

# Application Notes For Current Monitors Manufactured By **PEARSON ELECTRONICS, INC.**

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## History

Pearson Electronics has produced precision current-monitoring transformers since 1958. The Pearson design plus careful workmanship and quality control produce current monitors with excellent frequency response and amplitude accuracy. Originally developed for measuring pulse currents, Pearson Current Monitors™ are now also widely used to measure more complicated transients and periodic signals from a few hertz to well into the megahertz region.

## Operation

To use a Pearson Current Monitor one needs an oscilloscope and an appropriate length of coaxial cable, which would usually have a 50 ohm impedance. For RF work an RF voltmeter may be used. The output receptacle of the current monitor is connected via the coaxial cable to the high-impedance oscilloscope or voltmeter input. The conductor carrying the current to be measured is passed through the hole in the current monitor. The voltage wave-shape as displayed on the oscilloscope will then be a faithful reproduction of the actual current waveshape within the limitations of rise time and droop specified for the particular model used. The voltage amplitude will be related, on a linear basis, to the current amplitude by the sensitivity in volts-per-ampere.

## Performance Features

The standard accuracy for Pearson Current Monitors is within +1%, -0% of the nominal sensitivity. This accuracy applies to the midband response. Exceptions due to droop and monitor rise-time (low and high frequency cut-off) are particular to each model, and are treated separately in the specification sheet. Rise time is short, ranging between 2 and 100 nanoseconds (10-90% levels) in most cases. Droop values range from 0.1% per microsecond to 0.5% per millisecond for typical models. A significant advantage, of course, is the fact that the current monitor is physically isolated from the circuit under test.

This feature is invaluable for eliminating ground currents which usually occur when using current-viewing resistors. Another advantage is that low sensitivity can be used without suffering from the ringing commonly encountered with viewing resistors.

## Typical Applications

Pearson Current Monitors can be used for measuring and monitoring:

- Current waveshape and amplitude in high and low voltage circuits, from microamperes to megamperes.
- Circuits where the use of viewing resistors is unsuitable because of ground-loop noise, insertion resistance, or a lack of high voltage isolation.
- Pulse currents at high voltage, as associated with microwave or x-ray tube modulators, particle accelerators and lasers.
- Current transients and harmonics in power systems.
- Lightning-strike currents.
- Pulsed charged-particle beam current.
- Current in electrolytes and plasmas.
- EMI currents.
- Video and RF currents.
- Currents in spot and induction welders.
- Antenna phasing.
- Flash-tube current.

## Calibration

Pearson Current Monitors intended for general use are adjusted at the factory to yield an initial-pulse-amplitude error within specification (either  $\pm 1\%$  or +1, -0% depending on model), when terminated in a high impedance load such as an oscilloscope. The equivalent circuit of nearly every Pearson Current Monitor is that of a voltage generator in series with 50 ohms.

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## Specifications

A review of certain Pearson Current Monitor specifications may assist the engineer in choosing the right model for a particular application.

- **Sensitivity** The considerations here involve the peak current to be measured, the oscilloscope sensitivity, and trade-offs imposed by other specifications.

For Pulse Applications

The Time Domain Parameters Are:

- **Maximum Peak Current** This value is based primarily on the voltage-breakdown rating of the connector used. For instance, a 500-volt rating on the connector gives a 5000-ampere peak current rating for a 0.1 volt-per-ampere current monitor.
- **Droop** The value listed is the maximum amount to be expected at current levels above a few amperes. At low current levels, low initial core permeability may cause higher droop values and a corresponding increase in the low-frequency -3 dB point for some models.
- **Usable Rise Time** If the 10 to 90 percent rise time is greater than the specified usable rise time, initial overshoot and ringing will be less than 10% of the pulse step amplitude.
- **I·t Max** This parameter is analogous to the voltage-times-time constant of a pulse transformer. The product of current times time for a rectangular pulse must not exceed the value listed or the core will saturate, causing a distorted waveform. If two turns are used through the window to obtain twice as much sensitivity, the I·t rating necessarily will be halved.

For The Continuous Signal Applications,  
The Frequency Domain Parameters Are:

- **Maximum RMS Current** This value is based on heating considerations involving the long-term stability of the internal resistance element in the current monitor.
- **Approximate Low And High Frequency 3 dB Points** Due to the ac nature of transformers, the flat midband response will roll off at low frequency. The "corner" or "cut-off" frequency, at which the response is 3 dB down, is specified. Internal resonances determine the useful high frequency cut-off point. Response is within  $\pm 3$  dB at the specified high frequency limit.
- **I/f Max** This parameter is to sine-wave currents what the I·t product is to rectangular-wave currents. The quotient of peak current divided by frequency must not exceed the listed value or the core will saturate. If two turns are used through the window to obtain twice as much sensitivity, the I/f rating necessarily will be halved.

## External Termination

When viewing pulse rise times below 100 nanoseconds, RF currents above a few megahertz, or when using long cables, it is advisable to terminate the general-use current monitor output cable at the oscilloscope with 50 ohms to prevent standing waves or cable fill-time effects. With this termination the output voltage will be approximately half the unterminated value, subject to the accuracy of the termination resistance, and the attenuation of the cable.

Fast-rising pulses can produce spurious observed ringing due to high frequency current flowing on the outside of the cable shield. This current can be suppressed by increasing the inductance of the shield run by threading the cable through one or more magnetic cores. Good results have been obtained using three turns through four ferrite cores of about one inch inside diameter, two inch outside diameter and 1/2 inch thickness.

With termination, models 2877, 4100, 2100, 3100, 150, 410, 411, 110, 110A, and 1010 will exhibit lower droop and increased I·t product.

## Performance Trade-Offs

In general, as sensitivity decreases, peak current, rms current, and I·t product increase. In addition, it is difficult to combine low droop with high sensitivity.

## Electrostatic Shielding

All Pearson Current Monitors which have the 3 1/2 inch or 10 3/4 inch diameter hole are double shielded. The outer shield (case) is automatically grounded when the threaded mounting holes are used with metal screws through a grounded bracket. All other standard Pearson Current Monitors are single shielded. The shield and the coaxial cable braid are grounded by the mounting screws in all models except those having a 2-inch diameter hole. These have insulated mounting brackets and the only grounding is through the cable braid to the oscilloscope.

## Biasing

All Pearson Current Monitors use ferromagnetic cores which can become saturated by the dc component (average value) of the current ( $I_{dc}$ ), or by the current-time product (I·t) of the pulses. Since the output of the monitor is sustained by the changing flux level in the core, magnetic saturation will degrade performance. As a function of increasing  $I_{dc}$ , the effective permeability of the core decreases, causing the droop rate and low-frequency cut-off point to increase. Also, the available flux swing is decreased, reducing the maximum viewable I·t. When viewing a pulse, the output voltage will drop to zero when the

integrated value of current with respect to time causes the flux level to reach saturation. The monitor will recover after the applied current returns to zero and the flux returns to its remanent value.

Biasing can enable operation with a larger dc component of current, and/or improve the maximum viewable current-time product. The objective of biasing is to reset the flux in the core to a value near the negative saturation level so that the maximum flux swing is available.

The I-t value given in the specification sheets is based on a flux swing from zero to saturation for all models. However, models indicated in the specification sheet with \*\* have high-permeability core material which has a residual induction of 0.6 to 0.8 of the saturation value. These models will need bias to obtain more than 0.2 to 0.4 of the rated I-t. With bias all models can achieve nearly twice the specified I-t, since the flux can be reset close to negative saturation.

For pulses with small I-t, the droop rate will increase as  $I_{dc}$  approaches " $I_{dc\ max}$ " in the table.  $I_{dc\ max}$  is the approximate level at which the droop rate will be doubled. In this situation, bias is used to cancel  $I_{dc}$  and allow normal operation.

Bias current may be applied via an additional primary wire through the current monitor hole and should be of the opposite polarity to the expected signal. The correct value for the bias current is  $I_{dc}$ , plus, for \*\* models, " $I_{bias}$ " from the table. The bias current source must have enough resistance to avoid the effect of a shorted turn through the core.

Bias current may also be injected into the secondary winding via a "T" adapter connected to the output connector. The load at the instrument end of the cable should be high enough so that no significant bias current is diverted from the monitor. The source resistance of the bias current source must not load the output of the current monitor. For models with 50 ohm output resistance, a bias source resistance of 5000 ohms will result in a -1% shift in sensitivity. The amount of current to be applied with this method is that which was calculated above divided by "Ratio" from the table.

In a pure ac signal,  $I_{dc}$  is zero and the I-t of the positive and negative parts of the cycle are equal. The "1/f" value from the specification sheet gives the maximum amplitude for a sine wave of frequency f. Biasing cannot improve performance for ac signals.

Model	$I_{dc\ max}$ (A)	$I_{bias}$ (A)	Ratio
2877	0.17	0.13	50
4100	0.32	0.25	50
2100	0.78	0.59	50
3100	1.9	1.4	50
150	0.78	0.59	99
325	25		142
2878	0.17	0.13	45
410	10		424
411	0.32	0.25	424
110	0.78	0.59	414
110A	0.78	0.59	414
310	25		352
1010	160	120	490
1025	8		361
3025	25		513
2879	0.17	0.13	46
101	0.78	0.59	325
301X	60		312
1080	60		173
1330	60		345
1423	60		80
2093	150		473

### Transient Limitation

When monitoring high current transients it is possible to exceed the internal dissipation limits of the unit. For unidirectional currents saturation of the core protects the secondary circuit. The energy of a bidirectional transient is not limited in this way. The heat generated by such a transient current is proportional to the time integral of the square of the current. For any given model the limit can be found by multiplying the peak current rating by the I-t product. Exceeding this I<sup>2</sup>t value may damage the unit.

For example, the I<sup>2</sup>t limit for the 301X would be 50 kA times 22 A-sec, or  $1.1 \times 10^6$  A<sup>2</sup>-sec. If an ac current of 5 kA RMS were applied, the maximum duration should be  $1.1 \times 10^6 / (5 \times 10^3)^2 = 4.4 \times 10^{-2}$  sec.

### Phase Shift

Within their specified frequency ranges, the phase shift between the voltage output and the current being measured by Pearson Current Monitors is small. For frequencies at least one decade from the low and high frequency cut-off points, the phase shift is usually less than 6 degrees, and the amplitude error is less than 1%.

## High-Voltage Consideration

Pearson Current Monitors intended for high-voltage use have large hole diameters and radiused edges to keep voltage gradients low. The two standard case sizes are those with 3½ inch and 10¾ inch inside diameters. These sizes are double shielded, as mentioned previously. The extra shield affords excellent protection from electric field penetration. Since the mounting screws ground the outer shield, a direct path to ground is provided for possible arcs from the high-voltage conductor to the case. This direct path to ground minimizes the danger of high voltage entering the instrumentation circuit. The inner shield and coaxial connector are "floating" and hence can be grounded at the oscilloscope, at the oil tank bulkhead, or wherever convenient to minimize ground loops and promote safety.

A round conductor at high potential centered in the hole of a Pearson Current Monitor results in coaxial geometry. For this arrangement, the minimum voltage gradient at the surface of the conductor occurs when the ratio of conductor radius to hole radius is 1/e. Departure in either direction from the optimum conductor radius will increase the gradient and lower the permissible operating voltage. Voltages and recommended conductor sizes are tabulated for three Pearson case sizes. Cleanliness of the local environment is necessary to achieve reliable high-voltage operation.

Hole Diameter	Conductor Diameter	Typical Pulse Voltage *in Oil	Flashover Voltage in Air
2"	¾"	150kV	30kV
3½"	1¼"	300kV	50kV
10¾"	4"	900kV	150kV

\* Note: For pulses of under five microseconds duration.

All Pearson Current Monitors are constructed of materials compatible with transformer oil. For detailed information regarding the care and handling of transformer oil, use of pulse transformers in transformer oil, etc., refer to Pearson "Notes on High-Voltage Pulse-Transformer Insulating Oil Care and Accidental Transformer Overvoltages" (available on request from the Pearson factory).

When the conductor in the hole of a Pearson Current Monitor operates at a high direct-current potential in transformer oil, it is recommended that a barrier composed of solid insulating material be placed between the conductor and the current monitors to prevent arcs due to foreign particles "lining up" in the dc field.

Typical barrier materials include teflon tubing, laminated paper-phenolic tubing and oil-impregnated (by vacuum) Kraft paper. If the barrier material is used as a centering device, touching both conductor and current monitor, adequate creep distance should be allowed over the shortest surface path to prevent breakdown.

At voltage levels of a few kilovolts in air, ordinary high-voltage insulated wire will suffice for the center conductor. At levels above 10 kilovolts in air, it is advisable to use a centered conductor of large diameter. As the voltage level approaches the rated voltage for the hole size, it becomes more necessary to use the optimum conductor size.

## Insertion Resistance

A typical Pearson Current Monitor contains a distributed load resistance. When using such a current transformer this resistance appears as a very small equivalent series resistance in the circuit being measured. This resistance is usually so small it can be neglected. For those cases when it needs to be considered, the values are tabulated here.

Model Nos.	Insertion Resistance (Ohms)
2877, 4100, 2100, 3100	0.02
150	0.005
325	<0.002
2878	0.001
410, 411, 110, 110A, 1010	0.0002
310	<0.0003
1025	<0.00004
3025	<0.00003
2879	0.0001
101, 301X	<0.00002

## Special Designs

Inquiries for special current monitors are invited by Pearson Electronics. Our standard models cover most situations, but we do make custom-built models when needed.

*The foregoing notes are intended to aid the engineer in selecting and applying Pearson Current Monitors. For further information please contact the factory.*



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