



## Precision 28144

### Quad-Channel Wideband Transducer Conditioner with Voltage and BCC™ Current Excitation and REZCOMP® Technology

**28144 Quad-Channel Wideband Transducer Conditioner** with Voltage and Current Excitation offers four channels of conditioning to support a wide variety of transducers including those that require constant voltage excitation or constant current excitation. Balanced constant voltage excitation in a bridge configuration supports applications such as strain gages and pressure transducers. Balanced current (BCC™) excitation accommodates single arm static or dynamic strain gages, RTDs or other resistive transducers that require constant current to excite them. Gain is programmable to x8192.

The 28144 features optional patent pending REZCOMP transducer compensation technology that extends the useable frequency response of resonant sensors. REZCOMP is effective at compensating the seismic mass resonant response of an accelerometer, the organ pipe resonant response of a recessed mounted pressure sensor and the resonant response associated with the protective screen of a pressure or microphone sensor. Based on a characterization of the sensor Q and resonance frequency, the compensation technique extends the usable sensor bandwidth by a factor of 3 or more.

An optional 5th wire buffer interface allows for measurement of the temperature of a piezoresistive sensing element for transducers equipped with this feature.



### Precision 28144 Features

- Four channels per card, 64 channels per 28016 chassis
- Balanced programmable constant voltage excitation with remote sense – up to 20 V delivered to the bridge
- Balanced differential constant current (BCC) excitation (20 mA/20 V compliance) with AC current test mode for verifying transducer, cabling and frequency response
- Optional Push-Push BCC™ for half bridge static/dynamic temperature compensated strain measurements using as little as a 2-wire interface.
- Optional REZCOMP® technology to extend frequency response of accelerometer, unsteady pressure and microphone sensor measurements
- Option HC10 – RTD/Bridge/Thermocouple Configuration. 4-wire 0-1 mA RTD excitation. RTD substitution, thermocouple substitution (1 mV – 125 mV) and resistive shunt cal.
- Option HC14 – Bridge/Strain/IEPE Configuration. Prog. bridge configuration (1, 2, 4-Arm) or 2-wire/4-wire constant current. Prog. completion (120, 350 and 1 kOhm). Programmable precision 255 step bipolar resistive shunt calibration of R1 or R2. IEPE input mode (8 mA constant current source).
- On-the-fly report of measured transducer excitation, resistance and transducer open/short indication
- Transducer leakage resistance measurement in constant current excitation mode, Option L
- Automatic bridge balance/transducer suppress
- 2 to 10-wire plus shield bridge input interface
- 2 or 4-wire input plus shield transducer interface with constant current excitation
- Programmable AC/DC input coupling
- Programmable gain: x1/16 to x8192 with 0.05% vernier
- 4 or 8-pole low-pass filters with programmable pulse/flat characteristics with up to 204.6 kHz “filtered” bandwidth or 1.5 MHz “wide-band” bandwidth
- Prefilter overload detection
- Front panel connectors that accept output adapter modules for multiple buffered outputs per channel
- Optional unity gain buffer for measurement of 5<sup>th</sup> wire voltage with an external acquisition device

### Overview

## 28000 Analog Signal Conditioning System



**The Precision 28000 Signal Conditioning System** provides all the flexibility you need to manage your test measurements.

- Choose charge, IEPE w/TEDS, voltage (filter amplifier), strain, thermocouple, RTD, potentiometer, current, frequency, or other transducers.
- Graphical User Interface (GUI) and Ethernet network interface for system control
- Intelligent gain and system scaling algorithms
- Test input and output monitor busses
- Go/no-go test with diagnostics to be used before tests
- Rigorous factory acceptance test for maintenance
- Field swappable AC power supplies
- Built-in temperature and power supply monitoring with alarms

### 28144 Applications

- Static or dynamic strain gage conditioner
- Full bridge conditioner
- Static and dynamic pressure transducer conditioner
- Piezoresistive accelerometer conditioner
- Kulite sensor amplifier
- RTD conditioner
- Thermocouple amplifier
- Load cell conditioner
- MEMS transducer conditioner
- Hot wire anemometry
- AC or DC filter/amplifier (<1 mV to 10 V inputs)



# Precision 28144 Description

## Precision 28144 Description

The 28144 is a member of the Precision 28000 family of signal conditioners. The 28144 provides four channels of conditioning for transducers requiring constant current or constant voltage excitation. Up to sixteen 28144 cards may reside in the 28000 system to provide 64 channels per chassis. In addition, the 28144 may be mixed with other conditioners in the 28000 family to meet your unique signal conditioning requirements.

Large changes in sensor impedance or sensor excitation can indicate that data from this sensor is no longer meaningful. The unique transducer health monitor circuits of the 28144 provide an "on-the-fly" report of measured sensor excitation and resistance. Measured gage resistance is compared to user specified limits and flagged if out of tolerance. Also, the 28144 alerts the user to a transducer open or short condition. The input overload detector reports overloads by out-of-band signals which could cause in-band distortion.

The 28144 incorporates precise, automatic calibration of gain and offset for the entire channel, including the amplifier, filter, and excitation supply. Option HC14 supports programmable bridge configuration for 120  $\Omega$ , 350  $\Omega$  or 1 k $\Omega$  bridges along with 255 steps of precision bipolar shunt calibration and a current source for IEPE transducers. Option HC10 provides support for RTD's and thermocouples in addition to full bridge sensors.

## Balanced Constant Voltage Excitation

The 28144 provides balanced constant voltage excitation of up to 20 volts and conditioning for 1-, 2-, and 4-arm resistive bridges. The 2- to 10-wire input connection provides 6 wires for the bridge, 3 wires for shunt calibration, 1 wire for the shield, and 1 wire for single-arm bridges. Automatic balance of the bridge is accomplished by inserting a voltage ratio metric with the excitation supply to the amplifier input stage. This balance method provides outstanding stability without loading the bridge. A wide range of unbalanced conditions may be accommodated.

Balanced constant voltage excitation offers a number of advantages over single-ended excitation. It enables a true balanced instrumentation amplifier input for outstanding rejection of high frequency common mode signals. Single-ended voltage excitation to

balanced bridges produces a relatively large common mode voltage at half the excitation supply. The instrumentation amplifier must reject this signal. Balanced voltage excitation applied to balanced bridges results in lower common mode input voltages to the amplifier input stage.

The excitation supply has automatic amplitude and offset correction that may be run on the unit in place at any time. Dedicated remote sense lines allow the excitation supply regulator to deliver an accurate voltage to the bridge.

## Balanced Constant Current Excitation™

The 28144 is equipped with Precision Filters' proprietary balanced differential constant current excitation that is optimized for making dynamic strain measurements on single active strain gages. Balanced constant current excitation provides an accurate means of measuring dynamic strain with a single active strain gage using only a two-wire connection. Electrostatic pickup is reduced when compared to single-ended constant current excitation or a quarter bridge configuration with remote completion resistors or unbalanced current sources. The balanced current excitation circuit operates properly even under certain common gage fault conditions such as a direct short of the gage to the test model.

Balanced constant current excitation provides a true balanced input for rejection of common-mode signals. Programmable excitation provides 0 to  $\pm 20$  mA of constant current with an "excitation off" mode to detect input cable noise pickup. Gage open/short detection is also provided.

For dynamic strain conditioning applications, the 28144 can provide accurate measurements with only two wires by AC coupling the input. For best AC or DC measurements (required for RTD type transducers), the 28144 provides a 4-wire Kelvin connection for remote sense. Constant current excitation may be applied to full bridge applications with the advantage that excitation delivered to the bridge is unaffected by excitation supply lead wire resistance.

Push-Push BCC (option P) allows static or static/dynamic strain measurements on a half bridge with as low as a 2-wire interface. Unlike Wheatstone  $\frac{1}{2}$  bridge circuit, Push-Push BCC has excellent noise immunity and no desensitization due to cable resistance making it a superb choice to make accurate,

low-noise measurements in installations with moderate to long cable runs. In addition, the topology can provide temperature compensation for thermal (apparent) strain that is especially important for static strain measurements at extreme temperatures such as cryogenic environments or for testing of high temperature gas turbines.

Suppression of the gage DC operating point is performed automatically using the zero suppress feature of the 28144. Zero suppress allows the use of more gain to emphasize small gage fluctuations. Zero suppress also provides the user with an accurate means to balance a full bridge.

The excitation current source output may be modulated to allow AC current injection in the loop. The frequency and amplitude of the AC current is user controlled. This allows the user to simulate changes in gage resistance in the loop and provides direct AC input stimulation to the signal conditioner for end-to-end system calibration.

## REZCOMP Technology

Precision Filters developed the patent pending REZCOMP technology to extend the frequency response of accelerometers, pressure sensors and microphones in real-time with no need for data post-processing. For measurement of unsteady pressure, aerodynamically driven resonances associated with the sensor packaging and/or recessed mounting can produce large gain and phase errors in the frequency range of interest (10 Hz to 20 kHz).

When the pressure sensor is packaged in the transducer housing, a protective screen covering the sensing element is used. The screen and the cavity volume behind the screen produce Helmholtz resonances on the order of 20 kHz to 100 kHz which overlap and limit the usable sensor frequency response. The resonance causes unwanted amplification and phase shift errors in the measurement and if not accounted for, can exceed the maximum signal swing of the amplifier and severely distort the measurement.

Similarly, for applications where the sensor is recessed at the end of a tube, an organ-pipe resonance is created that amplifies the pressure signal by 20 dB or more depending on the length of the tube and other properties. This resonance limits the useful bandwidth to about 20% of the first resonance or about 1 kHz for a 1 inch tube.

REZCOMP flattens the sensor resonant response and compensates for phase in

order to make use of the full available frequency response of the sensor. REZCOMP compensation is based on user entry of sensor quality factor Q and resonance Fr. The complementary transfer function is programmed to flatten the sensor frequency response and linearize the sensor phase response. Vendors such as Kulite provide Q and Fr data specific to each sensor. For even more accurate results, the sensitivity of Q and Fr to temperature may be accounted for simply by entering the operating temperature of the sensor<sup>1</sup>.

As the block diagram on page 11 illustrates, programmable pre-filter gain is first applied to the input signal in order to preserve signal-to-noise ratio of the in-band sensor signal while allowing for headroom for out-of-band signals. Next the sensor frequency response correction is applied to compensate for the resonant response of the sensor. The programmable filter is then applied to the signal to eliminate out band energy and to prevent aliasing. The signal is then further amplified using post-filter gain to ensure the full use of the A/D dynamic range after compensation of the resonance characteristics.

It is possible to correct for undesired resonant frequencies by post-processing test data however post-processing data after digitization can result in poor signal-to-noise ratios since the A/D input must accommodate both the in-band signal of interest and the sensor resonance. Allocating amplifier headroom for the sensor resonance results in reduced amplification of the small in-band signal above the self-noise of the signal conditioner and A/D. This results in sub-optimal signal-to-noise ratios regardless of the resolution of the A/D. The REZCOMP correction approach provides superior real-time performance by maximizing signal-to-noise ratios.

## Input Stage

The 28144 input stage provides 120 dB of common-mode rejection and may be either AC or DC coupled. AC coupling is useful for dynamic applications where the DC bias on the transducer, that can limit dynamic range, can be coupled out of the signal. With the input DC coupled, low drift and ultra low noise ( $< -163 \text{ dBV}/\sqrt{\text{Hz}}$ ) is provided by the 28144 input stage. The input stage may be shorted under program control to verify signal conditioner channel noise and DC offsets.

1 Hurst, A. M., Carter S., Firth D., Szary A., and VanDeWeert, J., 2015, "Real-Time, Advanced Electrical Filtering for Pressure Transducer Frequency Response Correction," ASME 2015 Gas Turbo Expo, ASME, Montreal, Canada, pp. 1-13

A switch at the input stage is provided to connect the amplifier to the 28000 system test bus. The test bus is used to inject signals for performance verification. In addition, both drive and sink current levels may be monitored separately making it possible to detect excitation current leakage conditions in the external current loop.

## Amplifier and Filter

Programmable pre- and post-filter amplifiers provide an overall gain of 8192. Gain is distributed both before and after the filter to provide protection from large out-of-band energy or transients that could cause clipping before the filter, distorting the data. The Gain Wizard in the GUI allows the user to set a gain reserve and then apportions the gain between the input and output. This provides input gain for best noise performance yet conforms to the limitations of the user's worst case estimate of out-band or transient signals. Overload detectors alert the user to over-voltage conditions. A fully buffered output having over 25 mA of drive capability may be used to drive long output cable runs.

The 28144 may be specified with a 4 or 8-pole low-pass filter or an 8-pole band-pass filter with cutoffs programmable from 1 Hz to 204.6 kHz and programmable "flat" or "pulse" mode. The "flat" mode provides pass-band characteristics nearly identical to a Butterworth filter while providing a much sharper roll-off. This mode is a good choice for applications such as spectral analysis. The "pulse" mode has time domain response similar to the Bessel filter yet provides superior amplitude response characteristics. The "pulse" mode is ideal for time domain applications including transient (shock) measurements and time domain waveform analysis.

## Verification of Cables and Sensor Health

**Strain Gage Loop Resistance Measurement:** Dynamic strain measurements often require complicated wiring schemes. Long cable runs, multiple connection points, high-temperature high-impedance very small diameter wire and slip rings combine to cause uncertainty in the strain gage connection. Often a sudden increase in gage resistance is a predictor of gage failure. The Precision 28144 gives continual real time monitoring of the total "Loop Resistance" of the gage and cable circuit. This loop resistance reading can be compared to preset limits to alert the user of unexpected resistance shifts as well as gross gage short and gage open conditions.

**Cable Roll-off:** One often asked question of many measurements engineers is "How will my cable capacitance affect my high frequency strain measurement"? This question can be answered quickly and easily and all from the convenience of the control room. The AC dither current feature of the 28144 modulates a small AC current on top of the DC excitation current to stimulate an AC signal across the actual strain gage sensing element. Since the stimulus signal is based at the sensor, it will exhibit the same roll-off characteristics as a signal resulting from actual dynamic strain. The test frequency of the dither signal can be increased as necessary to chart the cable roll-off characteristics and validate the cable circuit for use at the desired measurement frequencies.

**Gage Leakage Measurements:** In extremely hot sections of a test article, it is impossible to use standard insulating materials in gage wiring. Often a rigid section of a stainless steel or Inconel sheath encloses high temperature inner conductor wires. The inner core of the sheath is filled with magnesium oxide (MGO) as a high temperature insulating material. The insulating properties of the MGO are affected by moisture absorption at damage points or improperly sealed cable terminations. In extreme conditions, insulation breakdown can cause a leakage path to ground and corrupt a gage reading. Other causes of cable leakage are fatigue or failure at extension wire tie-down points, or in the strain gage itself. The leakage detection feature of the 28144 continually monitors leakage and compares readings to preset threshold limits. Sensors which show higher than normal leakage can be quickly identified prior to or during the test run.

## Muting Faulty Sensors

Depending on the sensor type, various techniques must be used to quiet the channel's input and output circuits and ensure that no noise coupling occurs. For example, an intermittent gage will create a gage chatter condition whereby the connecting wires continually switch between the high voltage fault level and the proper low voltage operational level. This chatter condition creates a hostile noise source to any other gage extension wires in the vicinity of the hostile cable. Precision 28144 signal conditioning channels have a "MUTE" feature, which places the channel in its quietest quiescent state and minimizes the possibility of coupling noise to properly functioning channels.

# 28144 Details and Specifications

## 28144 Sensor Configuration

The high degree of modularity of the 28144 allows the card to be easily configured to condition a particular sensor type. Two sensor configuration options are available to support a wide range of transducer conditioning applications.

**Bridge/Strain/IEPE Configuration:** The HC14 configuration option supports measurements of strain in a ¼, ½ or full bridge configuration or 2-wire/4-wire constant current measurements. Precise low drift (0.2 PPM) completion resistors are included for 120, 350 or 1000 ohm bridges. 255-step bipolar shunt calibration provides programmable shunt cal resistance values ranging from 7.5 kΩ to 1.92 MΩ. Shunt calibration can be applied internally to the 28144 card or remotely at the actual bridge using dedicated shunt calibration connections. Single shunt of R1 or R2 bridge arms is supported.

The HC14 also supplies an 8mA current source for measurements with IEPE transducers. An AC coupling capacitor removes the sensor bias and connects to the amplifier input stage. Sensor Bias and fault conditions are monitored in real time to alert the user to a fault condition.

**Bridge/RTD/Thermocouple Configuration:** The HC10 Bridge/RTD/Thermocouple Configuration Module supports full-bridge, RTD and thermocouple measurements. A 1mA precision constant current excitation is supplied to the RTD. Current drive and signal sense terminals are available on the input connector to allow a 4-wire Kelvin connection to the RTD. Precision RTD substitution resistors are supplied for calibration purposes.

For thermocouple measurements it is assumed that a third party UTR is used with isothermal block temperature read and processed by external means to compensate the 28144 output for a reference junction and to perform linearization. Precision thermocouple DC input voltage substitution is supported.

For full bridge measurements, programmable single-step bipolar shunt of R1 or R2 is supported. In addition, relay contacts are used to connect the sensor internal cal resistor (if equipped) to + and - excitation.

**Sensor Configuration Options:** The HC10 and HC14 options are factory configured and support bridge, strain, IEPE, RTD and thermocouple configurations and are recommended for new installations. BC6, BC7 and BC8 options can be installed in the field.

## Configuration Module Specifications:

### Bridge Configuration\*:

1-arm, 1-arm w/ 3 wires, 2-arm or 4-arm, (programmable)

### Completion Resistors\*:

120 Ω, 350 Ω and 1 kΩ, programmable

### Constant Current:

2-wire/4-wire (Kelvin) input, programmable

### Resistor Temperature Coefficient\*\*:

±0.2 ppm / °C

### Resistor Accuracy\*\*:

±0.02%

## HC10 Full-Bridge/RTD/Thermocouple Configuration Module

### RTD Substitution Cal

**Values:** 62.5, 125, 500, 1 k and 2 kΩ, programmable

### Accuracy\*\*:

±0.01%, 5ppm/°C

### Thermocouple cal via prog. voltage substitution

**Range:** 1 mV - 125 mV w/ 0.1 mV min resolution of setting

**Accuracy:** +/-1-10mV: +/- 0.15%; ±10mV-100mV: +/- 0.07%

### DC Shunt Calibration (Constant Voltage Excitation Mode Only):

3-Step Bipolar Shunt Cal

### DC Shunt Selection:

R1 or R2 bridge arms

### Shunt Sensitivity:

±1 mV per volt of programmed excitation

### Shunt Resistance:

Selectable:  
29.940 kΩ,  
87.325 kΩ,  
249.5 kΩ

**Resistor Accuracy:** ±0.2%

### Sensor RCAL:

Connects sensor internal cal resistor to + or - excitation via relay contacts.

### Notes:

\* Not supported on HC10

\*\* These specifications are guaranteed by design, but are not testable to these limits with the 28000 Factory Acceptance Test (FAT) system.

## HC14 Bridge/Strain/IEPE Bridge/IEPE Configuration Module

### DC Shunt Calibration:

255-Step Bipolar Shunt Cal

### DC Shunt Selection:

R1 or R2 bridge arms

**Shunt Resistance:** 7.5 kΩ to 1.92 MΩ

**Resistor Accuracy:** ±0.1%

**Shunt Sensitivity:** Variable based on selected shunt resistance and bridge resistance, limited to 16mV/V.

### IEPE Input Mode:

**Level:** 8 mA, ±1%

**Compliance Voltage:** 26 V, Nominal

**AC Coupling Frequency w/ IEPE Selected:** 0.32 Hz ±5%

**Fault Monitor:** Sensor open/short

**IEPE Bias Monitor:** Bias voltage continuously monitored and compared to user defined limits

## BC6 DC Shunt Calibration

### DC Shunt Selection:

R1 or R2 bridge arms

### Equivalent Shunt Resistance Settings:

30.75R to 2000R w/ 0.2% minimum resolution where R = 120 Ω, 350 Ω, or 1 kΩ

### Shunt Sensitivity:

±0.125 mV/V to ±0.5 mV/V  
in ±0.25 μV/V steps  
±0.501 mV/V to ±2.0 mV/V  
in ±1.00 μV/V steps  
±2.004 mV/V to ±8.0 mV/V  
in ±4.00 μV/V steps

### Shunt Accuracy:

±0.2% for programmed excitation >1 V

## BC7 DC Shunt Calibration

### DC Shunt Selection:

R1 or R2 bridge arms

### Shunt Sensitivity:

±1 mV per volt of programmed excitation

### Shunt Resistance:

29.940 kΩ for 120 Ω bridge  
87.325 kΩ for 350 Ω bridge  
249.5 kΩ for 1 kΩ bridge

**Resistor Accuracy:** ±0.1%

## BC8 Current Sense:

### Modes:

2-wire sense or 4-wire sense

### Sense Resistor:

250 ohms ±0.1%

# 28144 Details and Specifications

## Bridge Wiring

- Input Connector:**  
26-pin high-density D-shell (2 ea.)
- Input Wires:**  
±EXCITATION (2)  
±SENSE (2)  
±SIGNAL (2)  
SHUNT CAL (3)  
¼ Bridge RTN (1) Single-Arm Bridge  
SHIELD (1)

## 28144 Excitation Supply

### Programmable Constant Voltage Excitation

- Maximum Output:**  
20.475 V, 30 mA (balanced)
- Steps:**  
Programmable from 0 to 20.475 in 5 mV steps
- Excitation Sense:**  
Programmable (instrument or gage sense)
- Accuracy:** ±0.03%, ±500 µV
- Noise:** 100 µVrms, 3 Hz to 200 kHz
- Temperature Drift:**  
±0.0025%/°C of setting or ±50 µV/°C, whichever is greater
- Sense Leakage Current:** Less than 10 µA
- Calibration:**  
Automatically calibrated for gain and offset. Calibration initiated at the GUI panel.
- Excitation Off:**  
The excitation supply is programmed to 0 volts.

## 28144 Constant Current Excitation Supply

- Type:**  
Balanced differential (Push-Pull) constant current excitation
- Excitation:** 0 to 20.475 mA in 5 µA steps
- Total Gage Voltage (Volts):**  
22 – I x 700 minimum
- Input Impedance:** 100 kΩ nominal per side
- CMRR (DC to 1 kHz):**  
80 dB for 120 Ω gage  
70 dB for 350 Ω gage  
60 dB for 1 kΩ gage
- Initial Accuracy:** 0.05%, 5 µA
- Temperature Drift:**  
30 nA + 0.0024% of setting per °C
- Noise:** 65 pA/√Hz at 1 kHz
- Bandwidth:**  
±0.2 dB to 200 kHz (RGAGE < 1 kΩ)
- Push-Push BCC (Option P):**  
Balanced Push-Push BCC mode optimized for static and static/dynamic half bridge measurements. Specs are equivalent to standard BCC except as indicated.
- Gage Voltage (per side):**  
11-I x 350 minimum
- Input Impedance:**  
10 MΩ nominal per side

## HC10 RTD Excitation

The HC10 option provides excitation levels optimized for RTD measurements.

- Type:**  
Balanced differential constant current excitation

- Level:**  
0 to 1.02375 mA in 0.25 µA steps
- Total Gage Voltage:**  
22 – I x 14,000 minimum
- Input Impedance:**  
2 MΩ nominal per side
- Initial Accuracy:** 0.05%, 250 nA
- Drift:**  
1.5 nA + 0.0024% of setting per °C
- Noise:** 3.5 pA per rt Hz at 1 kHz
- Bandwidth:** ±0.2 dB to 200 kHz

## 28144 MUTE Mode

Mute control places the channel in the quietest operational state to minimize system noise in the event of a failed sensor. The Mute Mode is also useful to terminate unused channels in a safe and quiet state.

## 28144 Transducer Health Monitor

**Sensor Excitation Monitor:** Transducer excitation voltage or current is monitored and reported to the user on-the-fly. Measured excitation is compared to factory set tolerance and GUI indicators report if out of tolerance.

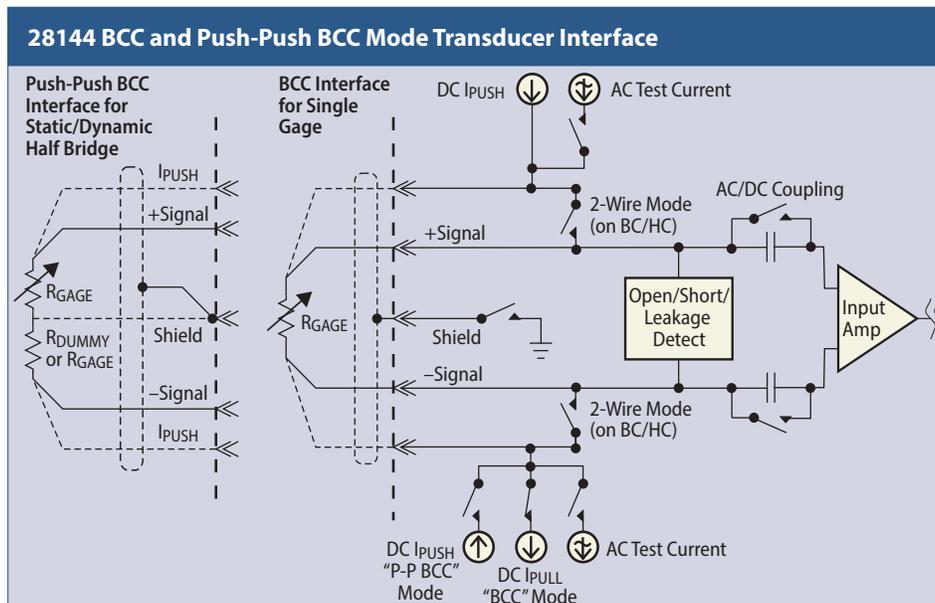
**Sensor Resistance Monitor:** Transducer resistance is monitored on-the-fly and compared to user defined limits. GUI indicators report if sensor resistance is out of user tolerance.

**Sensor Open/Short Monitor:** Transducer open or short condition is monitored and reported to the user via GUI indicators.

**Transducer Leakage Resistance Measurement, Option L:** The 28144 with Option L monitors gage bias levels in order to detect constant current excitation leakage conditions in the external current loop. Transducer leakage status is monitored and reported via the GUI.

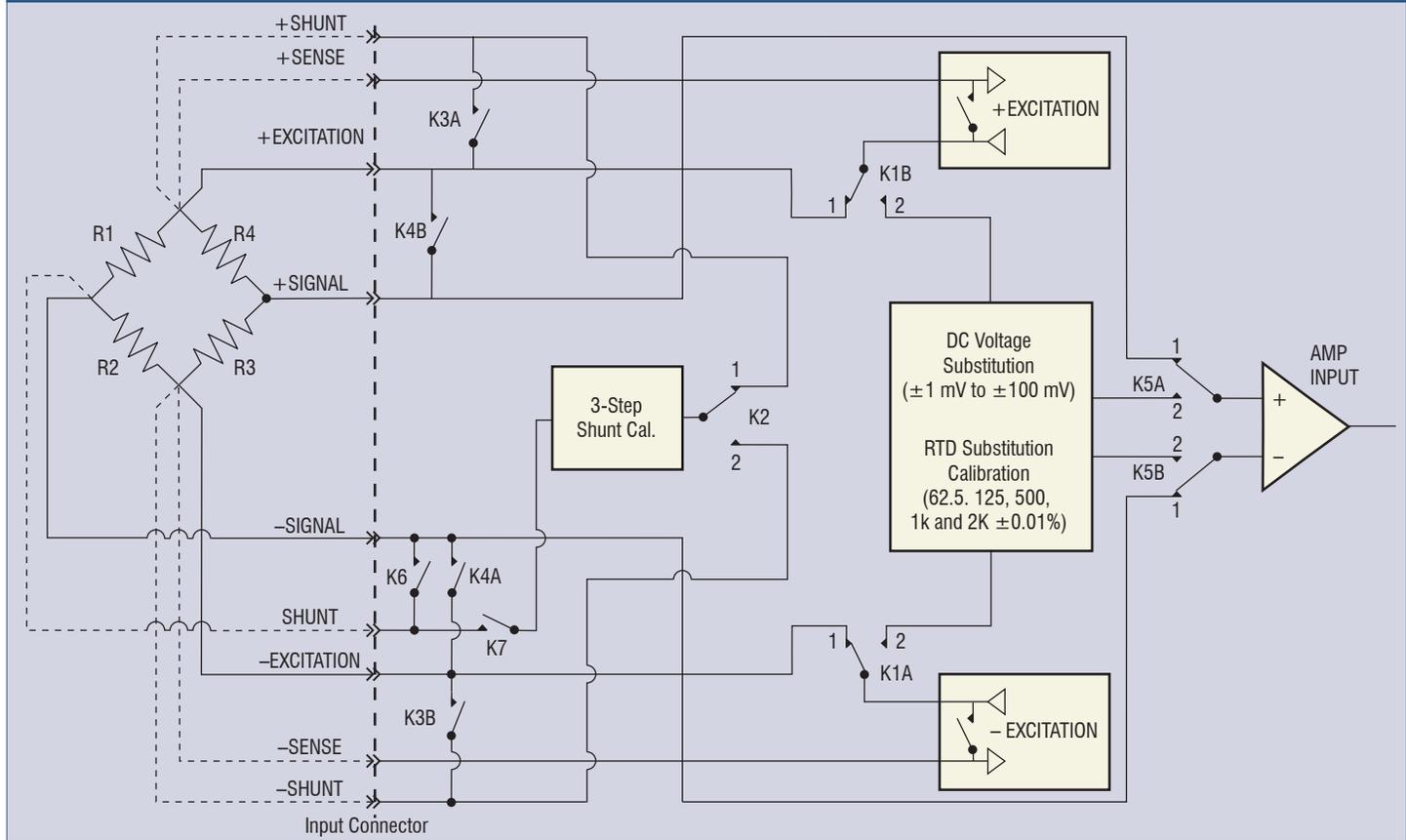
**Excitation Current Limit:** Current limit protection is provided by the 28144 excitation supply. Possible causes of current limit are an incorrect excitation setting or a shorted transducer. Current limit indicators are provided in the GUI.

**Excitation Thermal Shutdown:** The excitation supply regulator die temperature is continuously monitored and will shut down should the temperature reach a level where damage to the excitation supply may occur. Thermal shutdown indicators are provided in the GUI.



# 28144 Details and Specifications

Diagram with HC10 Bridge/RTD/Thermocouple Configuration Module

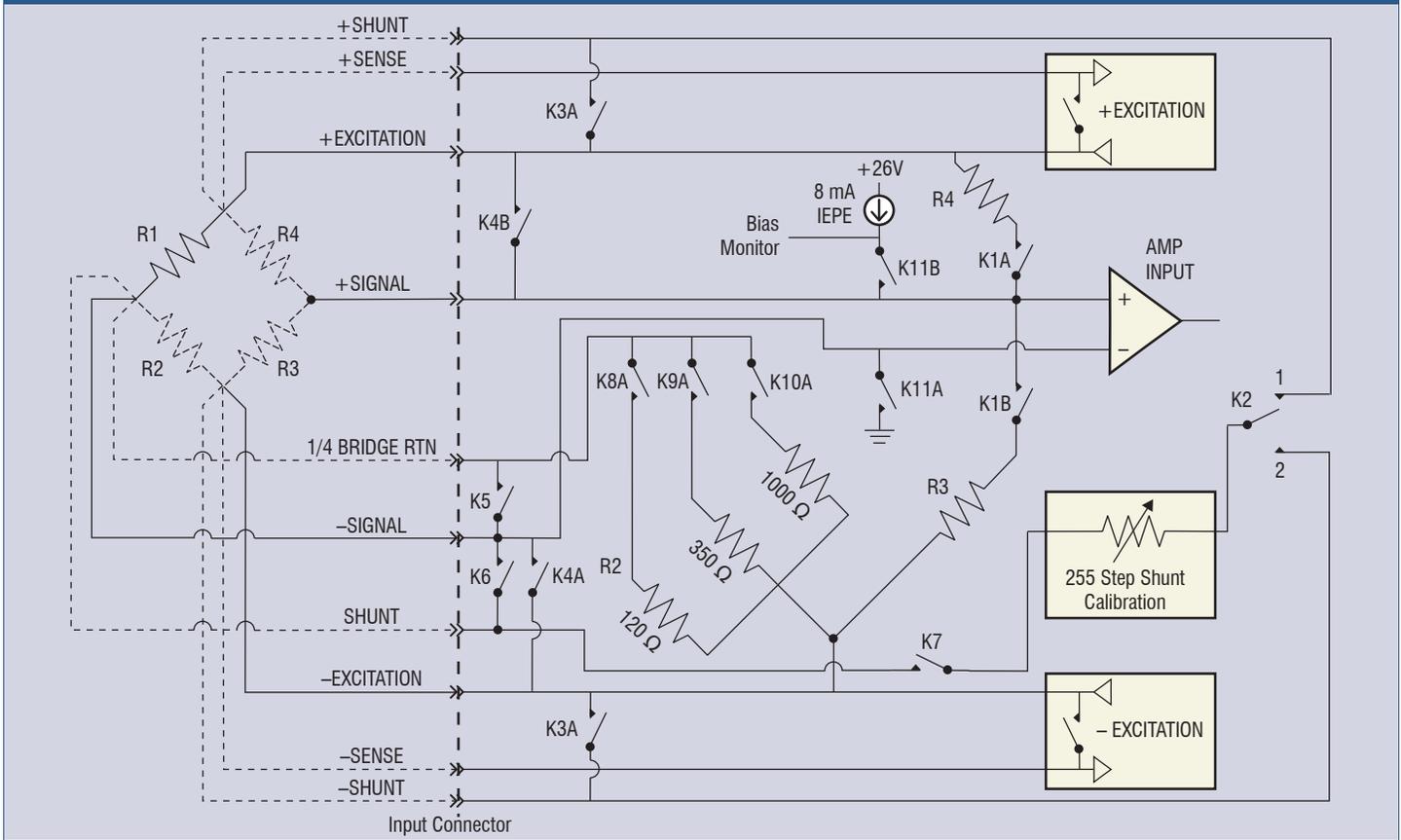


## Truth Table

Configuration	K1	K2	K3, K6	K4	K5	K7
Shunt Cal Gage	1		OUT		1	IN
Shunt Cal Instrument	1		IN		1	IN
Shunt R1	1	1			1	IN
Shunt R2	1	2			1	IN
Sensor RCAL	1				1	IN
Constant Current 2-Wire	1			IN	1	
Constant Current 4-Wire	1			OUT	1	
DC Voltage Substitution	2				2	
RTD Substitution	2				2	

28144 with HC10 Bridge Configuration Module

### Diagram with HC14 Bridge/Strain/IEPE Configuration Module



### Truth Table

Configuration	K1	K2	K3, K6	K4	K5	K7	K8	K9	K10	K11
¼ Bridge, 2-Wire	IN				IN		IN <sup>1</sup>	IN <sup>1</sup>	IN <sup>1</sup>	IN
¼ Bridge, 3-Wire	IN				OUT		IN <sup>1</sup>	IN <sup>1</sup>	IN <sup>1</sup>	IN
½ Bridge	IN						OUT	OUT	OUT	OUT
Full Bridge	OUT						OUT	OUT	OUT	OUT
120 Ohm Completion							IN	OUT	OUT	IN
350 Ohm Completion							OUT	IN	OUT	IN
1000 Ohm Completion							OUT	OUT	IN	IN
Shunt Cal Gage			OUT			IN				
Shunt Cal Instrument			IN			IN				
Shunt R1		1				IN				
Shunt R2		2				IN				
Constant Current 2-Wire				IN						
Constant Current 4-Wire				OUT						
8 mA IEPE Current Source	OUT		OUT	OUT	OUT	OUT				IN

<sup>1</sup> One switch selected at a time.

# 28144 Filter Characteristics

*You want your analog data to come clean before digital conversion.*

The 28144 Card has a variety of high performance filter characteristics available for HP, LP or BP Precision filtering.

## Flat/Pulse Low-Pass Filters

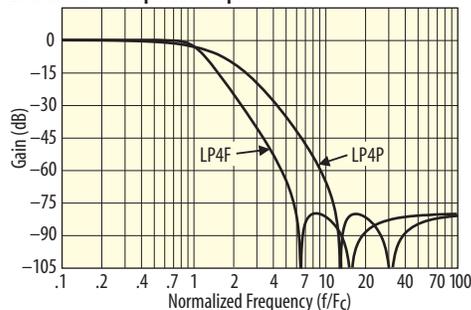
Our new choice of LP4FP 4-pole or LP8FP 8-pole flat/pulse low-pass filters provide the user with the versatility to address applications in either the time or frequency domain and are available on many 28000 card models. Frequencies can range as high as 204.6 kHz with fixed frequency choices for economy.

## Flat Mode Low-Pass Filters

Precision LP4F and LP8F "flat" mode characteristics are specified to have outstanding passband flatness equivalent to the Butterworth yet deliver very sharp roll-off characteristics.

The LP4F and LP8F are a good choice as an anti-aliasing filter and for applications such as spectral analysis. The LP8F has zero passband ripple and over 100 dB/octave attenuation slope.

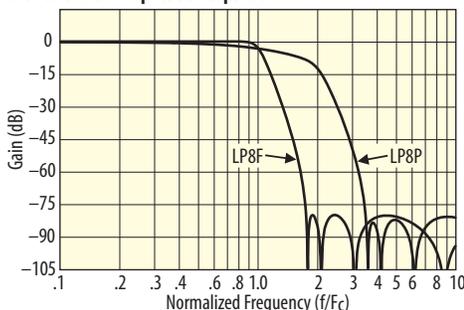
LP4F and LP4P Amplitude Response



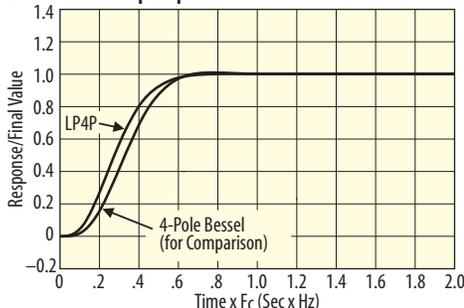
## Pulse Mode Low-Pass Filters

For the time domain, there are the LP4P and LP8P "pulse" mode low-pass filters. These filters have excellent transient response and phase linearity making them ideal filters for time domain applications including transient (shock) measurements and time domain waveform analysis ... all with roll-off characteristics superior to their Bessel filter counterparts.

LP8F and LP8P Amplitude Response



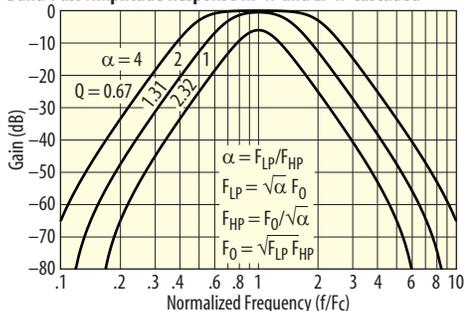
LP4P vs Bessel Step Response



## High-Pass and Band-Pass Filters

For high-pass filtering, we offer the HP4F 4-pole characteristics. For band-pass filtering, choose the HP4F/LP4FP band-pass characteristic to provide programmable bandwidth and center frequency filters.

Band-Pass Amplitude Response HP4F and LP4F Cascaded

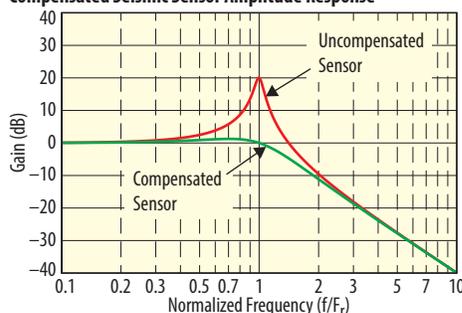


## REZCOMP Sensor Compensation

Patent pending REZCOMP™ technology extends the frequency response of accelerometers, pressure sensors and microphones in real-time with no need for data post-processing. Based on user entry of sensor Q and resonant frequency, REZCOMP extends usable sensor bandwidth by a factor of two or more.

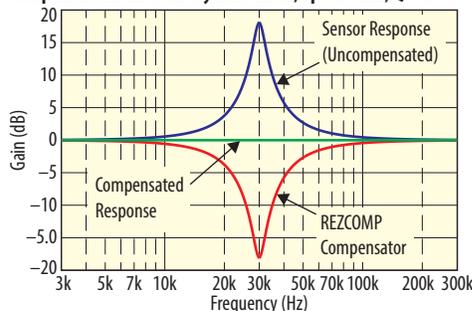
When applied to an accelerometer with Q of 10, REZCOMP extends useable 5% bandwidth by a factor of 5X as shown below.

Compensated Seismic Sensor Amplitude Response



The cavity resonant response caused by the protective screen of a microphone or a recess mount pressure sensor is reduced using REZCOMP technology.

Compensated Sensor Cavity Resonance,  $F_r = 30$  kHz,  $Q = 8$



## Traditional Filters

Of course, we offer the traditional filter types such as Butterworth and Bessel characteristics ... just ask!

In any case, we deliver to you a tightly controlled filter with phase match better than 1 degree and usually better than 0.5 degrees.

# 28144 Details and Specifications

## 28144 Filter Type Characteristics

### Option LP4FP:

4-pole, 4-zero low-pass filter.  
Programmable for maximally flat pass-band (LP4F) or linear phase with optimized pulse response (LP4P).

### Option LP8FP:

8-pole, 8-zero low-pass filter.  
Programmable for maximally flat pass-band (LP8F) or linear phase with optimized pulse response (LP8P).

### Option HP4F/LP4FP:

8-pole, 8-zero band-pass filter.  
Flat HP4F 4-pole, 4-zero high-pass filter cascaded with a 4-pole, 4-zero low-pass filter. Low-pass filter programmable for maximally flat pass-band (LP4F) or linear phase with optimized pulse response (LP4P).

### Option REZC/LP4FP:

REZCOMP<sup>®</sup> sensor compensation cascaded with LP4FP low-pass filter.

## Cutoff Frequencies:

### Flat Mode:

2 Hz to 2.046 kHz in 2 Hz steps  
2.2 kHz to 204.6 kHz in 200 Hz steps

### Pulse Mode:

1 Hz to 1.023 kHz in 1 Hz steps  
1.1 kHz to 102.3 kHz in 100 Hz steps

Note: Other filter types and cutoff ranges available upon request. Please consult factory.

## LP4F, LP4P, LP8F, LP8P:

### Amplitude Accuracy:

±0.1 dB max, DC to 0.8 Fc  
±0.2 dB max, 0.8 Fc to Fc (LP4P, LP4F)  
±0.25 dB max, 0.8 Fc to Fc (LP8P, LP8F)

### Amplitude Match:

±0.1 dB max, DC to 0.8 Fc  
±0.2 dB max, 0.8 Fc to Fc

### Phase Match:

±1° max, DC to 0.8 Fc  
±2° max, 0.8 Fc to Fc

## HP4F:

### Amplitude Accuracy:

±0.1 dB max, 1.2 Fc to 204.6 kHz  
±0.2 dB max, Fc to 1.2 Fc

### Amplitude Match:

±0.1 dB max, 1.2 Fc to 204.6 kHz  
±0.2 dB max, Fc to 1.2 Fc

### Phase Match:

±1° max, 1.2 Fc to 204.6 kHz  
±2° max, Fc to 1.2 Fc

## REZCOMP (Option REZC)

Sensor Compensation Q: 1 to 20 in 0.1 steps;  
20 to 50 in 0.5 steps

### Sensor Compensation Frequency (Fr):

**Low-Range:** 10 Hz to 2.55 kHz  
in 10 Hz steps

**Mid-Range:** 2.6 kHz to 51 kHz  
in 200 Hz steps

**High-Range:** 52 kHz to 255 kHz  
in 1 kHz steps

### Amplitude Accuracy:

#### Low-Range:

±0.1 dB DC to 0.8 Fr; 1.25 Fr ≤ f ≤ 10 kHz  
Q ≤ 10: ±0.2 dB; 0.8 Fr < f < 1.25 Fr  
Q > 10: ±0.02 dB \* Q; 0.8 Fr < f < 1.25 Fr

#### Mid-Range:

±0.15 dB DC to 0.8 Fr; 1.25 Fr ≤ f ≤ 100 kHz  
Q ≤ 10: ±0.25 dB; 0.8 Fr < f < 1.25 Fr  
Q > 10: ±0.025 dB \* Q; 0.8 Fr < f < 1.25 Fr

#### High-Range:

±0.2 dB; DC to 0.6 Fr;  
±0.5 dB; 1.7 Fr ≤ f ≤ 255 kHz  
Q ≤ 10: ±1.25 dB; 0.6 Fr < f < 1.7 Fr  
or 255 kHz whichever is less  
Q > 10: ±0.125 dB \* Q; 0.6 Fr < f < 1.7 Fr  
or 255 kHz whichever is less

### Phase Match:

±2°, DC to 0.8 Fr Low and Mid-Ranges;  
DC to 0.6 Fr High-Range

### Amplitude Match:

±0.2 dB, DC to 0.8 Fr Low and Mid-Ranges;  
DC to 0.6 Fr High-Range

Specification	LP4F Maximally Flat Low-Pass Filter	LP4P Constant Time Delay Low-Pass Filter	LP8F Maximally Flat Low-Pass Filter	LP8P Constant Time Delay Low-Pass Filter	HP4F Maximally Flat High-Pass Filter
Cutoff Frequency Amplitude	-3.01 dB	-3.01 dB	-3.01 dB	-3.01 dB	-3.01 dB
DC Gain	0.00 dB	0.00 dB	0.00 dB	0.00 dB	-80 dB
Stop-Band Frequency	5.9465 Fc	11.863 Fc	1.7479 Fc	3.4688 Fc	0.1682 Fc
Phase Distortion (DC to Fc)	< 31.8 deg	< 3.7 deg	< 102.0 deg	< 0.05 deg	-
Percent Overshoot	11.1%	0.5%	18.9%	1.1%	-
1% Settling Time	1.65/Fc	0.66/Fc	4.03/Fc	1.25/Fc	1.86/Fc
-0.1 dB Frequency	0.6348 Fc	0.1816 Fc	0.8527 Fc	0.1792 Fc	1.5753 Fc
-1 dB Frequency	0.8487 Fc	0.5742 Fc	0.9438 Fc	0.5685 Fc	1.1783 Fc
-3.01 dB Frequency	1.0000 Fc	1.0000 Fc	1.0000 Fc	1.0000 Fc	1.0000 Fc
-40 dB Frequency	2.9555 Fc	5.6932 Fc	1.4443 Fc	2.7556 Fc	0.3384 Fc
-80 dB Frequency	5.9465 Fc	11.8629 Fc	1.7479 Fc	3.4688 Fc	0.1682 Fc

# 28144 Details and Specifications

## 28144 Input Characteristics

### Type:

Balanced differential w/ programmable AC/DC input coupling

### Input Impedance:

10 M $\Omega$  //100 pF per side

### Max Level (AC + DC + Common Mode):

$\pm 10$  Vpk for  $f \leq 200$  kHz  
 $\pm 10$  Vpk x (200 kHz/f) for  $f > 200$  kHz

### Input Protection (Power On):

45 V continuous, 100 Vpk for 1 mS,  
10% duty cycle

### Offset Drift:

1  $\mu$ V/ $^{\circ}$ C, typical

### Noise:

9 nV/ $\sqrt{\text{Hz}}$  at 1 kHz and pre-filter gain  
>64, typical

### AC Coupling Frequency:

0.25 Hz ( 3.01 dB)

### CMRR (DC Coupled):

100 dB, DC to 440 Hz and input gain > x16

### CMRR (AC Coupled.):

80 dB, 10 Hz to 440 Hz

### Auto Bridge Balance Mode:

The bridge is automatically balanced using voltage insertion at the input amplifier when bridge balance mode is selected. The inserted voltage is derived from and tracks the excitation supply. A successive approximation A/D converter is used for rapid bridge balance.

### Range:

Bridge balance algorithm selects the most appropriate range to achieve balance with finest resolution.

### 32 mV/V Mode Auto-Balance Ranges:

$\pm 0.0002$  mV/V to  $\pm 0.5$  mV/V  
in  $\pm 0.244$   $\mu$ V/V steps  
 $\pm 0.502$  mV/V to  $\pm 4.0$  mV/V  
in  $\pm 1.95$   $\mu$ V/V steps  
 $\pm 4.016$  mV/V to  $\pm 32.0$  mV/V  
in  $\pm 15.625$   $\mu$ V/V steps

### 512 mV/V Mode Auto-Balance Ranges

(Gain limited to x512):  
 $\pm 0.004$  mV/V to  $\pm 8.0$  mV/V  
in  $\pm 3.9$   $\mu$ V/V steps  
 $\pm 8.03$  mV/V to  $\pm 64.0$  mV/V  
in  $\pm 31.25$   $\mu$ V/V steps  
 $\pm 65.25$  mV/V to  $\pm 512.0$  mV/V  
in  $\pm 250$   $\mu$ V/V steps

### Accuracy:

$\pm 0.1\%$  of setting  $\pm 0.1\%$  of F.S. range

### Stability:

$\pm 25$  ppm /  $^{\circ}$ C of setting

### Drift (RTI):

$\pm 0.3$   $\mu$ V /  $^{\circ}$ C for 32 mV/V range;  
 $\pm 5$   $\mu$ V /  $^{\circ}$ C for 512 mV/V range

### Auto Balance Time:

Less than 15 seconds per system of  
64 channels.

### Auto Suppress Mode:

Programmable DC offset derived from a precision 10 V reference is injected at the channel input stage to suppress the gage DC operating voltage. Supports manual or automatic suppression.

### 640 mV Suppress Ranges:

$\pm 0.005$  mV to  $\pm 10$  mV in  $\pm 4.9$   $\mu$ V steps  
 $\pm 10.04$  mV to  $\pm 80$  mV in  $\pm 39$   $\mu$ V steps  
 $\pm 80.31$  mV to  $\pm 640$  mV in  $\pm 312$   $\mu$ V steps

### 10.24 V Suppress Ranges

(Gain limited to x512):  
 $\pm 0.08$  mV to  $\pm 160$  mV in  $\pm 78$   $\mu$ V steps  
 $\pm 160.6$  mV to  $\pm 1.28$  V in  $\pm 625$   $\mu$ V steps  
 $\pm 1.285$  V to  $\pm 10.24$  V in  $\pm 5$  mV steps

### Accuracy:

$\pm 0.1\%$  of setting  $\pm 0.1\%$  of F.S. range

### Stability:

$\pm 25$  ppm /  $^{\circ}$ C of setting

### Drift (RTI):

$\pm 0.3$   $\mu$ V /  $^{\circ}$ C for 640 mV range;  $\pm 5$   $\mu$ V /  $^{\circ}$ C  
for 10.24 V range

### Auto Suppress Time:

Less than 15 seconds per system of  
64 channels.

### 5th Wire Input (Option 5):

Unity gain buffer for Kulite 5<sup>th</sup> wire sensor  
output

### Gain:

x1  $\pm 0.1\%$

### Input Impedance:

10 M $\Omega$

### Frequency Response:

Single-pole low-pass filter,  
-3 dB @ 114 Hz typical

## 28144 Amplifier Characteristics

### Pre-Filter Gain:

x1 to x512 in binary steps with overload  
detection (10.5 Vpk threshold)

### Post-Filter Gain:

x1/16 to x16 in binary steps with vernier  
adjustment

### Overall Gain: x1/16 to x8192

### Gain Resolution:

0.05% steps for POG  $\geq 0.5X$   
0.05%/POG for POG <0.5X

### DC Gain Accuracy:

0.01% typical, 0.1% maximum for  
POG  $\geq 0.5X$   
0.1%/POG maximum for POG <0.5X

### Stability:

$\pm 0.02\%$  for 6 months  
Temp Coef.:  $\pm 0.004\%/^{\circ}$ C

### DC Linearity:

$\pm 0.005\%$  re Fullscale, relative to the best  
straight line

### Frequency Response:

Two amplifier frequency response  
options are available. The standard  
500 kHz filtered amplifier response is  
recommended for SAR type ADC systems  
in order to reduce amplifier noise that  
folds into the Nyquist band. The wide-  
band option (opt. W) provides >1.5 MHz  
bandwidth and is recommended for ADC  
systems such as sigma delta type with  
built-in alias protection.

### Standard:

DC to 200 kHz, 0 dB  $\pm 0.1$  dB  
-3 dB typical @ 500 kHz

High Frequency Roll-off: 18 dB/octave

### Option W:

DC to 500 kHz, 0 dB  $\pm 0.2$  dB;  
-3 dB >1.5 MHz

## 28144 Test Modes

**Amplifier Short:** A switch at the amplifier  
input is utilized to ground the input stage for  
measurement of noise and DC offset.

**Test Bus:** Test input allows for injection of  
a test signal. An external test signal or the  
28000-?-TEST Test Subsystem may be con-  
nected at the rear panel.

**Shunt Cal:** Applies shunt to bridge.

### Excitation Monitor (Constant Voltage

**Mode Only):** The amplifier input is switched  
from the bridge to the excitation supply to  
monitor the excitation voltage at the ampli-  
fier output. Excitation monitor gain is x0.5.

**Excitation Off:** The excitation supply is pro-  
grammed to zero volts or zero mA.

### AC Current (Constant Current Mode Only):

An AC current is injected into the current loop  
to evaluate end-to-end system frequency  
response. The AC current is generated from a  
voltage waveform on the test bus.

**Sensitivity:** 100  $\mu$ Apk per V pk of test bus  
voltage; 5  $\mu$ Apk per V pk w/ option HC10.

**Bandwidth:** (350 ohm loop resistance at  
input connector): -5% at 50 kHz, typical.

## 28144 Output Characteristics

### Type:

DC coupled, single-ended output with ground sense

### Output Ground Sense:

Used for driving grounded single-ended loads. Output is referred to ground at the load. Output sense also reduces ground loop interference by providing a high impedance connection between the ground at the load and the output stage ground.

### Impedance:

Hi Output:  $10\ \Omega // 100\ \text{pF}$

Low Output (Sense Input):

$100\ \Omega // 100\ \text{pF}$  or ground via manual card switch.

### Max Output:

$\pm 10\ \text{Vpk}, \pm 25\ \text{mA pk}$

### Offset:

$< 5\ \text{mV}$  after auto-adjust at any gain setting

### Offset Drift:

$1\ \mu\text{V}/^\circ\text{C}, \text{RTI} + 150\ \mu\text{V} / ^\circ\text{C RTO}$

### Noise:

$2.8\ \mu\text{V rms RTI} + 60\ \mu\text{V rms RTO},$   
 $3\ \text{Hz to } 100\ \text{kHz}$

### Crosstalk:

$-90\ \text{dB}, \text{DC to } 100\ \text{kHz}$

### Output Monitor:

A switch at the output of each channel allows for multiplexed connection to the 28000 chassis output monitor bus BNC connector for viewing the channel output with an external device.

### 5th Wire Output (Option 5):

#### Type:

DC coupled, single-ended output

#### Impedance:

$10\ \Omega // 100\ \text{pF}$

#### Max Output:

$\pm 10\ \text{Vpk}, \pm 5\ \text{mApk}$

## 28144 General Characteristics

### 28144 Card Size:

$6.63 \times 17.5 \times 0.75$  inches

### Card Weight:

1.4 lb. net

### Temperature:

$0^\circ\text{C to } 40^\circ\text{C}$  (operating);

$-20^\circ\text{C to } 70^\circ\text{C}$  (storage)

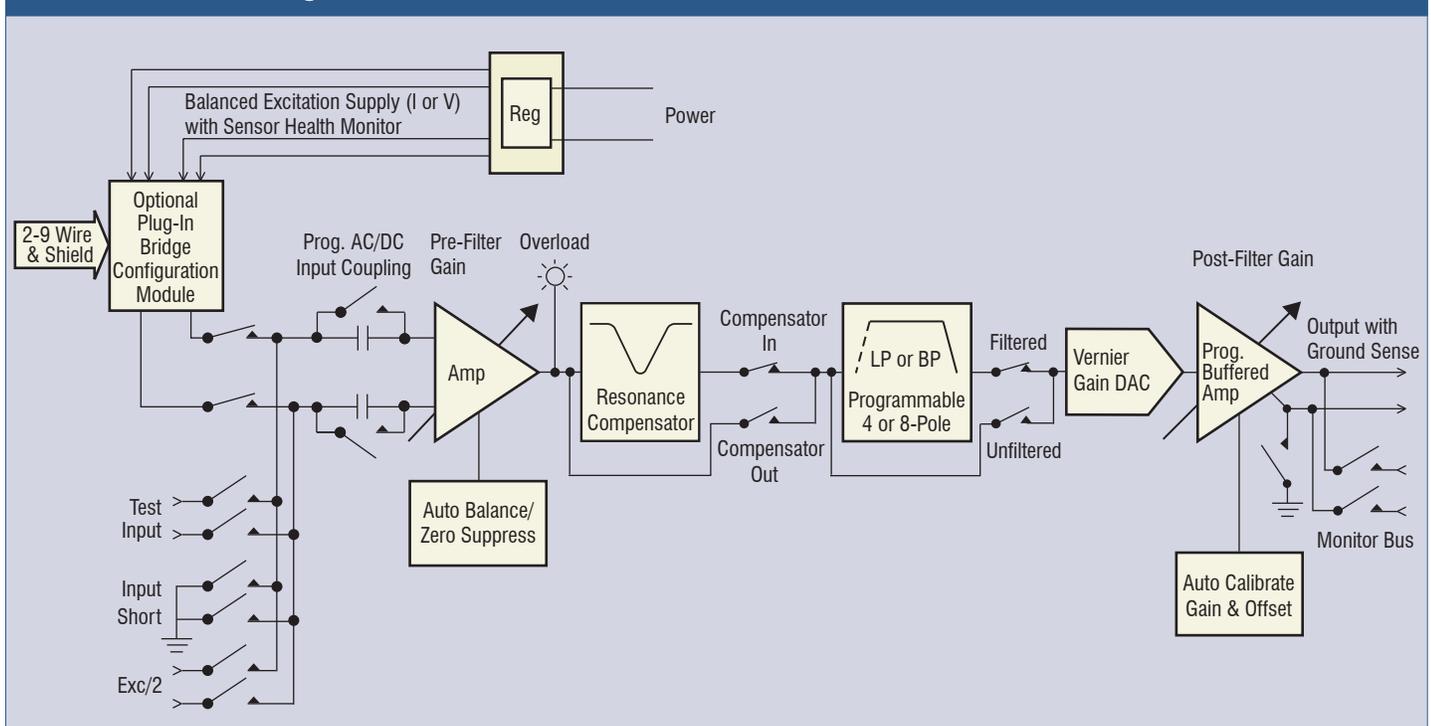
### Connectors:

The input connectors are integral to the 28144 card. Cutouts on the 28000 frames allow the input connector to pass through the backplane and to directly mate with the input cables.

Two 26-pin high-density D connectors are utilized for the 4 inputs (2 inputs per connector). Connectors have high quality machined gold plated pins/sockets.

28144 outputs are available on 50-pin D connectors that are integral to the 28000 System chassis. Three wires per output are provided to accommodate twisted/shielded cables.

28144 Channel Block Diagram



## Accessories

### Mating Connectors

Precision Filters mating connectors accommodate up to 22-AWG wire and are supplied with high quality metal backshells with strain relief and gold plated screw machined contacts for high reliability connections and long service life.

**CONN-IN-26D:** High-Density 26-pin D-shell mating output connector.

**CONN-IN-26D-SC:** High-Density 26-pin D-shell mating output connector with machined solder cup pins.

**CONN-OUT-26D:** High-Density 26-pin D-shell mating output connector with machined crimp pins.

**CONN-OUT-26D-SC:** High-Density 26-pin D-shell mating output connector with machined solder cup pins.

**CONN-I/O-50D-A:** 50-pin D-shell mating connector with machined crimp pins.

**CONN-I/O-50D-SC-A:** 50-pin D-shell mating connector with machined solder cup pins.

### Output Adapters

Measurement systems often require multiple outputs per signal conditioning channel or special functions such as a DC output in proportion to the AC signal level. These outputs may be routed to control systems, tape backup systems, auxiliary data acquisition systems, scope bays and other destinations.

28144 cards are fitted with front panel connectors which accept Precision output adapter modules. Adapters plug on to the front of the signal conditioner card and are secured to the card by two screws. The adapters provide one or two additional fully buffered outputs per channel or RMS to DC functionality.

**28000-RMS/DC4:** Quad RMS-to-DC Converter Module

**BUFF-4BNC/15D:** Quad Output Buffer with single output per channel on four BNC Connectors or one 15-Pin D Connector

**BUFF-4CH/(2)15D:** Quad Output Buffer with dual outputs per channel on two 15-Pin D Connectors

### Precision PF-1U-FA Multi-Channel Programmable Filter/Amplifier System



#### Exceptional desktop performance.

Ideal for conditioning low-level voltage inputs in front of high-resolution digital data acquisition systems. Fully programmable 8-channel and 16-channel configurations are available, both offering a choice of either 4 or 8-pole low-pass filters with programmable gain.

### High Density Programmable Switch Systems

Computer controlled analog signal switching replaces tedious manual patch panels.



### Precision 4164 64x64 Switch Matrix System

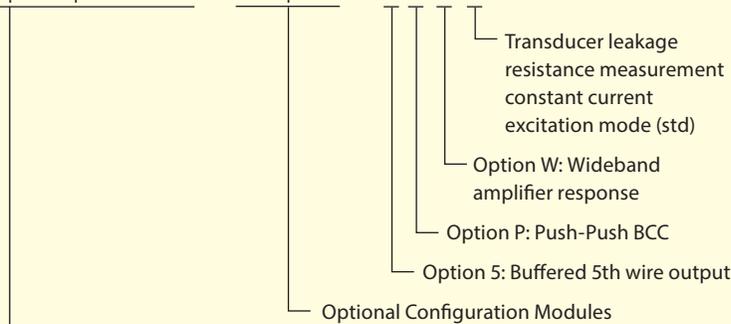


### Precision 464kC Switch Matrix System

Precision switch systems are reliable solid-state switch matrix systems, providing computer-controlled connection between input and output signals. Configure the 464kC with up to 256 inputs and 256 outputs, all in a single mainframe, or choose the compact 4164 system with 64 inputs and 64 outputs. Save time and reduce errors on test system setup. Download switch configurations from the host computer over the network. Built-in self-test with fault diagnostics.

## Ordering Information

28144-<LP4FP|REZC/LP4FP|LP8FP|HP4F/LP4FP>-<HC10|HC14>-<5, P<sup>3</sup>, W>L



Filter Specification:

- 4-pole low-pass (LP4FP)
- REZCOMP w/4-pole low-pass (REZC/LP4FP)
- 8-pole low-pass (LP8FP)
- 8-pole band-pass (HP4F/LP4FP)

### BC6, BC7, BC8, HC10, HC14 Optional Programmable Configuration Modules:

<sup>2</sup> Only one BC or HC module may be supported per 28144 card.

BC6, BC7 and BC8 are separately ordered plug-on modules that are automatically identified and controlled by the system. One module supports all four channels on the card.

HC10 and HC14 are factory installed configuration modules and are specified as an option for the 28144 card.

<sup>3</sup> Option P may not be ordered with option HC10.