A CLIP-ON CURRENT PROBE FOR WIDE-BAND OSCILLOSCOPE MEASUREMENTS

SOME five years ago the -hp- laboratories developed a precision milliammeter that measured current merely by clipping a special probe around the conductor in question[1,2]. The probe thus avoided the need for breaking the circuit to make a measurement, a convenience appreciated by all. At the same time the probe had the additional advantage that it introduced virtually no loading into the circuit being measured. The immediate acceptance of this clip-on probe, which was designed for dc measurements, subsequently led to the development of two ac current probes which have been widely used[3,4].

A new clip-on probe for ac current has now been developed especially for oscilloscope use. By itself, the probe has a medium sensitivity and a frequency range that extends to above 40 megacycles with a corresponding pulse risetime of less than 9 nanoseconds. However, most of its capabilities other than high-frequency response are extended if the probe is used with a companion amplifier. In that case the bandwidth of the combination becomes 20 megacycles (18 nsec risetime), while the sensitivity is increased to 1 milliampere per oscilloscope division for oscilloscopes having a 50-millivolt/cm sensitivity, the usual basic value for wide-band oscilloscopes. Further, the combination has an adjustable sensitivity and can be used to measure up to 50 amperes peak-to-peak. The probe by itself or the combined probe/amplifier can be used with any of the -hp- oscilloscopes. The probe by itself is particularly useful with the -hp- sampling oscilloscopes (Models 185A/B), since the widest probe frequency response is obtained with these scopes.

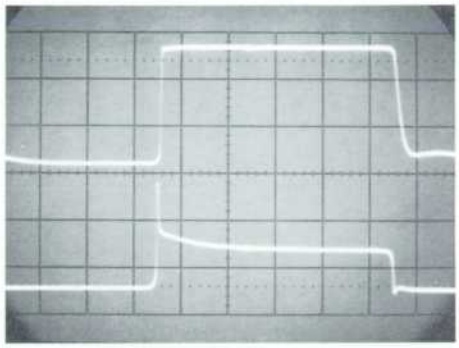


Fig. 1. *Typical example of use of new clip-on probe is shown in oscillogram in which emitter current waveform (lower trace) is presented and measured on dual-trace scope along with collector voltage waveform (obtained with voltage probe in usual way). Waveforms are from a saturating multivibrator transistor which has current spike injected to speed saturation. Oscillogram made using -hp- 175A/1750A scope on* Alternate *sweep at 5 v/cm (upper) and 20 ma/cm (lower).*

[1] Arndt Bergh, Charles O. Forge, and George S. Kan, "A Clip-On DC Milliammeter For Measuring Tube and Transistor Circuit Currents," Hewlett-Packard Journal, Vol. 9, No. 10-11, June-July, 1958.

[2] Donald E. Barkley and Arndt Bergh, "Broader Information Capabilities in the Clip-On DC Milliammeter," Hewlett-Packard Journal, Vol. 13, No. 3-4, Nov.-Dec., 1961.

[3] Robert R. Wilke, "A Clip-On Oscilloscope Probe For Measuring and Viewing Current Waveforms," Hewlett-Packard Journal, Vol. 10, No. 9-10, May-June, 1959.

[4] Charles O. Forge, "A New Clip-On Oscilloscope/Voltmeter Probe For 25 cps —20 Mc Current Measurements," Hewlett-Packard Journal, Vol. 11, No. 11-12, July-Aug., 1960.

PROBE

When used without the amplifier, the probe has a very wide frequency response and a sensitivity suitable for medium-level measurements. The basic sensitivity is an output of 1 millivolt per milliampere flowing in the measured conductor. Operated by itself, the probe has a pulse response typified by the oscillogram in Fig. 6 and a frequency response

Fig. 2. *-hp- Model 1110A AC Current Probe and Model 1111A Amplifier. Probe clips around conductor being measured.*

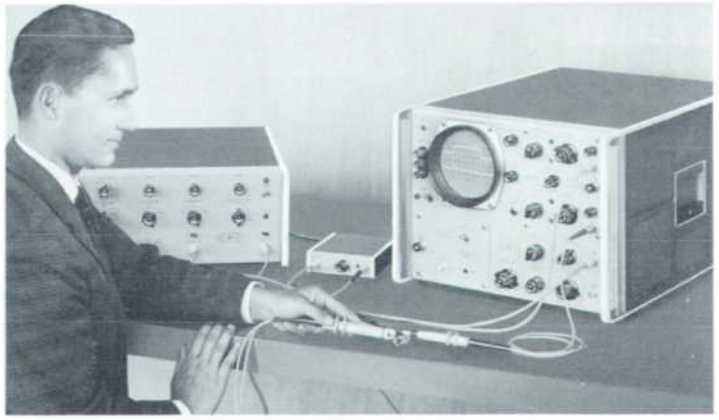


Fig. 3. *Typical test setup using new clip-on current probe together with voltage probe to simultaneously observe and measure current and voltage in test circuit.*

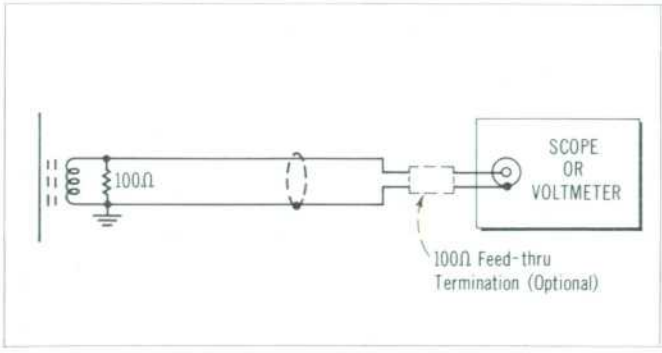


Fig. 4. *Circuit representation of -hp- 1110A probe as used with scope or voltmeter.*

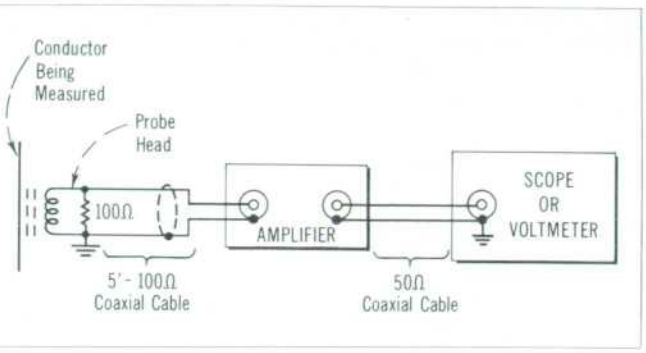


Fig. 5. *Circuit representation of -hp- 1110A/1111A probe and amplifier in typical setup.*

typified by the curves in Figs. 8(a) and 8(c).

The relatively small perturbations in the pulse response of Fig. 6 can be reduced further and the probe's low-frequency response extended if the probe is operated with a resistive termination at the end of its output cable. The probe head is designed as a current transformer using the conductor being measured as a one-turn primary. The secondary is shunted with 100 ohms to provide a 100-ohm source impedance and drives a 100-ohm coaxial cable. The arrangement is such that reflections from the open end of the cable are absorbed almost completely, as indicated by the quality of the response in Fig. 6. However, terminating the open end of the cable in 100 ohms further reduces reflections and standing-wave patterns, although at the expense of a 50% reduction in sensitivity. The oscillogram of Fig. 7 shows the typical pulse response when the probe cable is terminated, and Fig. 8(c) the typical low-frequency response which now extends from below 1 kilocycle (to above 40 megacycles as in Fig. 8(a)). The effect of an oscilloscope input capacitance of 30 pf is shown in the response curve of Fig. 8(a). When the probe cable is terminated, the sensitivity becomes 0.5 mv/ma, as indicated by the reduced pulse height in Fig. 7. The -hp- #10100B 100-ohm termination is designed for terminating the probe cable and was used for the data shown.

The probe is especially valuable for fast current measurements in low-impedance circuits because it reflects only a slight impedance into the circuit being measured. This impedance is approximately .01 ohm shunted by 1 μh. The capacitance to ground when the probe is clamped on a #22 gage wire is less than 3 pf. An electrostatic shield is located between the probe head and a measured wire, and a magnetic shield surrounds the probe head to reduce the effects of external magnetic fields.

The probe has the ability to measure very high currents before the ferrite core is driven into its non-linear region (Fig. 8(e)). With a 100-ohm termination the current probe itself can measure up to 30 amperes p-p above 4 kc and greater values when used with the amplifier, as shown in Fig. 8(f). The maximal allowable measured current is lower at low frequencies because of core distortion and is lower at high frequencies due to heating in the core. Somewhat more than 0.5 ampere dc can be flowing in the conductor being measured before distortion of the ac measurement is noticeable.

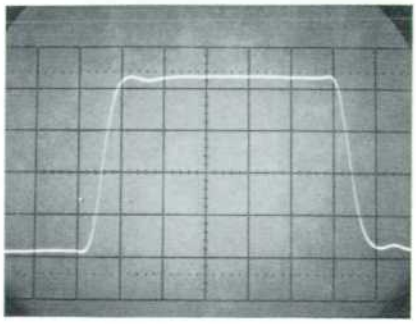


Fig. 6. *Oscillogram of typical pulse response of -hp- 1110A probe operating directly into high-impedance oscilloscope (-hp- 175A/1751A).*

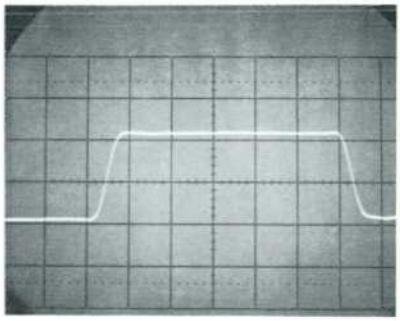


Fig. 7. *Same as Fig. 6 except probe cable terminated with -hp- 10100B feed-thru termination, as in Fig. 4.*

PROBE WITH AMPLIFIER

Using the probe with the amplifier provides additional sensitivity and low-frequency response (Fig. 8 (d)), and also provides a very useful 50-ohm output impedance so that the response is not critical with different load capacities or lengths of output cable (Fig. 8(b)). The frequency response of the combined probe/amplifier is from 50 cps to 20 Mc at the —3 db points with a pulse risetime of approximately 18 nanoseconds and a low frequency pulse sag of 3% in 0.2 millisecond.

When used with the amplifier,

the probe has a basic current-to-voltage conversion of 50 mv/ma. This is calibrated on the amplifier panel as 1 ma/cm which requires that the oscilloscope be set for 50 mv/cm. Current will then be direct-reading in milliamperes on the oscilloscope screen. An attenuator and range switch on the amplifier reduce the basic sensitivity in a 1-2-5 sequence from 1 ma/cm to 5000 ma/cm in 12 ranges. Fig. 3 shows a typical test setup using the probe/amplifier combination.

GENERAL

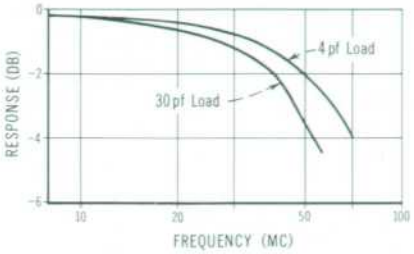
Current measurements using the -hp- clip-on current probes are in many cases more convenient and more accurate than voltage measurements and can yield information that would not otherwise be obtained. Such measurements as transistor base and emitter currents, tube screen currents, load resistor currents measured on the power supply side of the resistor where capacity has no effect, current summing and equalizing by measuring two current-carrying conductors simultaneously, power supply ripple, current-voltage comparisons, and charging currents and turn-on surges are especially valuable. The probe is marked to indicate its directional sense in terms of conventional current flow.

The high-frequency capability of the probe and amplifier means that an awareness of high-frequency ground current effects is important. The standard precautions regarding grounding and low inductance are in order. A resistive ground lead is provided with the probe for damping of ground-loop resonances.

ACKNOWLEDGMENT

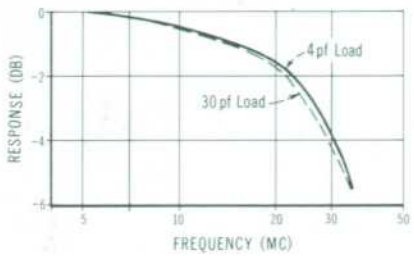
The design group for the probe and amplifier included Arthur M. Johnston, James M. Umphrey and the undersigned. Valuable suggestions were provided by Arndt Bergh and Norman B. Schrock.

— John G. Tatum



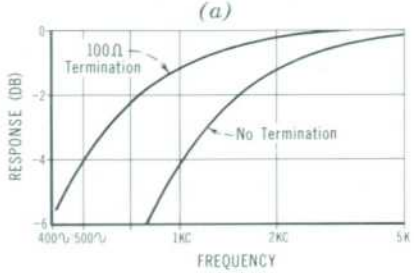
TYPICAL HIGH-FREQUENCY RESPONSE OF -hp- MODEL 1110A PROBE WITH 100-OHM TERMINATION (-hp- 10100B)

(a)



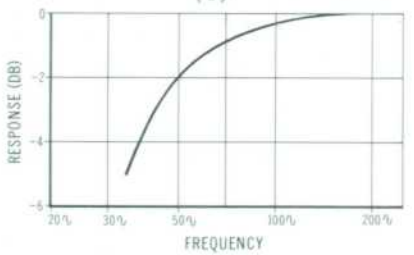
TYPICAL HIGH-FREQUENCY RESPONSE OF -hp- MODEL 1110A PROBE WITH 1111A AMPLIFIER USING 3' OF 50-OHM CABLE

(b)



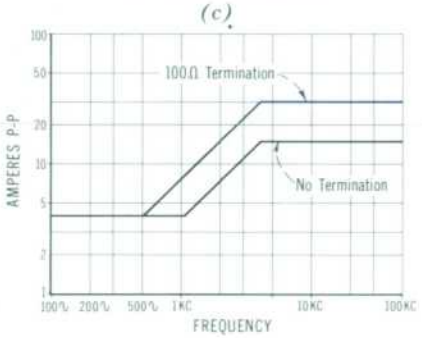
TYPICAL LOW-FREQUENCY RESPONSE OF -hp- MODEL 1110A PROBE

(c)



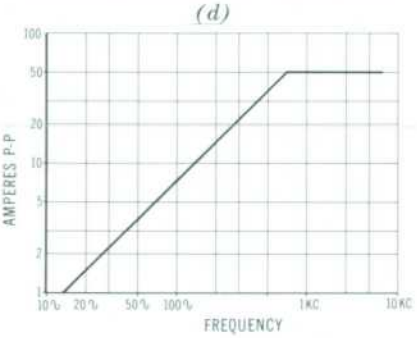
TYPICAL LOW-FREQUENCY RESPONSE OF -hp- MODEL 1110A PROBE WITH 1111A AMPLIFIER

(d)



MAXIMUM CURRENT RATING OF -hp- MODEL 1110A PROBE

(e)



MAXIMUM CURRENT RATING OF -hp- MODEL 1110A PROBE WITH 1111A AMPLIFIER

(f)

Fig. 8. *Typical performance data for -hp- 1110A AC Current Probe and 1111A Amplifier.*

SPECIFICATIONS

-hp-
MODEL 1110A
AC CURRENT PROBE
(without amplifier)

SENSITIVITY: 1 mv/ma.
ACCURACY: ±3%.
BANDWIDTH:
4 PF LOAD: (e.g. 185B/187B), 1700 cps to greater than 50 mc, 7 nsec rise-time.
30 PF LOAD: (e.g. 175A/1750A), proportional decrease (capacity vs frequency) to 40 mc, 9 nsec rise-time.
MAXIMUM DC CURRENT: 0.5 ampere.
MAXIMUM AC CURRENT: 15 amperes p-p above 4 kc; decreasing below 4 kc at the rate of 3.8 amps/kc (30 amps p-p max. with -hp- No. 10100B 100-Ohm termination).
INSERTION IMPEDANCE: Approximately 0.01 ohm, shunted by 1 μh; capacity to ground is less than 3 pf.
ACCESSORY AVAILABLE: -hp- 10100B 100-ohm feed-through termination; decreases sensitivity to 0.5 mv/ma, lower cutoff to 850; increases maximum ac current to 30 amps p-p above 4 kc. Price, $17.50.

-hp-
MODEL 1110A AC CURRENT PROBE
AND
MODEL 1111A AMPLIFIER

SENSITIVITY: 1 ma/cm to 50 ma/cm in X1, and 100 ma/cm to 5 amps/cm in X100 — 1,2,5 sequence.
ACCURACY: ±3% on 50 ma/cm sensitivity and below; ±4% on 100 ma/cm sensitivity and above.
BANDWIDTH: 50 cps to 20 mc (18 nsec rise-time).
NOISE: Less than 100 μa p-p, referred to input.
MAXIMUM AC CURRENT: 50 amps p-p above 700 cps, decreasing below 700 cps at the rate of 1.4 amps/20 cps.
OUTPUT IMPEDANCE: 50 ohms.
DIMENSIONS:
Amplifier: 1½ in. high, 5⅛ in. wide, 6 in. deep.
Probe: Aperture, 5/32 in. diameter, 5 ft. cable.
WEIGHT: Approximately 2 lbs.
POWER: 115 or 230 volts ±10%, 50 to 60 cps, approximately 1.5 watts.
PRICE: Model 1110A AC Current Probe, $100.00; Model 1111A Amplifier, $160.00.

Prices f.o.b. factory
Data subject to change without notice