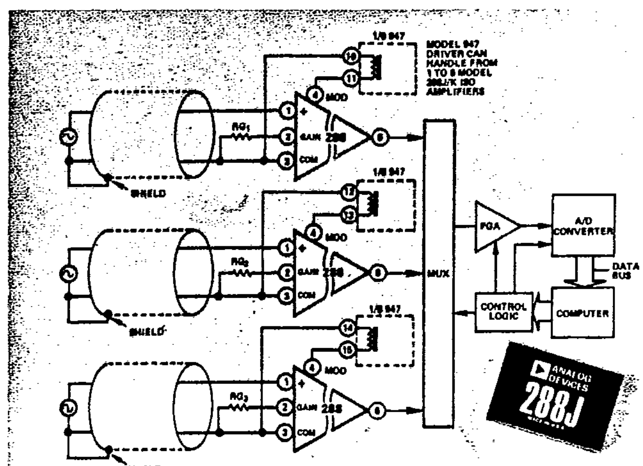
ANALOG DEVICES

Low Cost, High Accuracy, Synchronized Isolation Amplifier

MODELS 288, 947, 948

FEATURES
Low Cost: $28 (100's, 288J); $39 (1-24, 947)
Versatility: 3-Port Isolation
Multichannel
Adjustable Gain: 1 to 1,000V/V
Accuracy: Nonlinearity: 0.05% max (288K)
Low Gain Drift: 0.01%/°C max (288K)
Low Input Drift: 5μV/°C max (288K)
Single Supply Operation: +13.5V dc to +26V dc
High CMV Isolation: 850V dc

APPLICATIONS
Transient Voltage Protection: Data Acquisition Systems
Isolated 10-Bit D/A Converters
Ground Loop Elimination: Industrial Process Control
Process Signal Isolator
Off-Ground Measurements



3 CHANNEL ISOLATED DATA ACQUISITION SYSTEM

GENERAL DESCRIPTION

Model 288 is an economy isolation amplifier offering both high accuracy, 0.05% (model 288K), and a unique transformer isolated, multichannel design with separate signal and modulator/demodulator modules. Designed for low level, multichannel industrial instrumentation and control applications, this new design can be applied to achieve 4-channel, 3-port isolated systems, or low cost 8-, 16- or 32-channel systems with complete input/output isolation and channel/channel isolation.

Available in two high accuracy selections, this design features guaranteed low nonlinearity, 0.05% max (model 288K), 0.1% max (model 288J) and guaranteed low gain drift, 100ppm/°C max (model 288K), 300ppm/°C max (model 288J). The low drift bipolar input stage, 5μV/°C max (288K), 10μV/°C max (288J), provides gain adjustment from 1 to 1,000V/V with a single external resistor. Front-end differential protection (850V dc, continuous) combined with high CMV (850V dc, continuous) and high CMR (92dB min @ 60Hz) facilitates low level precision measurements in the presence of harsh RFI. Model 288J/K will interrupt ground loops, leakage paths and high voltage transients to ±850V pk, providing dc to 3.5kHz (−3dB @ G = 1V/V) response.

WHERE TO USE MODELS 288, 947, 948

Model 288 has been designed for multichannel data acquisition systems that have to handle dc sensor inputs such as thermocouples, strain gages and other low level signals in harsh industrial environments. Providing complete galvanic isolation and protection from line transients and fault voltages, model 288's low noise, high accuracy performance suggests applications such as process controllers, isolated 10-bit DAC's, current loop receivers, weighing systems, high CMV instrumentation and computer interface systems.

DRIVER MODEL SELECTION

Model 288 requires external modulator and demodulator drive signals. Model 947 and 948 are available for driving up to 8 model 288J/K isolation amplifiers.

Model 947 offers 8 separate isolated modulator drive outputs for applications where complete input-to-input isolation as well as input-to-output isolation is required. For example, a single model 947 could be combined with four model 288J/K to configure a 4-channel 3-port isolated system (see page 3).

Model 948 affords the same 850V dc input-to-output isolation for 1 to 8 model 288J/K isolation amplifiers with a common ground input reference as illustrated in Figure 1.

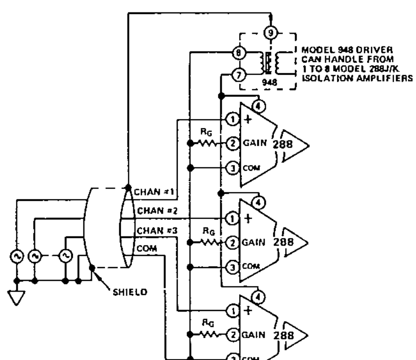


Figure 1. Application of Models 288/948 in Multichannel Data Isolation — (Note Common Signal Data Reference at Input)

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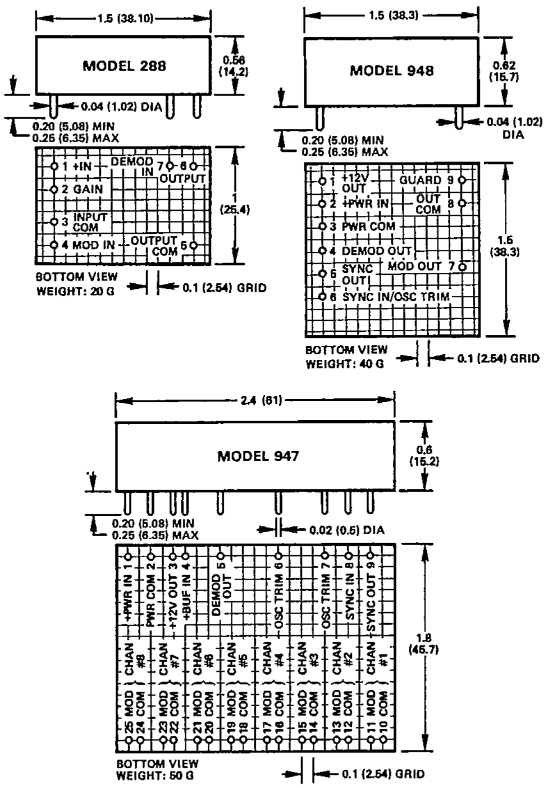
SPECIFICATIONS (typical @ +25°C over full range of power supply input unless otherwise noted, see note 1)

Model	288J	288K
GAIN (NON-INVERTING)		
Range (50kΩ Load)	1 to 1000V/V	
Gain Formula	Gain = 1 + 100kΩ/R_i(kΩ)	
Deviation from Formula	±4%	
vs. Temperature (0 to +70°C)[2]	±0.01%/°C typ, ±0.03%/°C max	±0.0035%/°C typ, ±0.01%/°C max
vs. Time	±0.001%/1000 hours	
Nonlinearity,[3] ±5V Output (G = 1 to 1000V/V)	±0.05% typ, ±0.1% max	±0.01% typ, ±0.05% max
INPUT VOLTAGE RATINGS		
Linear Differential Range, G = 1V/V	±5V min	
Safe Differential Input Voltage		
Continuous	240V rms max	
Pulse, 10ms Duration, 1 Pulse/sec	±400V pk max	
CMV, Inputs to Outputs		
ac, 60Hz, One Minute Duration	750V rms	
Continuous, ac or dc	±850V pk max	
CMR, Inputs to Outputs, 60Hz, $R_S \leqslant 1k$		
Balanced Source Impedance	100dB	
1kΩ Source Impedance Imbalance	92dB min	
Leakage Current, Inputs to Outputs @ 115V ac, 60Hz	5.0µA rms max	
OFFSET VOLTAGE, REFERRED TO INPUT		
Initial, @ +25°C (Adjustable to zero)		
Gain = 500V/V	±0.5mV typ, ±1mV max	±0.1mV typ, ±0.5mV max
Gain = 1 to 1000V/V	±(1.0 + 50/G)mV max	±(0.5 + 30/G)mV max
vs. Temperature (0 to +70°C)		
Gain = 500V/V	±5µV/°C typ, ±10µV/°C max	±2µV/°C typ, ±5µV/°C max
Gain = 1V/V	±250µV/°C typ, ±500µV/°C max	±100µV/°C typ, ±300µV/°C max
Gain = 1 to 1000V/V	±(10 + 500/G)µV/°C max	±(5 + 300/G)µV/°C max
vs. Supply Voltage	$\pm\left(20 + \frac{500}{G}\right)\mu V/V$	
INPUT BIAS CURRENT		
Initial, @ +25°C	±25nA max	
vs. Temperature (0 to +70°C)	±0.1nA/°C	
INPUT IMPEDANCE		
Differential	10^8Ω‖70pF	
Overload	200kΩ	
Common Mode	10^8Ω‖30pF	
INPUT NOISE		
Voltage, Gain = 500V/V		
0.01Hz to 10Hz	1.5µV p-p	
10Hz to 1kHz	0.8µV rms	
Current		
0.01Hz to 10Hz	5pA pk-pk	
FREQUENCY RESPONSE		
Small Signal Bandwidth, -3dB		
Gain = 500V/V	400Hz	
Gain = 1V/V	3.5kHz	
Full Power Response, 10V pk-pk Output		
Gain = 500V/V	400Hz	
Gain = 1V/V	2.0kHz	
RATED OUTPUT		
Voltage, 50kΩ Load	±5V min	
Output Impedance	1kΩ	
Output Ripple, 1MHz Bandwidth	2mV pk-pk	
POWER SUPPLY[4]		
Voltage Range, Rated Performance	+13.5V dc to +26V dc	
Current, Quiescent, Model 947	+23mA @ V_S = +15V dc	
Current, Quiescent, Model 948	+15mA @ V_S = +15V dc	
TEMPERATURE RANGE		
Rated Performance	0 to +70°C	
Operating	-25°C to +85°C	
Storage	-55°C to +85°C	
PACKAGE SIZE	1.0" X 1.5" X 0.56"	
PRICE		
(1–24)	$39	$49
(100's)	$28	$35

NOTES:
[1] Specifications apply using either model 947 or model 948 mod/demod drive.
[2] Gain temperature drift is specified as a percentage of output signal level.
[3] Gain nonlinearity is specified as a percentage of output signal span.
[4] Power supply voltage ratings refer to models 947 or 948 mod/demod modules.
Specifications subject to change without notice.

OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).



SPECIFICATIONS (typical @ +25°C over full range of power supply input unless otherwise stated)

Model	947(948)
OUTPUT	
Frequency	100kHz ±5%
Waveform	Squarewave
Voltage	
Mod Drive	22V p-p (18V p-p)
Demod Drive	22V p-p (18V p-p)
Fan-Out[1,2]	8
POWER SUPPLY	
Voltage, Rated Performance	+13.5V dc to +26V dc
Current, Quiescent @ +15V dc	
No Load	+23 (+15)mA
Full Load[3]	+40 (+32)mA
TEMPERATURE	
Rated Performance	0 to +70°C
Operating	-25°C to +85°C
Storage	-55°C to +85°C
CASE SIZE	2.4" X 1.8" X 0.6" (1.5" X 1.5" X 0.62")
PRICE	
(1-24)	$39($29)
(25-49)	$38($28)
(50-99)	$36($27)

NOTES
[1] Model 288J/K Mod Input and Demod Input represent unity load.
[2] For applications requiring more than eight 288's, additional 947's or 948's may be used in a master/slave mode. Refer to Figure 5.
[3] Full load consists of eight model 288's and a driver module (either 947 or 948).
Specifications subject to change without notice.

ORDERING GUIDE

Model	Type	Socket	1–24	25–49	50–99	100
288J	Iso Amp	AC-1055	$39	$35	$32	$28
288K	Iso Amp	AC-1055	$49	$45	$40	$35
947	Driver	AC-1056	$39	$38	$36	$35
948	Driver	AC-1057	$29	$28	$28	$25

Applying the Multi-Channel Isolation Amplifier

GUIDELINES ON INTERCONNECTION TECHNIQUES

To preserve the high CMR performance of model 288, care must be taken to keep the capacitance balanced about the input terminals. Best CMR performance will be achieved by using twisted shielded cable to reduce inductive and capacitive pickup. To reduce the effective cable capacitance, the cable shield should be connected to the common mode signal source by connecting the shield as close as possible to the signal low. To reduce capacitive coupling from input to output, dress all leads from the driver modules, models 947 or 948, short at the connection terminals and reduce the area formed by these leads. Input and output signal leads should be dressed away from the driver signals, demod and mod. Input leads should not be twisted together to reduce crosstalk noise.

BASIC INTERCONNECTION – MODELS 288, 947 AND 948

4-CHANNEL 3-PORT ISOLATED SYSTEM

Figure 2 illustrates the basic interconnection between model 288J/K and 947 to provide a 4-channel system with 3-port isolation. Total isolation exists between the input signal commons, the output signal commons and the power supply common. The model 947 provides two separate isolated drive signals for each 288 signal channel. Independent gain setting of each channel, from 1V/V to 1,000V/V, is available. To achieve the highest CMR performance, the input/output driver leads must be dressed to minimize capacitive cross-talk.

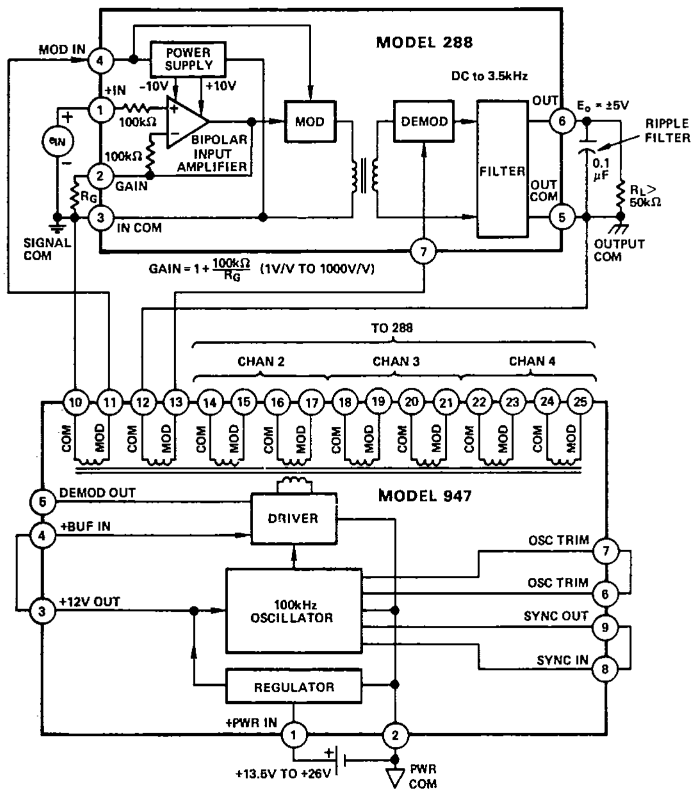
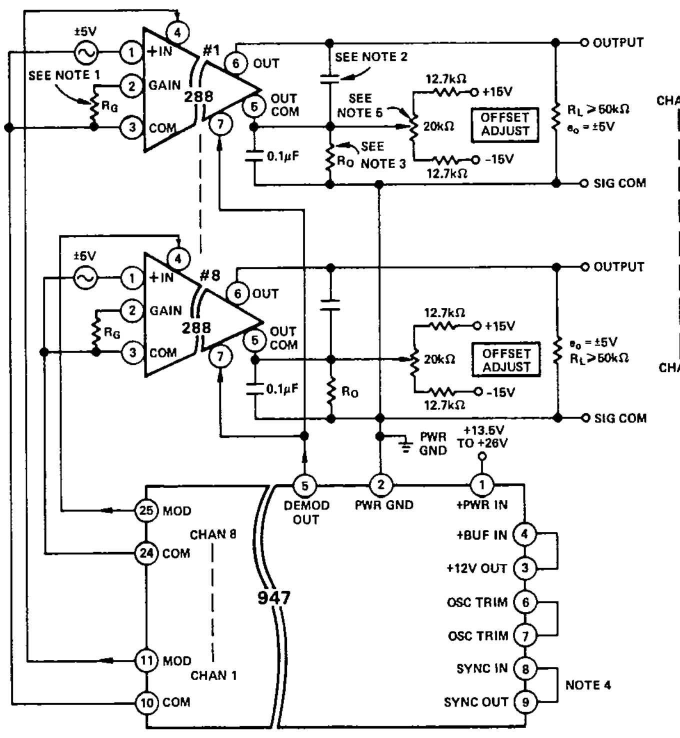


Figure 2. 4-Channel, 3-Port Isolated System

8-CHANNEL SYSTEM – MODELS 288 AND 947

Figure 3 illustrates the basic interconnection between a single model 947 and up to eight model 288 isolation amplifiers to provide complete input-to-output isolation as well as channel-to-channel isolation at the input. Each channel output is referenced to a common power supply ground. Offset voltage trimming is also provided for each channel. When offset voltage trimming is not required, the output common, pin 5, should be connected to the power common.



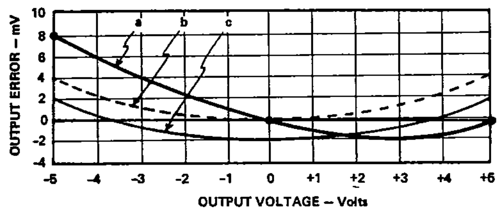
NOTES:
1. GAIN FORMULA = 1 + 100kΩ/R_G (kΩ).
2. TO ROLL OFF NOISE AND OUTPUT RIPPLE, USE BANDWIDTH FORMULA f(-3dB) = 1/2πC(1kΩ).
3. FOR GAINS = 1 TO 100V/V, R_O=200Ω; FOR GAINS = 100 TO 1000V/V, R_O = 1kΩ.
4. SEE DRIVER SYNCHRONIZATION, PAGE 4, FOR SYSTEMS WITH MORE THAN 8 CHANNELS.
5. OFFSET ADJUSTMENT POT SHOULD BE 10 OR 20 TURN CERMET TYPE.

Figure 3. 8-Channel System

GAIN AND OFFSET TRIM PROCEDURE

In applying model 288, highest accuracy is achieved by adjustment of gain and offset voltage to minimize the peak output error over the operating output voltage span. A calibration technique illustrating how to minimize the output error is shown below. In this example, model 288K is operating over an output span of +5V to −5V and a gain of 100V/V.

1. Apply $E_{IN} = 0$ volts and adjust R_O for $E_O = 0$ volts.
2. Apply $E_{IN} = +0.05V$ dc and adjust R_t for $E_O = +5.000V$ dc.
3. Apply $E_{IN} = -0.05V$ dc and measure the output error (see curve a).
4. Adjust R_t until the output error is one half that measured in step 3 (see curve b).
5. Apply $E_{IN} = +0.05V$ dc and adjust R_O until the output error is one half that measured in step 4 (see curve c).



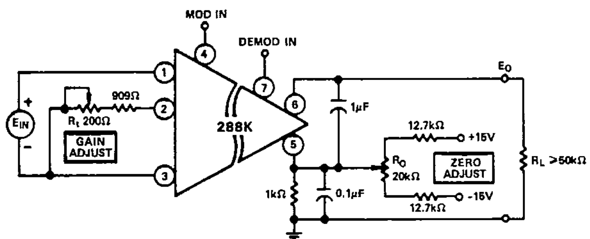


Figure 4. Gain and Offset Adjustment

APPLICATION IN DATA ACQUISITION SYSTEMS HAVING MORE THAN 8 CHANNELS

Driver Synchronization: A single model 947 or model 948 driver can be applied in systems having from 1 to 8 data channels, as shown in Figures 3 and 10. Additional model 947's and 948's may be driven in a slave-mode, as shown in Figure 5, to expand the total system channels from 8 to virtually any number of channels.

Optional Oscillator Adjustment: Models 947 and 948 provide the user with a method to trim the internal 100kHz oscillator over a range of ±5% (95kHz to 105kHz). This feature may be used when an external noise is "beating" with the 100kHz oscillator and a small trim adjustment of the oscillator frequency will eliminate the resulting noise frequency. As shown in Figure 5, a trim adjust, R_t, is installed between the OSC TRIM terminals. No specification changes occur when this trim adjustment is employed.

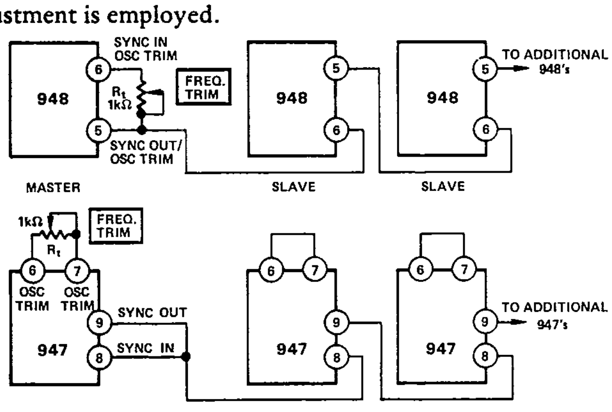


Figure 5. Model 948 and 947 Connections for Systems with Greater than 8 Channels

Selecting Bandwidth: In low frequency signal measurements, such as thermocouple temperature measurements, strain gage measurements and geophysical instrumentation, an external filter is used to select bandwidth and minimize output noise. As shown in Figure 6a, a capacitor connected between the OUT and OUT COM terminals will result in model 288's bandwidth set according to the following: $f(-3dB) = \frac{1}{2\pi C(1k\Omega)}$. For lowest noise performance, the filter capacitor should be located as close to the actual load as possible.

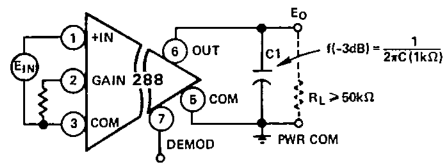


Figure 6a. Selecting Bandwidth with External Capacitor (C)

When used with a buffer amplifier as shown in Figure 6b below, a series resistor (R_S) is used to lower the effective value of the filter capacitor required to achieve very low frequency (under 200Hz) noise filtering.

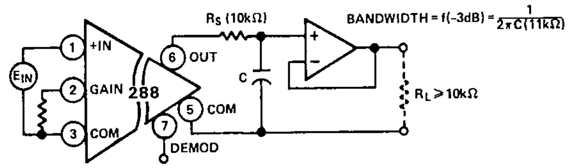


Figure 6b. Selecting Bandwidth with External Capacitor and Buffer

An active filter, as illustrated in Figure 6c will significantly improve 60Hz noise reduction at the output by providing a sharp rolloff characteristic. The 5Hz 3-pole active filter design illustrated in Figure 6c, will increase the 60Hz noise reduction by 50dB. Overall CMR performance of model 288 and the 5Hz active filter approaches 140dB @ 60Hz and 1kΩ imbalance.

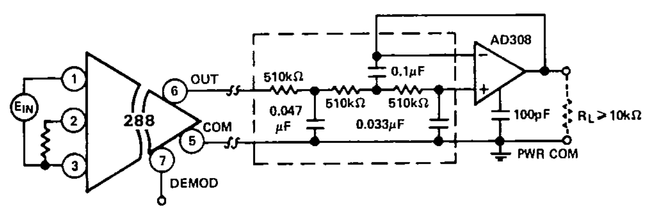


Figure 6c. Selecting Bandwidth with a 3-Pole 5Hz Active Filter

Noise Reduction in Data Acquisition Systems: In multichannel data acquisition systems using a multiplexer to select sequentially the channel for A/D conversion, a filter can be easily applied to reduce the input noise and select the channel bandwidth. As illustrated in Figure 7, a single 3-pole active filter is inserted at the mux output.

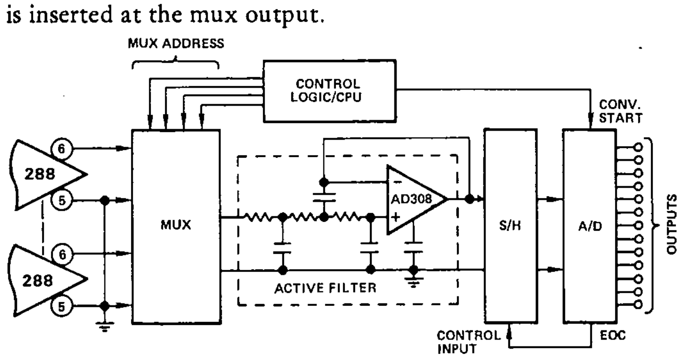


Figure 7. Applying Active Filter in Isolated Data Acquisition System to Select Bandwidth, Reduce Input Noise to A/D Converter and Increase CMR to 140dB @ 60Hz

Applications for the Multi-Channel Isolation Amplifier

ISOLATED 10-BIT D/A CONVERTER WITH 4/20mA CURRENT LOOP OUTPUT

The versatility of models 288/947 for industrial process control applications is illustrated in Figure 8. A low cost 10-bit CMOS D/A converter, model AD7533, is combined with models 288K/947 to provide an isolated 4/20mA current loop D/A converter to drive remote actuators. The 850V dc isolation provided by model 288K protects the microprocessor interface from power-line switching spikes and other voltage transients introduced in the remote cabling to the process control actuators.

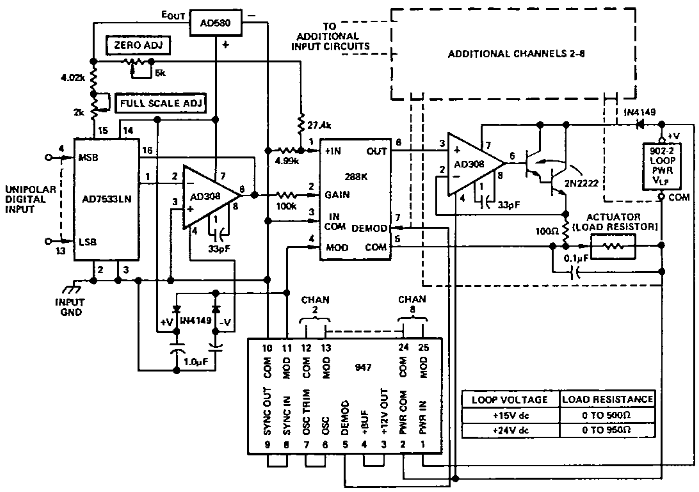


Figure 8. 10-Bit DAC with 4/20mA Output

The 947 driver module provides drive signals for both the 288K isolator as well as a power supply rectifier/filter circuit. Sufficient power is available to handle the D/A converter, voltage reference and the D/A converter output amplifier. The 947 and 288K isolated outputs are referenced to a floating loop power source (V_{LP}) which can be set from +15V dc to +24V dc. With a loop power of +24V dc the load range is 0 to 950 ohms. A series diode protects the model 288K output current stage in the event loop power polarity is accidently reversed. The 947 driver module has internal protection for accidental power reversal.

A total of 8 isolated channels can be configured using a single loop power source, 8 model 288K channels and a single model 947. Each 4/20mA current loop will add an additional 20mA to a single 288K channel—thus the maximum loop power required for eight channels is 200mA. Each input will be isolated from the loop power common as well as from each input common. In this manner, a total of eight isolated 10-bit D/A converters, with 4/20mA output drive capability and a single loop power source of +15V dc to +24V dc, is easily configured.

FRONT-END SIGNAL CONDITIONING USING ISOLATED POWER

To provide the capability to interface source impedances greater than 10k, a high impedance buffer amplifier, as illustrated in Figure 9 can be used. The modulator drive signal is applied to a rectifier/filter circuit to generate isolated dual voltages for powering the front-end buffer. In applications where additional isolated power is required, a separate modulator drive signal can be used to provide dual 12V dc @ ±2.5mA output capability. This approach eliminates the need for a separate isolated dc/dc converter for powering front-end signal conditioning circuits.

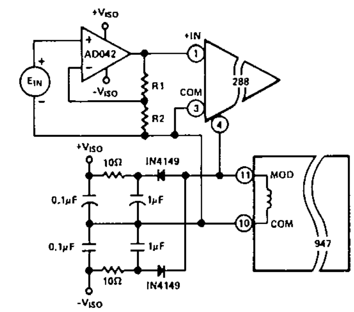


Figure 9. Developing Isolated Dual 12V dc for Powering Front-End Signal Conditioning Circuitry

ISOLATED INSTRUMENTATION AMPLIFIER

To interface low level, differential signals from bridge type sensors, two model 288 units can be connected as shown in Figure 10 to provide a true differential, high accuracy isolated instrumentation amplifier. Gain is set using a single resistor, R_G, as shown. Using a single 947 driver, up to four isolated channels can be configured. The output 47k resistors are contained in a single thin-film network chip, reducing cost and circuit density. Gain is programmable from 1 to 1,000V/V.

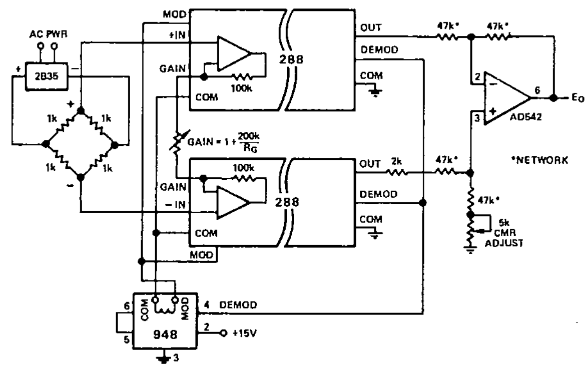


Figure 10. Floating Instumentation Amplifier

ISOLATED TEMPERATURE MEASUREMENTS

Industrial temperature measurements are often performed in harsh environments where accidental line voltages can be impressed on the temperature sensor. To provide protection for the delicate recording instrumentation, model 288 can be applied as shown in Figure 11. The AD590 is a temperature sensor whose output is a current directly proportional to absolute temperature. The 288/947 provides the isolated power (+12V dc) as well as the input/output isolation. Zero calibration is performed by placing the AD590 probe at a zero temperature bath and adjusting R_O for E_O to 0 Volts. Full scale output is performed by placing the AD590 probe in boiling water (100°C) and adjusting R_S for 1.000V output.

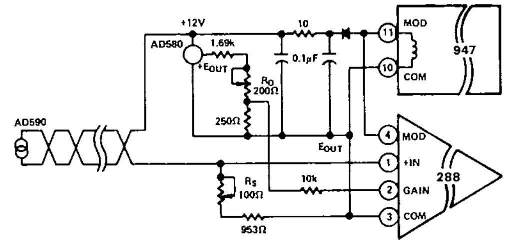


Figure 11. Isolated Temperature Measurements

PERFORMANCE CHARACTERISTICS

Gain Nonlinearity: Linearity error is defined as the peak deviation of the output voltage from the best straight line and is specified as a % of the peak-to-peak output voltage span; e.g., ±0.05% @ 10V p-p output = ±5mV max RTO linearity error. Model 288 is available in two nonlinearity selections; ±0.05% (288K) and ±0.1% (288J)—max over the 10V p-p output span. The curves of Figure 12 illustrate typical linearity error over the 10V p-p (±5V) output span. At output levels less than 5V p-p (±2.5V), linearity error is typically less than ±0.025% for both models 288J and 288K.

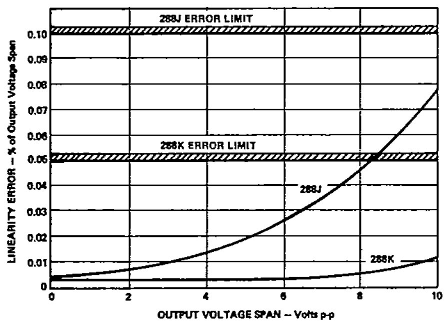


Figure 12. Gain Linearity Error vs. Output Voltage

Common Mode Rejection: Input-to-Output CMR is dependent on source impedance imbalance, signal frequency and amplifier gain. CMR is rated at 115V ac, 60Hz and 1kΩ imbalance at a gain of 1V/V. Figure 13 illustrates CMR performance as a function of signal frequency and gain. CMR approaches 130dB at dc with source imbalances as high as 1kΩ in the INPUT COMMON lead (worst case condition).

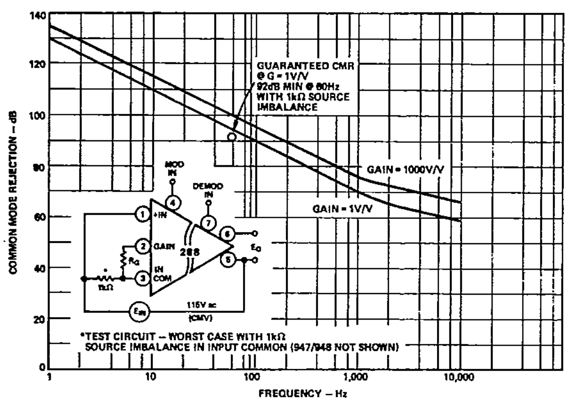


Figure 13. Common Mode Rejection vs. Frequency

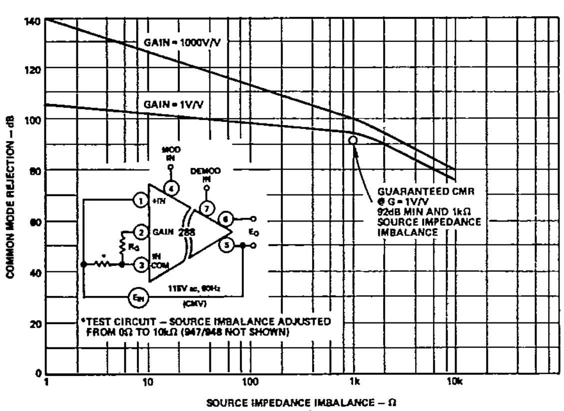


Figure 14. CMR vs. Source Impedance Imbalance

Figure 14 illustrates the effect of source imbalance on CMR performance at 60Hz and gains of 1V/V and 1,000V/V. CMR is typically 140dB at 60Hz, gain of 1,000V/V and a balanced source. CMR is maintained greater than 70dB for source imbalances up to 10k ohms.

Input Offset Voltage Drift: Model 288 is available in two drift selections: 5μV/°C (288K) and 10μV/°C (288J)—max, RTI, G = 500V/V. Total input voltage drift is composed of two sources (input and output stage drifts) and is gain dependent. The curves of Figure 15 illustrate the worst case total input drift (RTI) over the gain range of 1 to 1,000V/V.

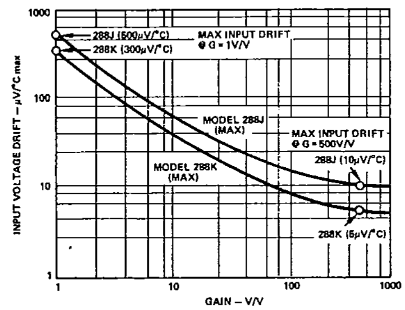


Figure 15. Max Input Offset Voltage Drift vs. Gain

Input Voltage Noise: Voltage noise, referred to input (RTI), is dependent on gain and bandwidth as illustrated in Figure 16. Rms voltage noise is shown in a bandwidth from 0.01Hz to the frequency shown on the horizontal axis. The noise in a bandwidth from 0.01Hz to 10Hz is 1.5μV p-p at a gain of 500V/V. This value is derived by multiplying the rms value at f = 10Hz shown in Figure 16 (0.22μV rms) by 6.6.

For lowest noise performance, a low pass filter at the output should be used to selectively roll-off noise and undesired signal frequencies beyond the bandwidth of interest (see Figure 6).

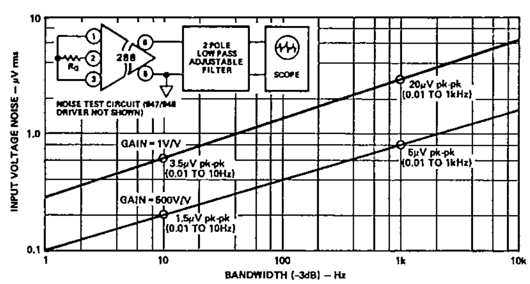


Figure 16. Input Voltage Noise vs. Bandwidth

Frequency Response: Small signal bandwidth and full power bandwidth versus gain are shown in Figure 17. For gains greater than 100V/V, both bandwidths are identical and approach 200Hz at G = 1000V/V. Full power response is measured with the output set at 10V p-p; small signal bandwidth (-3dB) is measured with the output set at 100mV p-p.

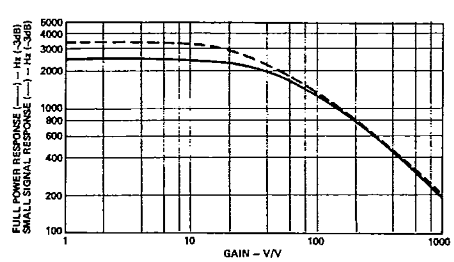


Figure 17. Full Power and Small Signal Bandwidth vs. Gain

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