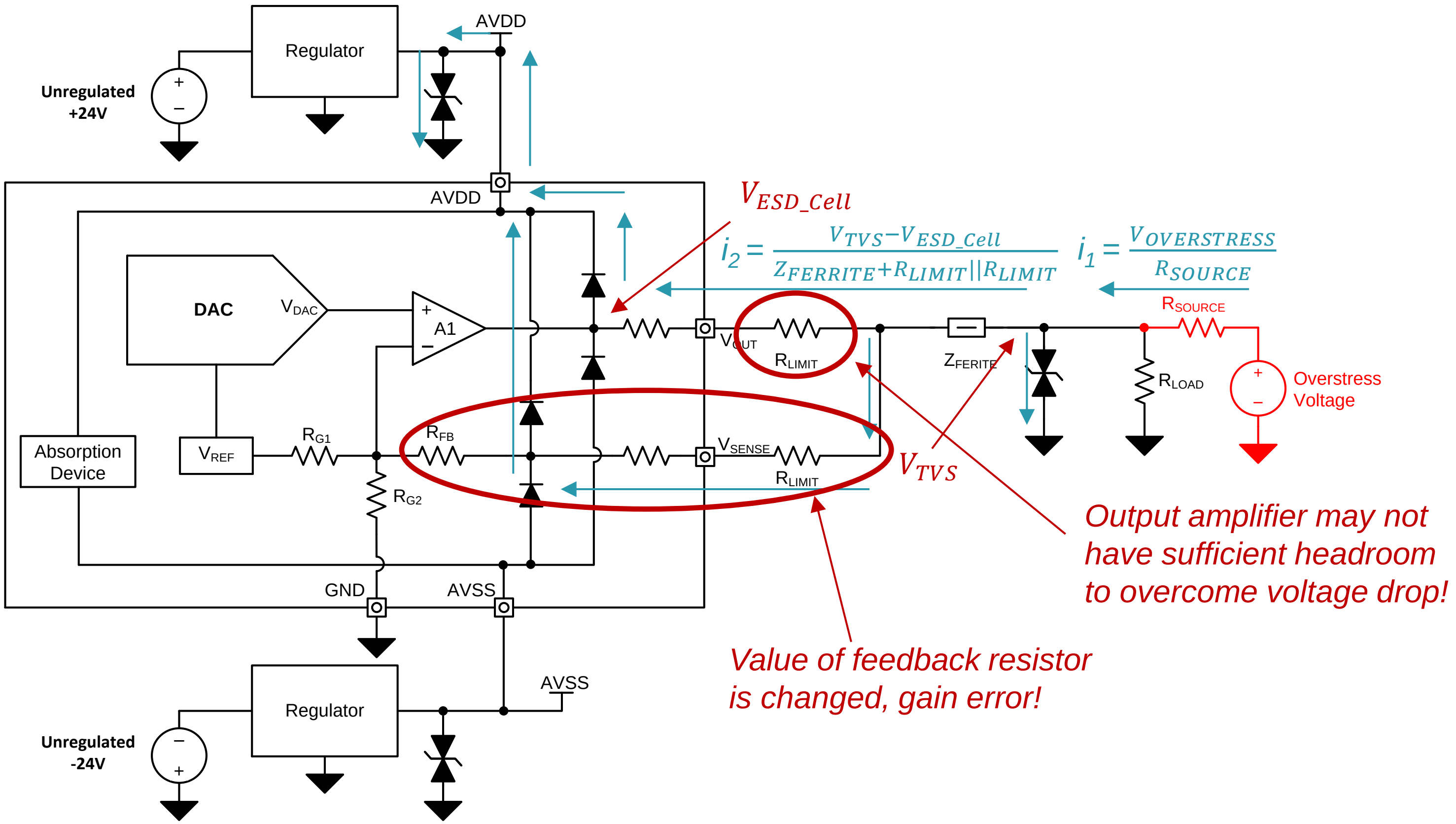
TVS Diodes & Pass Elements



Output amplifier may not have sufficient headroom to overcome voltage drop!

Value of feedback resistor is changed, gain error!

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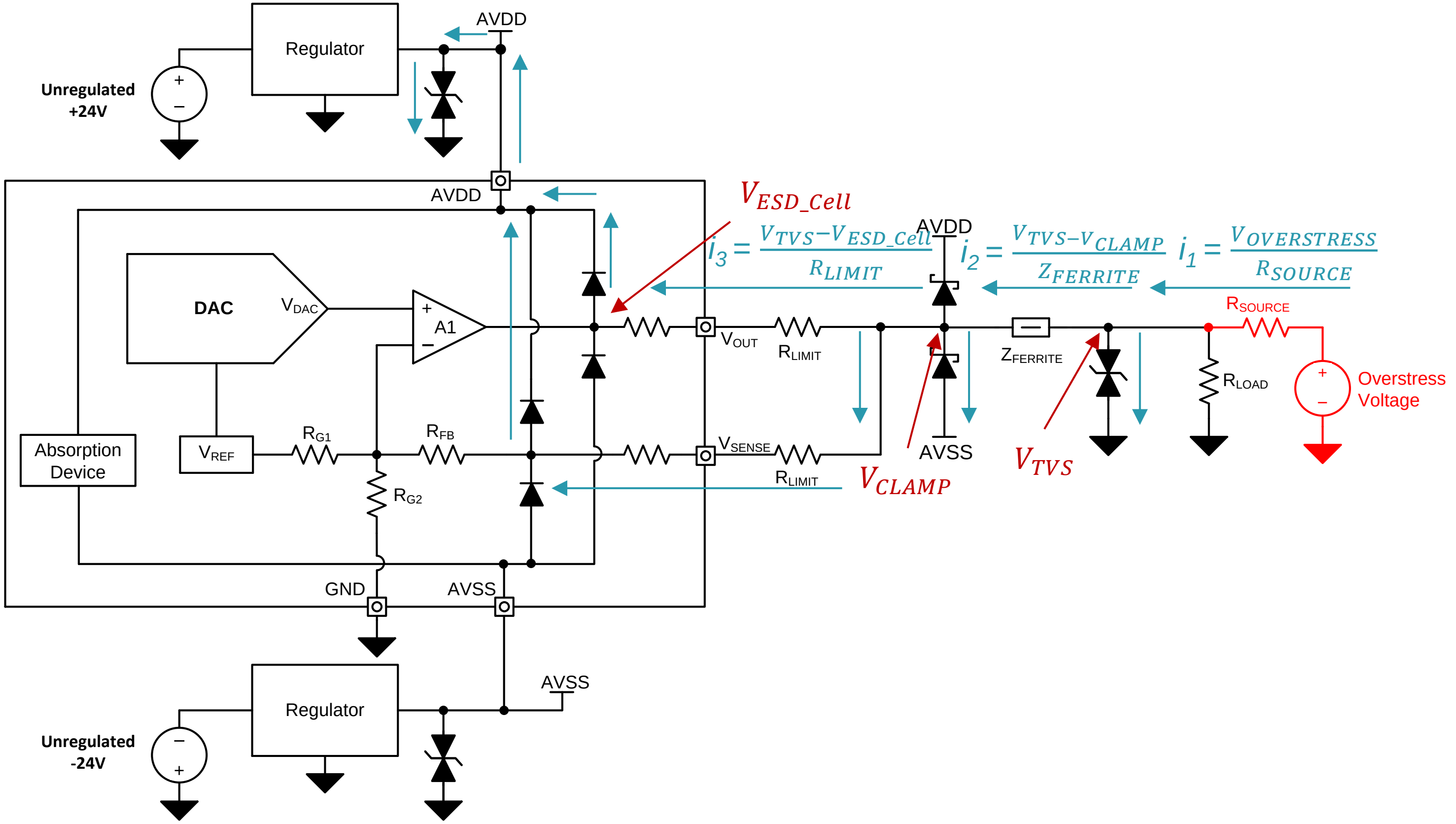
TVS Diodes, Clamp-to-Rail, & Pass Elements



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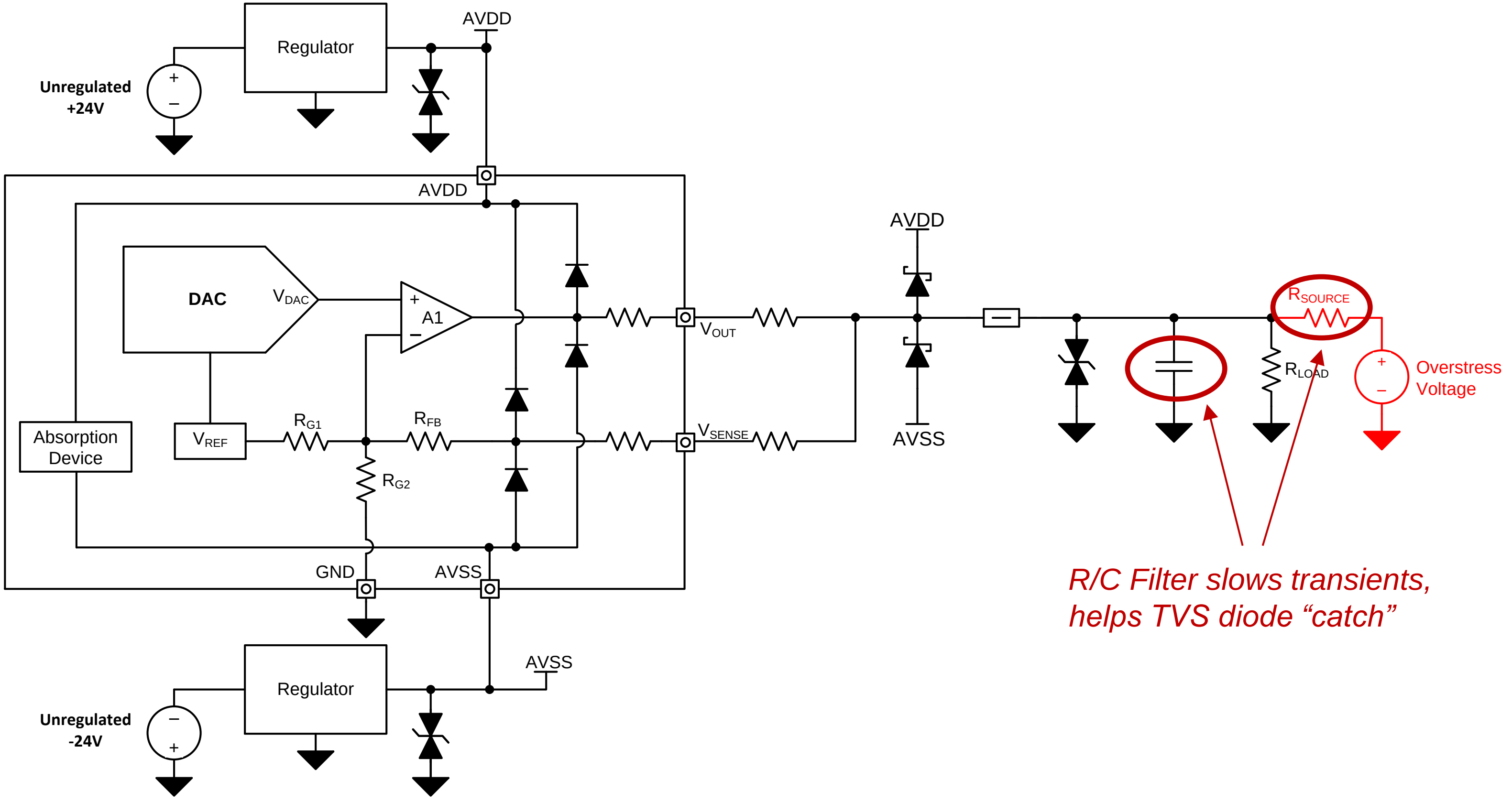
Complete Protection Circuit



Closing

Key questions to ask

Supporting Collateral

- TI Precision Designs
  - TIPD101: Low-Side Voltage-to-Current Converter
  - TIPD102: High-Side Voltage-to-Current Converter
  - TIPD119: Single Channel Shared Voltage/Current Output Terminal
  - TIPD125: Bipolar +/-10V from a Unipolar DAC
  - TIPD126: Bridge Sensor Conditioner with 2-wire 4-20mA Transmitter, EMC/EMI Tested
  - TIPD153: Single-Channel 3-wire Voltage/Current Output, EMC/EMI Tested
  - TIPD155: Dual Channel Shared Bipolar Voltage/Current Output Terminal
  - TIPD158: Low Cost 2-wire 4-20mA Transmitter, EMC/EMI Tested
  - TIPD160: Analog Linearized 3-Wire PT100 RTD to 2-Wire 4-20mA Current Loop Transmitter Reference Design
  - TIPD190: 2-wire, 4-20mA Transmitter, EMC/EMI Tested Reference Design
  - TIPD202: Analog Linearized 3-Wire PT1000 RTD to 2-Wire 4-20mA Current Loop Transmitter Reference Design
  - TIPD215: Less Than 1-W, Quad-Channel, Analog Output Module w/ Adaptive Power
  - TIPD216: Quad-Channel Industrial Voltage and Current Output Driver, EMC/EMI Tested
- Blog Posts
  - Industrial DACs – Kevin Duke
    - Part I, Part II, Part III, Part IV, Part V, Part VI
  - Input Isolation for 3-wire Analog Outputs – Kevin Duke
  - 4-wire 4-20mA Transmitters
    - Part I, Part II, Part III, Part IV
  - Two-Wire 4-20mA Transmitters: Background & Common Issues – Collin Wells
    - Part I, Part II, Part III, Part IV, Part V, Part VI
  - Electrical Overstress in a nut shell – Art Kay
    - Part I, Part II, Part III
  - Get CerTIfied, not certi-FRIED! Electromagnetic Compatibility Testing Explained – Ian Williams
    - Part I, Part II, Part III, Part IV

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