ISOLATING AMPLIFIERS

Until recently, isolating amplifiers were generally accessible to professional engineers only. These integrated circuits, widely used in laboratory and industrial measuring instruments, were simply too expensive for amateurs. Now, Burr Brown have available a series of isolating devices that, without any relaxation of specification, are available at prices that are affordable for most.

An isolating amplifier, as its name suggests, is a circuit between whose input and output no electrical connection exists (at least in theory). Normally, such a device consists of an input amplifier, a modulator, an isolating barrier, and a demodulator with a voltage follower at the output. The signal paths in the input and output sections are electrically fully isolated from each other. An important feature of an isolating amplifier is that it has a completely floating input, which helps eliminate cumbersome connections to source ground.

Fundamentals

The block diagram of a typical isolating amplifier is shown in Fig. 2. The input section may take one of many forms from a complete instrumentation amplifier with programmable gain to a simple impedance converter that uses only one input pin.

The signal at the output of the input section is superimposed on to an HF carrier to enable it being transferred across the inductive or capacitive isolating barrier.

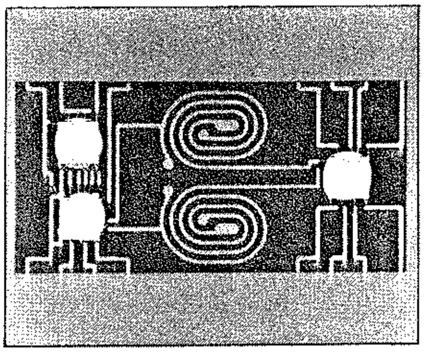

Fig. 1 Capacitive isolating barrier.

There are isolating amplifiers with an optical barrier. These devices do not need a modulator or (external) low-pass filters for reducing the modulation residue at the output.

Of the three types of isolating barrier already mentioned, inductive, capacitive and optical, the inductive one is the oldest and most widely used. Although it has not the bandwidth of the less expensive optical type, it has some important advantages: a very high isolating voltage (up to 8 kV) and great accuracy (see later).

The barrier of a typical capacitive type is shown in Fig. 1. The two spirals in the centre form the 1 pF coupling capacitors to which the modulated signal is applied in push-pull. Since the capacitors and the two signals are of equal value, the resultant sum signal is zero. This is vital as otherwise energy might be transferred from the input to the output, which would manifest itself as interference. This technique affords good bandwidth without detriment to the precision of operation or the maximum isolating voltage.

Theory of operation

The description that follows is based on Burr-Brown's Type ISO 122P isolating amplifier. This device uses an input and an output section that are galvanically isolated by matched 1 pF isolating capacitors built into the plastic package. The input is duty-factor modulated and transmitted digitally across the barrier

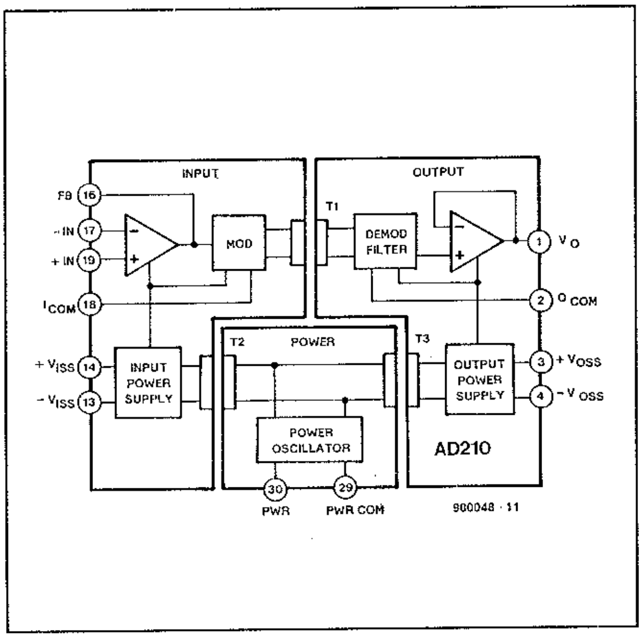

Fig 2. Block diagram of a typical isolating amplifier

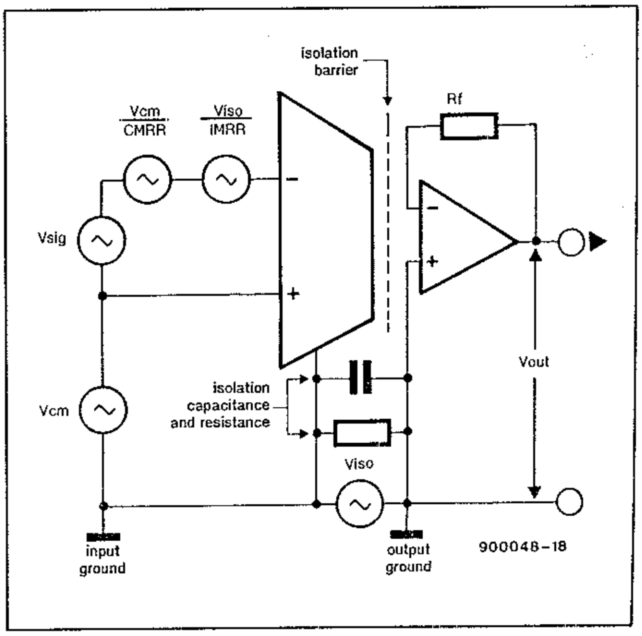

Fig 3 The isolating voltage exists between the two earths

The output section receives the modulated signal, converts it back to an analogue voltage and removes the ripple component inherent in the demodulated signal.

The input and output sections are laser trimmed for accurate circuit matching, after which they are mounted at opposite ends of the package with the isolating capacitors mounted between the sections.

Modulator The input amplifier, A1 in Fig. 4, integrates the difference between the input current (V_{in}/200 kΩ) and a switched ±100 μA current source. This current source is implemented by a switchable 200 μA source and a fixed 100 μA current sink.

To understand the basic operation of the modulator, assume that V_{in} = 0.0 V. The integrator will ramp in one direction until the comparator threshold is exceeded. The comparator and sense amplifier will force the current source to switch; the resultant signal is a triangular waveform with a 50% duty factor. The internal oscillator forces the current source to switch at a frequency of 500 kHz. If V_{in} changes, the duty factor of the integrator will change to keep the average d.c. value at the output of A1 near zero volts.

Demodulator The sense amplifier drives a switched current source into integrator A2. The output stage balances the duty-factor modulated current against the feedback current through the 200 kΩ feedback resistor, resulting in an average value at the V_{out} pin equal to V_{in}. The sample and hold amplifiers in the output feedback loop serve to remove undesired ripple voltages inherent in the demodulation process.

Signal and power connections Each power supply pin should be bypassed with 1 μF tantalum capacitors located as close to the amplifier as possible. The frequency of the modulator/demodulator is set at 500 kHz by an internal oscillator. Therefore, if it is desired to minimize any feedthrough noise (beat frequencies) from a d.c./d.c. converter, use a pie filter on the supplies as shown in Fig. 5.

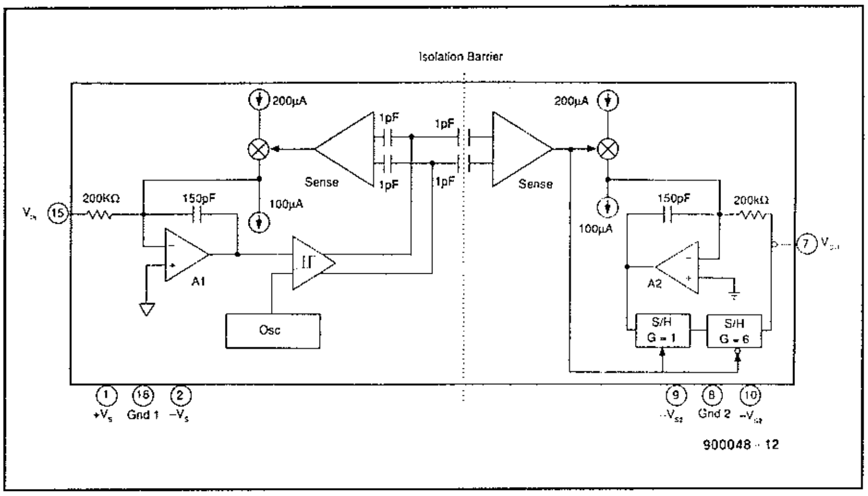

Fig. 4. Block diagram of the ISO 122P.

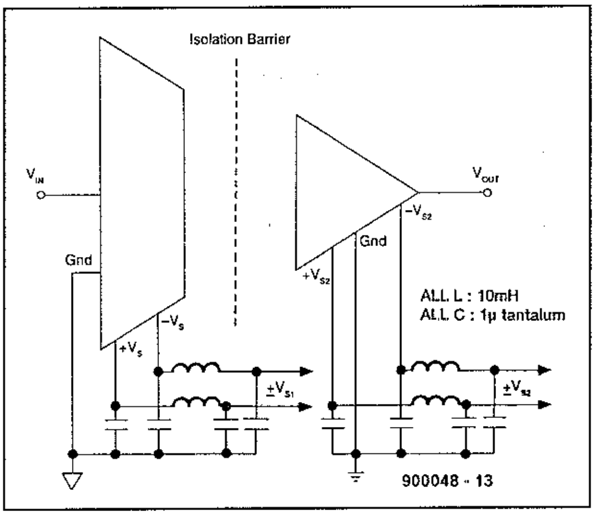

Fig. 5. Decoupling for linear and switch-mode power supplies.

Parameters

Although it is as easy to work with most isolating amplifiers as it is with opamps, there are a few parameters that need closer examination or that do not exist in opamps. Typical voltages in isolating amplifiers are shown in Fig. 3.

V_{sig} is, as in opamps, the differential input voltage; its level is ±10–15 V.

V_{CM} is the common-mode voltage, that is, the voltage between the signal inputs and the input earth. The maximum level at either input pin with respect to earth, should not be higher than V_{CM}—in practice about ±10 V. If levels higher than that are needed, there can be no earth at the input, only at the output. It may also be impossible to use an earth. In that case, V_{ISO} becomes the reference.

V_{ISO} is the maximum isolating voltage between the reference earths of the input and output signal. Its level may be several kilovolts.

CMRR, the common-mode rejection ratio, shows the change in output voltage with respect to output earth for simultaneous changes in input voltages referred to the input earth, that is, V_{CM}.

IMRR, the isolation-mode rejection ratio, is $\Delta V_{ISO}/\Delta V_{out}$.

The foregoing parameters can now be used to express the amplication function:

$$V_{out}=\alpha(V_{sig}\pm V_{CM}/CMRR\pm V_{ISO}/IMRR)$$

where α is the amplification factor.

Another important parameter is the **accuracy**, which takes acoount of temperature stability, long-term stability, amplification error and non-linearity, which are well known from opamps. Peculiar to isolating amplifiers is the **leakage current**, which expresses the input error current as a function of the isolating voltage and frequency. In data sheets these are normally given as 240 V and 60 Hz respectively; the leakage current is expressed in μA.

WARNING In medicine, isolating amplifiers are used primarily for ground loop elimination. Readers are warned not to use isolating amplifiers (for instance for mains isolation) in equipment that is in frequent contact with their bodies.

Basic circuits

Isolating amplifiers, like all circuits that combine digital and analogue techniques, are particularly sensitive to external interference. Reference has already been made to the need of decoupling capacitors at the power supply pins.

Since the ISO 122P superimposes the signal on to a 500 kHz carrier, the transfer function for signals at frequencies up to 25 kHz may be considered linear. At higher frequencies, the output contains more residual modulation as may be seen from Fig. 6. A sinusoidal input at a level of 10 V and a frequency, *f*, of 2 kHz results in an undistorted output signal. The

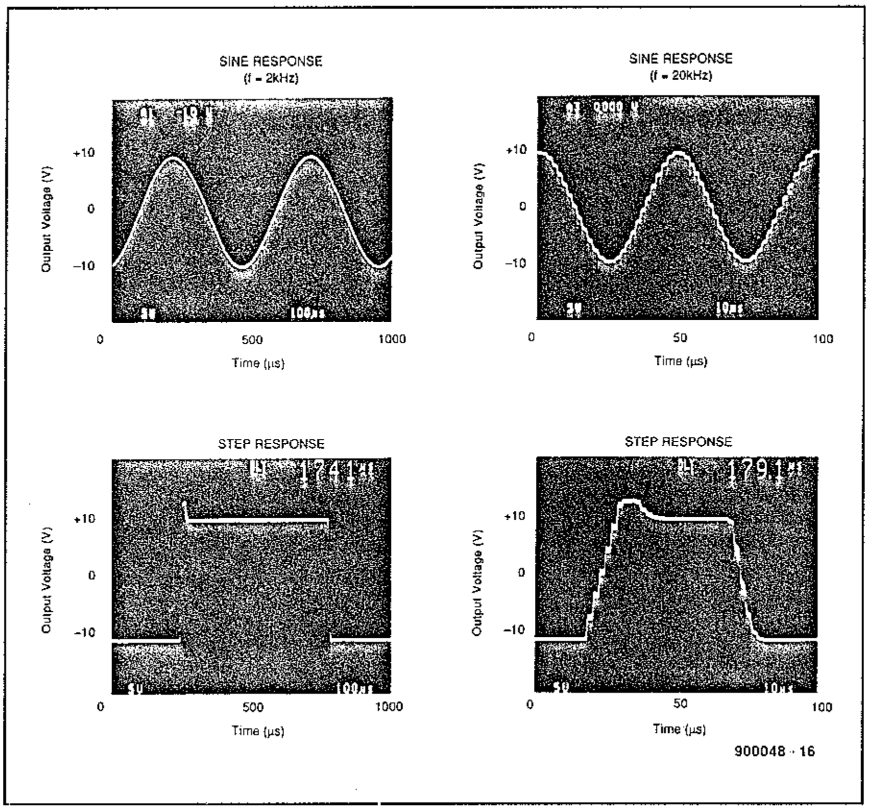

Fig 6 The higher the input voltage, the greater the modulation residue and distortion.

same is true for a rectangular signal even though the leading edge rising to +10 V is seen as a small overshoot.

When the frequency is increased by a factor of 10, the modulation residue on the waveforms is clearly visible. Furthermore, the edges of the rectangular signal have become less steep and the input rise time has increased appreciably.

Most of the modulation residue may be removed with the aid of an active low-pass filter of the first or second order as shown in Fig. 7. The cut-off frequency of that filter is 100 kHz when R1=R2=13 kΩ; R3=385 Ω; C1=100 pF; C2=4700 pF. For most applications, this is a good compromise between effective bandwidth and modulation suppression.

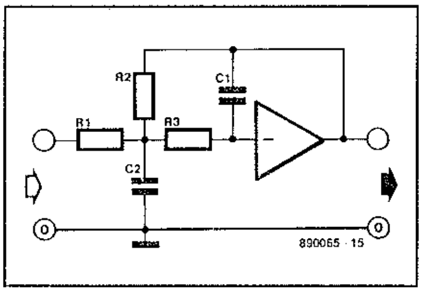

Fig. 7 Active low-pass filter for the suppression of modulation residue.

Error sources

Normally, the maximum signal frequency of a scanning circuit should be limited to half the scanning rate—at least, according to the relevant Nyquist or Shannon theorems. However, here there is a little leeway: up to 50 kHz, the specified bandwidth, the output signal is identical to the input signal as far as frequency and level are concerned. Over the range 50–250 kHz the amplification factor drops from 1 to 0.063 but there is no discernible increase in distortion.

At even higher frequencies, the isolating amplifier produces a relatively small noise signal at a frequency below 250 kHz in addition to the normal output signal. This behaviour may be explained with the aid of Fig. 8. The composition of the whole output signal may be considered in steps for which on the one hand the frequency behaviour and on the other the amplitude must be taken into account.

The triangular characteristics show the relation between input frequency and the interference frequency at the output (straight y-axis). When the input frequency lies between 250 kHz and 500 kHz the interference frequency drops, rises again when the input frequency increases to 750 kHz, drops until the first harmonic (1 MHz) is reached, then rises again, and so on.

The amplification factor may also be evaluated from Fig. 8, and it is seen that at frequencies above that of the carrier it

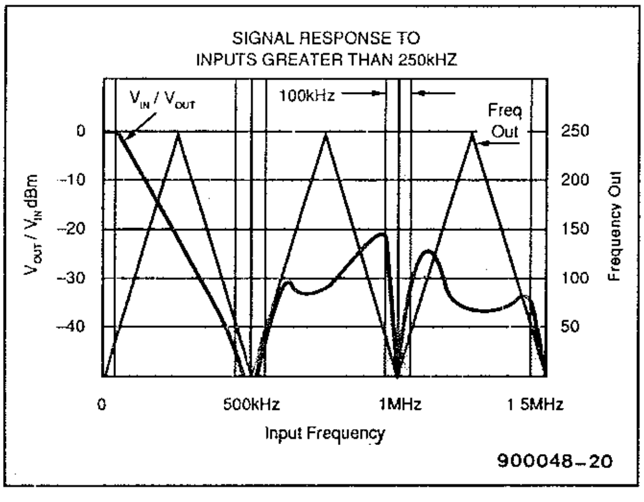

Fig 8. For input signals above 250 kHz, operation of the isolating amplifier is no longer linear.

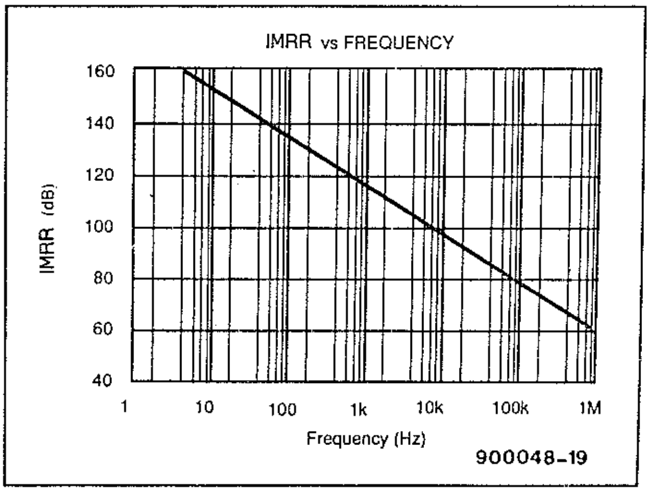

Fig. 9 To work with high isolating frequencies, the circuit must be designed for smaller maximum isolating peak voltages.

has a pronounced irregular behaviour For example a 10-volt 800 kHz input signal results in an attenuated (–30 dB) 800 kHz output signal (this may be read from the ampliciation characteristic and the left-hand y-axis) At the same time a 200 kHz interference signal is produced (which may be read from the triangular characteristic and the right-hand y-axis). At the 200 kHz point on the x-axis it will be seen that the interference signal is attenuated by a further 10 dB Expressed in figures this means that the output consists of a 800 kHz signal at a level of 316 mV and one of 200 kHz at a level of 100 mV If the interfering signal is eliminated with the aid of a filter, the isolating amplifier can work with signal frequencies that are higher than the carrier frequency

The same applies to the isolating voltage. to which the Nyquist theorem is. of course. equally applicable To eliminate an interfering signal caused by the isolating voltage from the output. the IMMR as a function of frequency should be added to Fig 8 For example. when V_{ISO}=1000 V at 800 kHz, the IMMR≈ –62 dB as may be seen from Fig 9. Part of the output signal, viz. 794 mV at 800 kHz was already seen to be an interfering signal From Fig. 8 it is seen that the output additionally contains a 200 kHz signal at a level 30 dB below that of the first interfering signal. that is. 92 dB below 1000 V or 25 mV

In this connection Figures 10 and 11 should also be taken into account The maximum permissible isolating voltage decreases with rising frequency Furthermore, when V_{ISO} rises and the rise time exceeds 1000 V/µs. the triggering of the sense amplifier may go awry with the result that the condition of energy-less signal transfer is no longer met. and a com-

SPECIFICATIONS

At T_A = 25°C and V_S1 = V_S2 = ±15V unless otherwise noted

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
ISOLATION					
Voltage Rated Continuous AC 60Hz		1500			VAC
100% Test 1	1s 5pc PD	2400			VAC
Isolation Mode Rejection			140		dB
Barrier Impedance			10^{14} || 2		Ω || pF
Leakage Current at 60Hz	V_{ISO} = 240Vrms		0 18	0.5	µArms
GAIN	V_O = ±10V				
Nominal Gain			1		V/V
Gain Error			± 05	± 30	%FSR
Gain vs Temperature			±10		ppm/°C
Nonlinearity			±.008	±.015	%FSR
INPUT OFFSET VOLTAGE					
Initial Offset			±5	±50	mV
vs Temperature			±200		µV/°C
vs Supply			±2		mV/V
Noise			4		µV/√Hz
INPUT					
Voltage Range		±10			V
Resistance			200		kΩ
OUTPUT					
Voltage Range		±10	±12		V
Current Drive		±5	±15		mA
Capacitive Load Drive			1000		pF
Ripple Voltage(2)			10		mVp-p
FREQUENCY RESPONSE					
Small Signal Bandwidth			50		kHz
Slew Rate			1 5		V/µs
Settling Time	V_O = ±10V				
0 1%			50		µs
0.01%			150		µs
Overload Recover Time			150		µs
POWER SUPPLIES					
Rated Voltage			15		V
Voltage Range		±4 5		±18	V
Quiescent Current: V_{S1}			±4 5	±6 5	mA
V_{S2}			±4.5	±6.5	mA
TEMPERATURE RANGE					
Specification		0		70	°C
Operating		–25		85	°C
Storage		–25		85	°C
θ_{JA}			100		°C/W

NOTES: (1) Tested at 1.4 X rated fail on 5pC partial discharge leakage current on five successive pulses (2) Ripple frequency is at carrier frequency (500kHz)

Table 1. Technical specification for the ISO 122P at TA = 25 °C; Vs1 = Vs2 =±15 V and RL = 2 kΩ

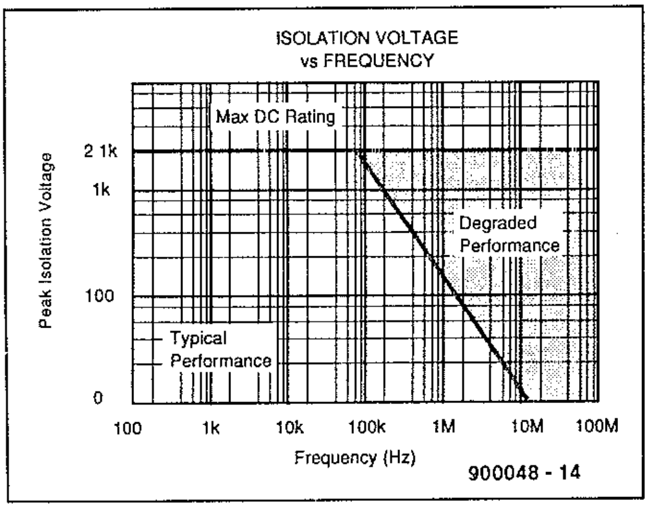

Fig. 10 Isolating voltages at high frequencies cause degrading of the output signal

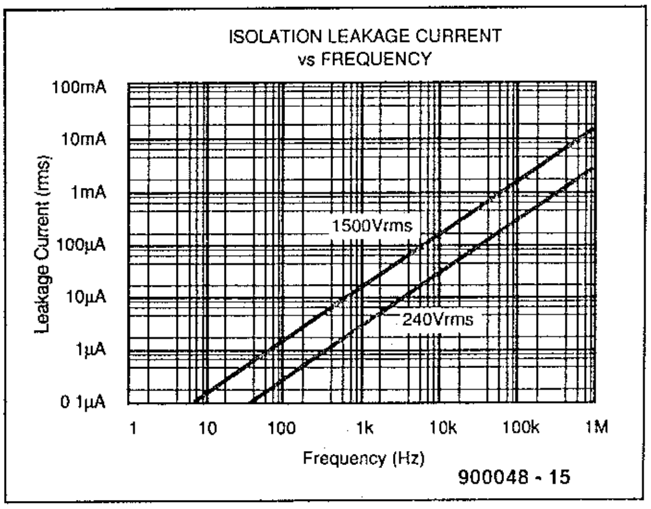

Fig 11 At high frequency isolating voltages there is no longer en energy-free transfer across the barrier

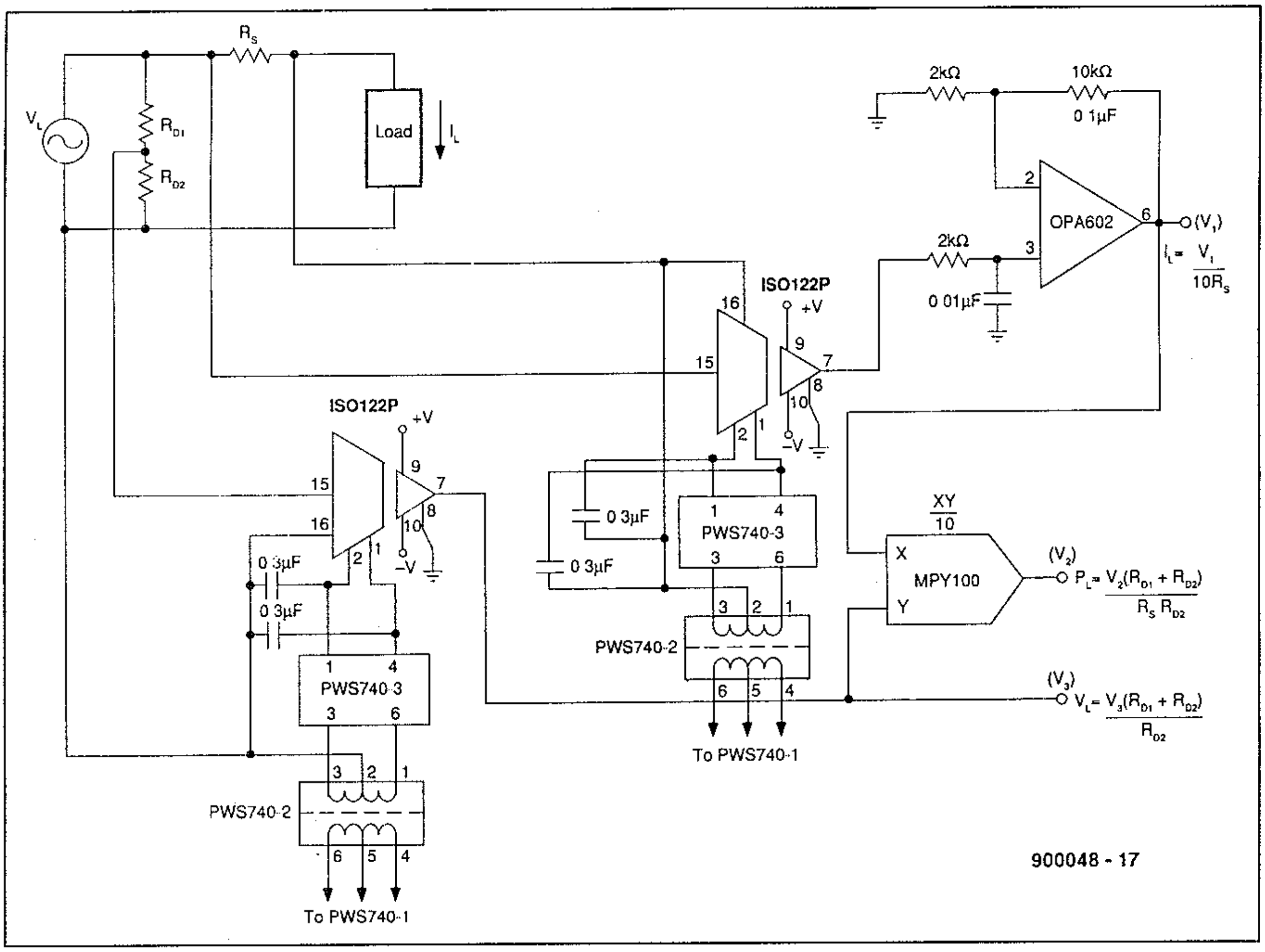

Fig. 12 Typical application of an isolation amplifier: a measuring instrument with current, voltage and power indication.

mon mode current flows across the barrier. It should be noted that supply voltages below ±15 V reduce the maximum permissible slew rate by about half.

A typical application: a power measuring instrument

Finally, as an example of what kinds of application may be satisfied with a typical isolating amplifier such as the ISO 122P (although other types may also be used, of course), we have chosen a power measuring instrument, whose circuit is shown in Fig. 12. The instrument can indicate the load current, the source voltage and the resulting power dissipated in the load.

One of the isolating amplifiers is used to evaluate the source voltage with the aid of potential divider R_{D1}-R_{D2} and the other to measure the load current with the aid of current sensor R_S. Both amplifiers are connected in an identical manner.

The input earth that serves as the reference for the input potential at pin 15 is not grounded. Only the output sections are referred to ground potential.

The Type PWS740-1, PWS740-2 and PWS740-3 devices are Distributed Multichannel Isolated DC-to-DC Converters from Burr-Brown. These converters are able to produce up to eight ±7–20 V supply voltages, which are galvanically isolated from one another, from a single 7–20 V direct voltage. Currents of up to 60 mA may be drawn from each of the resulting supplies.

Although this is not a cheap way of producing power supplies, it guarantees that no interference will be transferred from the mains to the isolating amplifiers.

The MPY100 is a four-quadrant multiplier-divider that, apart from multiplication, performs analogue square-root and division without the bother of external amplifiers or potentiometers. Here it is used to compute the power, $P = UI / 10$.

Since the multiplier always divides by 10, the output of the voltage-indicating amplifier may be used directly as the multiplicand, whereas that of the current-indicating amplifier must first be amplified by 10 before it can be so used.

The Type OPA602 high-speed precision operational amplifier, also from Burr-Brown, is used as an active low-pass filter and impedance converter. Other types of high-speed precision operational amplifier may, of course, also be used. ■

Further information on all devices discussed in this article may be obtained from

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