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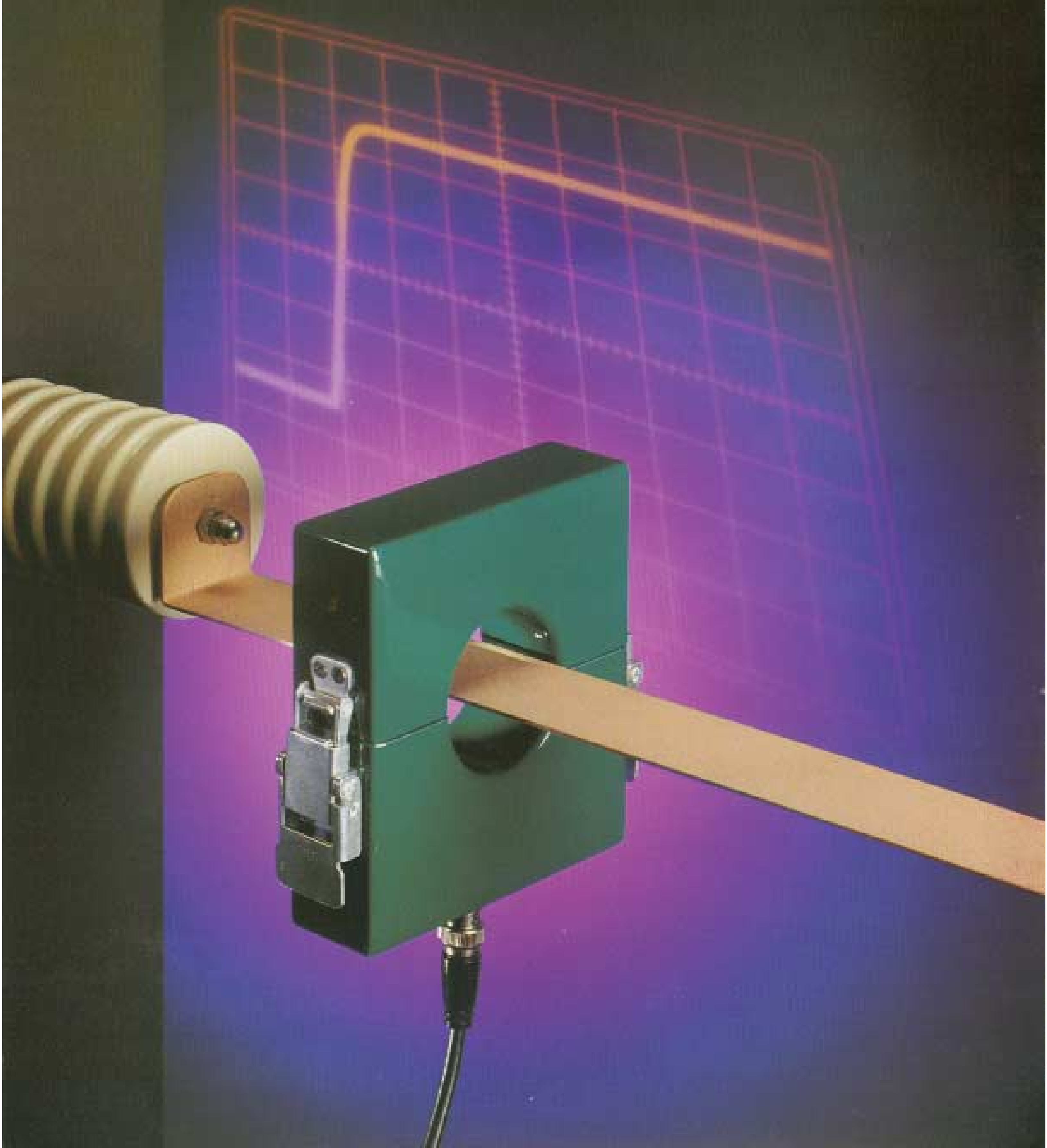

# Clamp-On Current Monitors Achieve Wide Bandwidth

**Chris Waters**, Pearson Electronics, Inc., Palo Alto, California

*A wideband current monitor consists of two halves that clamp together over a conductor, offering measurement convenience from near DC to 15MHz.*

Viewing and measurement of electric current is so important that a variety of devices and methods have been developed and refined over the years. In its simplest form, current may be measured by placing a resistor in the circuit under test, and then measuring the resulting voltage developed in accordance with Ohm's law. Such current-viewing resistors (CVRs) have evolved into sophisticated devices with many important applications. The necessity for direct conductive contact with the circuit under test is one of the CVR's shortcomings.

These shortcomings have been addressed by devices that read current by means of its associated magnetic field, which also reduces the effect of the measurement device on the circuit under test. Such devices are generically transformers, and they are used in many current measurement disciplines. They range

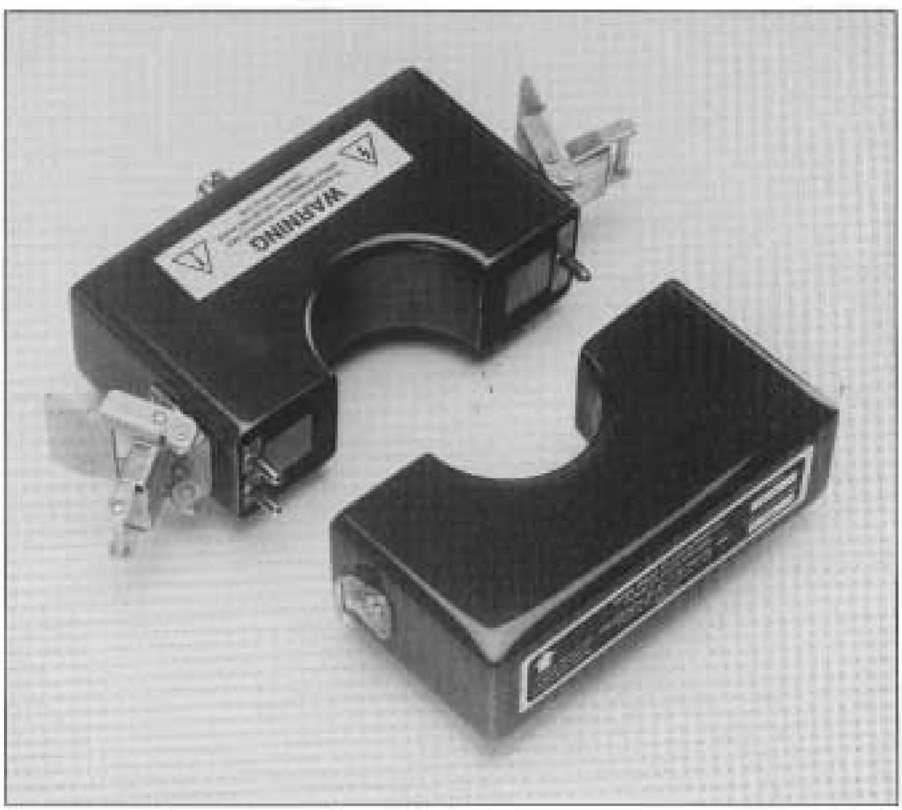


*Figure 1. Model 3525 Clamp-On Current Monitor*

from simple 60 Hz AC transformers used in many power line measurement to parametric current transformers that use flux modulation to measure DC current. They can measure frequencies from DC to hundreds of megahertz.

The internally terminated current transformer, also known as a current monitor, is a direct replacement for the CVR for AC signals. It has the advantages of low inserted resistance, no conductive contact, and a voltage output proportional to the current being measured. Simple devices are used at fixed frequency and broadband units are employed for more general-purpose measurement.

Another feature distinguishing classes of current transformer is the ability to open the transformer ring to enable clamping it onto a fixed conductor. Such transformers are available as oscilloscope and meter probes, and as application-specific transducers in complex systems. The possibility of clamping a current transformer onto the circuit extends the usefulness of the measurement method to circuits that cannot be broken to pass through a fixed-window transformer or connect to a busbar transformer.

The main application characteristics that suggest use of a clamp-on current monitor are the physical impossibility of opening the circuit at the point where current needs to be measured, and the necessity not to interrupt circuit operation. In the latter case, proper insulation of the test conductor is assumed to avoid the shock hazard inherent in mounting a transformer on an energized conductor. In other cases, it may be a matter of convenience to be able to clamp the current monitor onto the conductor. Most applications for clamp-on units are for temporary installations, although some also include retrofitting a current measurement feature to an existing system.

Clamp-on current monitors are used in many interesting applications. In one, leakage currents are measured on the guy wires of power transmission poles and towers. Information is gathered both at the 60Hz power frequency, and also at other frequencies by application of appropriate test voltage signals.

Another application uses clamp-on current monitors to measure the level of protection provided by lightning surge protectors. Clamp-on monitors are placed on circuits inside the protected enclosure, and simulated lightning strikes are applied to the external connections. The current levels observed internally measure the performance of the surge protection. A large aperture clamp-on current monitor has

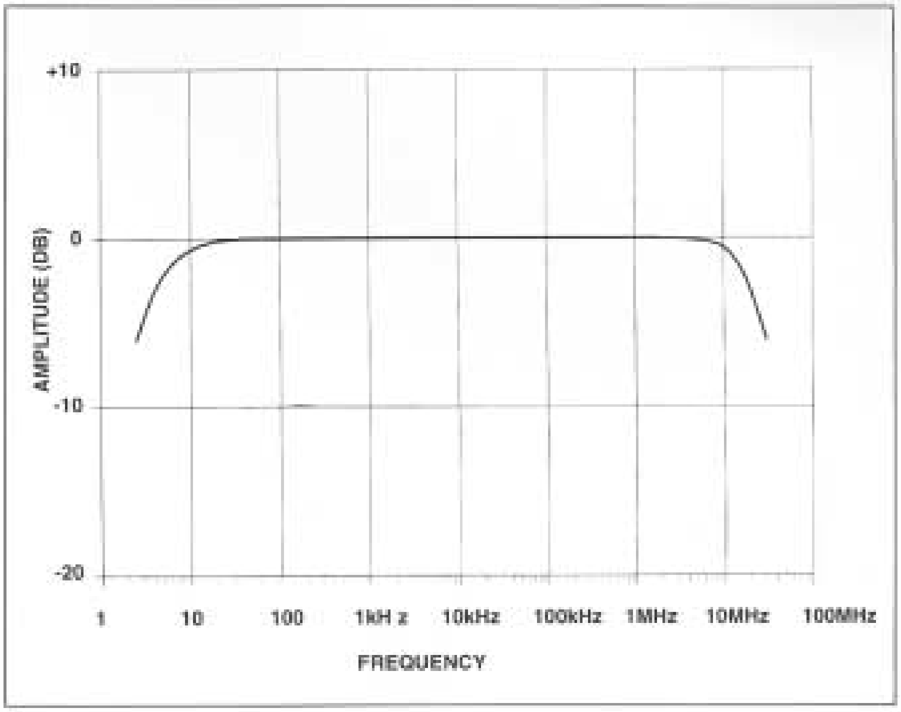


*Figure 2. Frequency Response of Model 3525.*

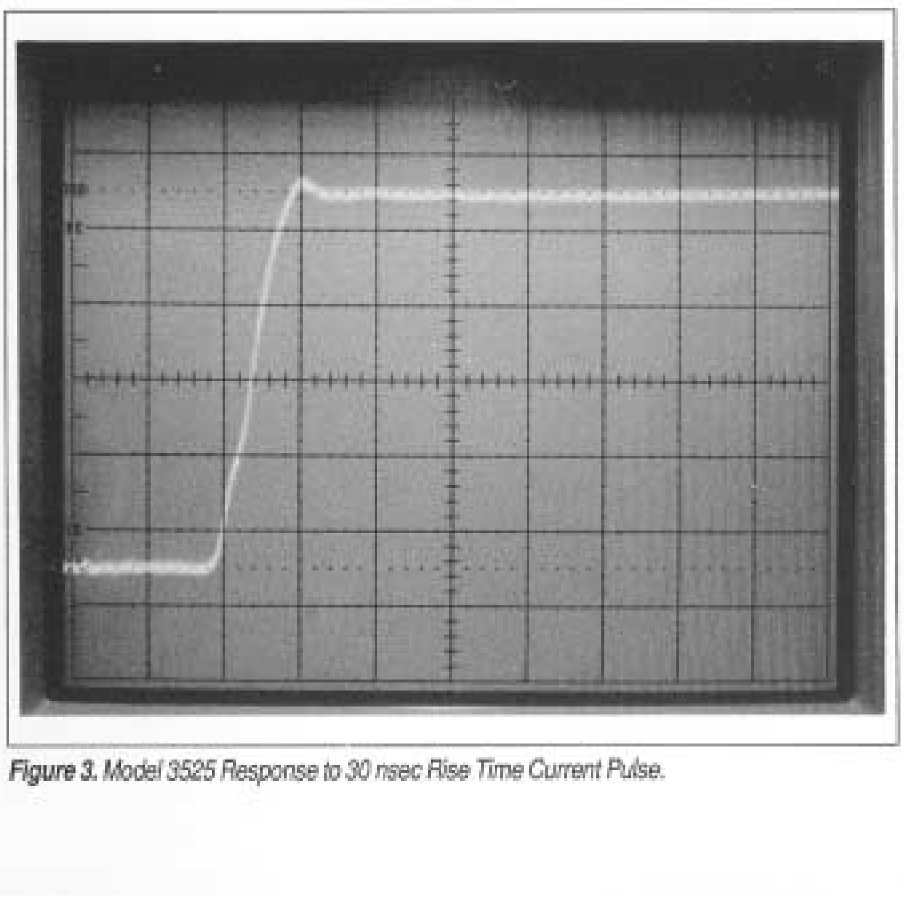

*Figure 3. Model 3525 Response to 30 nsec Rise Time Current Pulse.*

also been retrofitted to a missile launch tower to record lightning strike data.

Clamp-on current monitors are being used to test large electronically controlled motors and observe their current waveforms. Both pulse-driven and sine-wave induction motors can be monitored. In one instance fundamental and harmonic components of current are observed in a motor system driven by variable frequency sinewave power.

One high-frequency model is used to measure RF current supplied to plasma machines used in semiconductor processing. Flat response to beyond 13.6MHz combined with large aperture and clamp-on convenience open new possibilities in such measurements.

## Frequency Response

In developing a clamp-on version of a broadband current monitor, performance problems at both low and high frequency extremes must be addressed, as well as the mechanical requirements to make a convenient device. The response of a current monitor at low frequency is limited by the L/R time constant of the secondary winding and termination circuit. Cutting the magnetic core to enable separating the transformer has two consequences. In order to be cut, the layers of the tape-wound core must be bonded together. This can introduce mechanical stresses that degrade the core permeability. When the core halves are mated together by clamping the transformer, there is an inevitable residual air gap that further reduces the effective permeability. The effect is to reduce the inductance of the secondary winding and increase the low frequency cut-off point of the transformer. Even with careful polishing and mechanical alignment this increase may be as much as a factor of five for a high-permeability core material. For 60Hz work, the air-gap may be accounted for in the design, and may not cause problems. However, for lower frequencies or long pulses, the increase in cut-off point or droop rate may be a significant disadvantage compared with the corresponding non-clamp-on design. A beneficial side effect of the gap is that it permits good AC operation for currents having a larger average level (DC component).

At the high frequency end, the uniformity of the core winding termination assembly is broken by the parting plane of the transformer. Winding and termination connections must be made across this plane, and irregularities here can cause spurious magnetic pick-up. Connections across the parting-plane must be made correctly or there could be sensitivity variations with position and orientation of the test conductor in the current monitor window.

When viewing pulse rise times below 100nsec, RF currents above a few megahertz, or with long cables, it is advisable to terminate the current monitor output cable at the oscilloscope with 50Ω to prevent standing waves or cable fill-time effects. With this termination the output volt-

***Table 1.*** *Important Parameters for Pulse Applications With Current Monitors.*

| Parameter | Description |
|---|---|
| Maximum Peak Current | Based primarily on the voltage breakdown rating of the connector that is used. For example, a 500V connector rating gives a 5000A peak current rating for a 0.1V/A current monitor |
| Droop | For a flat-top current pulse, the output voltage decays toward zero. Initially, this decay appears linear and the slope is referred to as the droop rate. |
| Usable Rise Time | If the 10 to 90% 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 | The product of current and time for a rectangular pulse must not exceed the value listed or the core will saturate, causing a distorted waveform. |

***Table 2.*** *Important Parameters for Continuous Signal Applications With Current Monitors.*

| Parameter | Description |
|---|---|
| Maximum RMS Current | Based on heating considerations involving long-term stability of the internal resistance element in the current monitor. |
| Approximate Low and High Frequency 3dB Points | Due to the AC nature of transformers, the flat midband response will roll off at low frequencies. Internal resonances determine the useful high frequency cutoff point. Response will be flat to within ± 3 dB between these limits. |
| I/f Max | This is to sinewave current what the I•t product is to rectangular pulse currents. The quotient of current and frequency must not exceed the listed value or the core will saturate. |

age will be approximately half of 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 the 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 thick.

*Table 1* lists the important parameters for pulse applications and *Table 2* lists those for continuous signal applications.

***Table 3.** Model 3525 Characteristics.*

| **Category** | **Parameter** | **Specification** |
|---|---|---|
| Dimensions | Inner Diameter | 2.0 in. |
| ^ | Height | 5.0 in. |
| ^ | Width | 4.55 in. |
| ^ | Thickness | 1.5 in. |
| Sensitivity | Transfer Resistance | 0.1 Volt/Ampere |
| ^ | Accuracy | Midband ±1% |
| Pulse | Maximum Peak Current | 5,000A |
| ^ | Droop Rate | 0.004% per ±sec |
| ^ | Usable Rise Time | 25nsec |
| ^ | Maximum I•t | 0.5A-sec |
| Continuous | Maximum RMS Current | 100A |
| ^ | Low-frequency Cut-off | 5Hz |
| ^ | High-frequency Limit | 15MHz |
| Other | Inserted Resistance | 0.0002Ω |
| ^ | Maximum DC Current | 5A |
| ^ | Voltage in Air | 15kV |
| ^ | Weight | 3.5 pounds |
| ^ | Connector | BNC |
| ^ | Temperature Range | 0 - 65°C |

## Wideband Current Monitor

One of the new wideband current clamp-ons is the Model 3525 (*Figure 1*), whose specifications are given in *Table 3*. It has a fast rise time and low droop, so it can be used with a wide range of pulse or transient waveforms, such as those encountered in motor control and switching power supplies. The low-frequency cut-off point is low enough for accurate power line measurements, showing both fundamental and harmonic content. Measurement of switchgear transients in power systems is another important application for the clamp-on current monitor.

In use, the transformer is mounted onto the conductor to be measured, and the latches secured. The output BNC connector is connected with a standard coaxial cable to an oscilloscope, voltmeter or other voltage reading instrument. Using a high input impedance instrument ensures obtaining its built-in volt/ampere sensitivity and accuracy. This is the simplest measurement setup, and gives excellent results for low to mid-band frequencies.

*Figure 2* shows the frequency response of Model 3525. The flatness and roll-off of this curve predicts a transient response of minimal overshoot and ringing. This is illustrated in *Figure 3*, the 30nsec rise time voltage output of the 3525 for a 200mA current step input and 50Ω termination resistor. Other clamp-on models achieve low-frequency response down to 1.5Hz, and high frequency response to 30MHz. □

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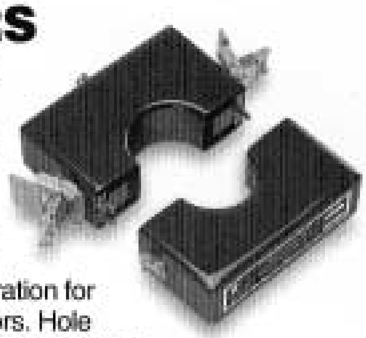
## CLAMP ON CURRENT MONITORS

Clamp-on versions of several Pearson™ Current Monitors are now available. These incorporate wide-band frequency response in a demountable configuration for use on fixed conductors. Hole diameter is 2 inches, and sensitivity ranges from 0.001 to 1.0 Volt/Ampere.



Model 3525, typical of the group, has a sensitivity of 0.1 V/A, a frequency range of 5 Hz to 15 MHz, and 5,000 Amperes peak pulse current capability. Pulse rise-times down to 25 nanoseconds can be viewed.

We welcome inquires regarding custom clamp-on monitors to meet special requirements.

**PEARSON ELECTRONICS, INC.**
1860 Embarcadero Road
Palo Alto, California 94303, U.S.A.
Telephone (415) 494-6444 • FAX (415) 494-6716