Broader Information Capabilities in the Clip-On DC Milliammeter

ABOUT three years ago the Hewlett-Packard Company introduced a notable new instrument: a dc milliammeter that measured current merely by clipping around the conductor under test.* Because of its clip-on feature this instrument eliminated the inconvenience of opening the circuit under test to measure current. Further, the new milliammeter reflected no dc resistance into the measured circuit—current could be conveniently measured in all sorts of previously-impractical or difficult cases such as low impedance transistor circuits. Current could even be measured in the absence of conventional conductors as in electrolytes or by clipping around small composition resistors.

Finally, the milliammeter is virtually burn-out proof; overloads of hundreds of amperes do not harm it.

Needless to say, the Clip-On DC Milliammeter has been a tremendously useful and popular instrument. Now, however, its information-gathering abilities have been made even broader in a new alternate version of the instrument. The new model differs from the former by the addition of a wider dc-current measuring range and by the addition of the ability to sense low-frequency ac currents in the measured circuit. For dc measurements the sensitivity of the instrument has been increased from 3 milliamperes full scale to 1 milliamper full scale. At the same time the largest current-

measuring range has been increased from 1 ampere full scale to 10 amperes full scale. Hence, the usability of the instrument in measuring both low-power and high-power transistor circuits is significantly increased.

The low-frequency sensing feature in the new instrument is provided in the form of an output that has a response from dc to 400 cps. By means of this output low-frequency currents from a fraction of a milliampere to 4 amperes peak* in the measured circuit will result in a proportional voltage from the Milliammeter. The voltage is calibrated and can be applied to an oscilloscope for observation and measurement of the current under test. For obtaining such information as the peak value of the current pulses in power supply rectifiers, this output is unparalleled for convenience. A specific example of the value of the proportional output in measuring a rectifier current is shown in Fig. 2 (front page).

Since the frequency response of this output extends down to dc, it is also of value when it is desirable to observe or plot dc current phenomena. In such cases it can be used to operate an analog recorder. For dc, currents up to 10 amperes can be observed.

**INSTRUMENT ARRANGEMENT**

The Milliammeter consists of a small penholder style probe for clipping around the conductor and a small cabinet that contains the amplifying circuitry and indicating

*This is the maximum rating at 120 cps. At lower frequencies the rating is as high as 10 amperes peak, while at higher frequencies it decreases from 4 amperes.

The presence of the probe introduces into the measured circuit a very slight inductance of about 0.5 microhenry and a slight shunt capacity of about 2 mmf, but these are not of consequence in most circuits. Often, too, a measurement can be made at a circuit point which is bypassed with a capacitor for minimal effect from these factors.

The probe does couple into the measured circuit a small ac voltage of up to 15 millivolts peak. The Milliammeter has been designed so that this voltage occurs at a little-used frequency, 20 kc and its harmonics, for minimum measurement inconvenience. In rare cases where this small voltage might prove undesirable, it, too, can usually be avoided by selection of the measurement point.

**PROPORTIONAL OUTPUT**

The proportional output feature provided on the new Milliammeter has proved very valuable and has been designed to drive high-impedance devices such as oscilloscopes and potentiometric recorders as well as low-impedance galvanometer recorders. The output jack has associated with it a screwdriver type control (Fig. 5) which has a switch position at one end of its rotation but is otherwise adjustable in the usual fashion. When the control is set to the switch position, the Milliammeter produces an output of 1 volt across high-impedance loads of several tens of kilohms and more for a full-scale reading. This output is
calibrated and is accurate within a few percent. It thus permits accurate recording of dc current information and also permits oscilloscopes to be used to measure low-frequency ac currents in the range from dc to 400 cps.

When the output control is switched out of its calibrated position, it adjusts the output voltage up to a maximum of about 1.5 volts so that 1 milliampere will be available to operate 1400-ohm galvanometer type recorders.

INCREASED SENSITIVITY

It is often practical to increase the effective sensitivity of the instrument by looping additional turns of the measured conductor through the aperture in the Milliammeter's probe. This technique increases the sensitivity of the measurement in direct proportion to the number of loops through the probe. The reverse-coupled voltage of 15 mv peak maximum will also increase proportionately, but this can often be minimized by measuring at a point bypassed with a capacitor. At -hp- the sensitivity of the instrument has been experimentally increased one thousand times to 1 microampere full scale by clipping onto a coil consisting of 1000 turns of #40 wire. The reverse-coupled noise was then held to less than 15 millivolts peak by bypassing this coil with an .027-mf capacitor.

ACCURACY

The Clip-On Milliammeter measures dc currents with a very desirable order of accuracy: ±3% ± 0.1 ma. Furthermore, the dc indication is virtually unaffected by the presence of ac currents. In a typical case the presence of ac in the measured circuit will usually produce no observable effect on the meter. In any case the instrument is rated such that ac with a peak value equal to the full scale value to which the Milliammeter is set will have less than ±2% effect on the dc reading. In general this is not a serious limitation, since in electronics work the dc current is generally larger than the peak ac. An exception to this, however, occurs when measuring rectified currents such as those illustrated in Fig. 2. Here, the peak ac is considerably larger than the average dc current so that a range should be used where the meter indication is sufficiently downscale to maintain the peak ac value within the full-scale value of the range. In case of doubt the output provided on the Milliammeter can be applied to an oscilloscope for observation of the ac waveform. The possibility of an erroneous reading will be indicated by limiting of the waveform peak.

When measuring pulse currents such as those shown in Fig. 2, the finite high frequency response (400 cps) of the instrument can diminish the apparent peak value of the pulse. The amount of this effect will vary,
cycles of 20 kc and its harmonics can

but in the case of 120 cps pulses the
amount will typically be in the vicin-
ity of —5% and will seldom exceed —10%.

Ac currents located within a few
cycles of 20 kc and its harmonics can
cause a beat in the meter reading but
this has not been found to be a
problem in practice because of the
remote location of this frequency.

Two additional ratings apply to
insure the accuracy of measurements
involving ac currents in "fringe area" cases. One is that the maxi-
mum ac that the instrument will ac-
commodate without affecting the dc
reading is 4 amperes peak. The sec-
ond is that the instantaneous sum of
dc and ac below 5 cps in frequency
should not exceed the full scale value
of the range used.

The probe is well shielded and
uses a balanced type of construction
so that external magnetic fields sel-
dom affect the measurements. It is
good practice, however, to avoid
strong magnetic fields.

GENERAL

The variety of uses to which the
Clip-On Milliammeter has been and
can be put is remarkable. It can be
used to sum, subtract, and balance
currents. It can be used to search
for short—and for open—circuits. It
can be used to check power supply
ratings and to insure proper current
drain by load circuits. As mentioned
previously, it has even measured
current in the absence of metallic
conductors.

The possibility of current meas-
urements in a number of other un-
usual applications has also been
suggested and these are under inves-
tigation.

Because of its sheer usefulness and
convenience, the Clip-On Milliam-
meter has won a place as one of the
principal instruments in the elec-
tronics laboratory. Now, with the
addition in this alternate version of
the instrument of wider current ca-
pabilities and the ability to extract
dc and low-frequency information
from the measured current for ex-
ternal use, the instrument becomes
even more valuable.

—Donald E. Barkley and
Arnold Bergb

**MAGNETIC INK TESTING**

An interesting application of the
Clip-On Milliammeter described in
this issue has occurred in an unusual
place for electronic equipment—the
banking field. There, to use the new
style checks which are magnetic-ink
encoded for computer processing, it is
necessary to quality-control the mag-
netic properties of the ink impression
placed on the checks during printing.
To do this, a modified form of the
Milliammeter has come into use in
check printing.

In essence, the ink tester consists of
one of the Milliammeters with a special
form of probe that can sample the
magnetic field of the ink impression
on the printed check. Included in the
arrangement is a permanent magnet
which is used to magnetize the im-
printed ink prior to a measurement
with the tester. The tester is provided
with a special meter face which shows
the operator whether the ink impres-
sion is within acceptable limits.

Two variations of the tester are in
use. One is for sheet-fed presses and
makes a test on a sheet of paper taken
from the press. The second, which is
the one shown in the accompanying
photograph, is designed for presses
that use a continuous roll of paper.
In this arrangement the special probe
attaches to the press where it continu-
ously monitors a test impression
printed on the paper edge.

**SPECIFICATIONS**

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**MODEL 4288**

**CLIP-ON DC MILLIAMMETER**

Current Range: Full scale readings from 1 ma to
10 amperes in 9 ranges. 1-30 sequence.
Accuracy: ±3% of full scale ±0.1 ma.
Probe Inductance: Less than 0.5 ph. No notice-
able loading, even up to 1 mc.
Probe Induced Voltage: Less than 15 mv peak
(On 10 kc and harmonics).
Output: (a) Calibrated output: 1 volt ±3% across high-impedance loads or (b) Adjust-
able output: Adjustable up to approx. 1.5 volts maximum across loads of 1400 or more
ohms.
Output Bandwidth: dc to 400 cps (min. 3 db point).
AC Rejection: AC with peak value less than full
scale affects meter accuracy less than 2% at frequencies above 5 cps and different from the
carrier (20 kc) and its harmonics. (On 10
amperes range, ac is limited to 4 amperes
peak.) Below 5 cps total instantaneous cur-
rent must not exceed full scale.
Probe Insulation: 300 volts, maximum.
Probe Tip Size: Approximately ½ in. by 9/32
in. Aperture diameter 3/16 in.
Power: 115 to 230 volts ±10%, 50 or 60 cps,
approximately 70 watts.
Dimensions: Cabinet Mount. 7½ in. wide, 11½ in. high,
14½ in. deep, Rock Mount. 19 in. wide, 7 in. high, 13 in.
deep behind panel.
Weight: Cabinet Mount: Net 19 lbs. Shipping 24 lbs.
Rock Mount: Net 24 lbs. Shipping 35 lbs.
Prices: hp- Model 4288, Cabinet Mount, $550.00.
—hp— Model 4288R, Rock Mount, $555.00.

Prices f.o.b. Palo Alto, Calif.
Data subject to change without notice
AN INSTRUMENT FOR AUTOMATICALLY MEASURING FREQUENCIES FROM 200 MC TO 12.4 GC

IN the microwave field the demands of doppler tracking, spectrum analyzing and similar work are resulting in signal sources of increased stability. Consequently, the ability to make precise frequency measurements in the microwave region has become increasingly important.

At present, measurements can be made up to 510 mc with an accuracy of up to 3 parts in 10^8 using the -hp- Model 524 series Frequency Counter in conjunction with the -hp- Model 525 series Frequency Converter. Above 510 mc measurements are made using the Counter and Converter in combination with a transfer oscillator such as the -hp- Model 540A or 540B. The Transfer Oscillator provides for manual zero-beating of one of its harmonics against the unknown signal to frequencies as high as 12.4 gc. Reading the Transfer Oscillator frequency on the Counter/Converter combination then yields the value of the unknown frequency with a high accuracy determined by the accuracy of zero-beating. On clean signals, accuracies of 1 part in 10^7 can be achieved. This arrangement is a convenient one and is currently in wide use. However, when the signal contains f-m or is drifting at a moderate rate, it becomes more difficult to obtain an accurate or meaningful reading.

To permit not only measuring the frequency of these difficult signals more accurately and conveniently than previously but also to permit more information to be obtained about the signal than is obtainable with the manual-visual link method, an automatic zero-beating process or equivalent effect is needed. This has now been designed in the form of a closed-loop phase control system provided by the Dymec DY-5796 Transfer Oscillator Synchronizer shown in Fig. 1. The Synchronizer connects to the Transfer Oscillator as shown in Fig. 2. In operation it controls the frequency of the Oscillator so that a harmonic thereof is phase-locked to the frequency being measured. The Oscillator frequency is then measured by the Counter/Converter in the regular way. If desired, the Counter readings can be recorded in digital and/or analog form so that a continuous record of the Oscillator frequency (and hence the drift in the initial measured signal) can be obtained, as indicated in Fig. 5.

![Fig. 1. Model DY-5796 Synchronizer produced by -hp's Dymec division enables frequency measurements to be made automatically from 200 mc to 12.4 gc with -hp- transfer oscillator and frequency counter. Unit is particularly valuable when measured frequency is drifting or has residual f-m.](image1)

![Fig. 2. Synchronizer locks harmonic of transfer oscillator to measured signal; transfer oscillator frequency is then measured by counter in usual way. Visual records of measurement can be made as shown. Residual f-m in measured signal can be examined via output provided on Synchronizer.](image2)

![Fig. 3. Oscillogram of residual f-m in a 10 kmc measured signal made using setup of Fig. 2. Vertical sensitivity is 25 kc/division. Sweep time is 5 milliseconds/cm.](image3)

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signal. A typical example of f-m information extracted by this technique is shown in Fig. 3.

SEARCH PROVISION
The Synchronizer is also arranged so that it can cause the Transfer Oscillator to search for a signal to which it is only approximately tuned or to automatically resynchronize with a signal that has been interrupted. To accomplish this, the Synchronizer is provided with a set of Search Input terminals on the rear panel. An external voltage such as a 60 cps signal can be applied to these terminals to cause the Transfer Oscillator to sweep. If the signal is passed, a capture is made and the Oscillator locks onto the signal. The maximum search range varies from about 25 mc at 12.4 gc to 1 mc at 500 mc.

AUTOMATIC CONTROL ARRANGEMENT
The phase locking achieved by the Synchronizer provides absolute synchronization of the external signal and Transfer Oscillator harmonic and eliminates zero-beat errors. In order to give direction sense to the system, a reference or frequency offset of 30 mc is used. No measurement error is introduced by this technique, since the offset is obtained from the time base in the Counter by tripling its 10 mc standard frequency. Offset is accounted for by adding 30 mc to the indicated transfer oscillator frequency after multiplying by the harmonic number. Overall measurement accuracy of a direct frequency measurement is that of the Counter time base (typically in the order of 5 parts in 10^8).

Fig. 6 shows a more detailed block diagram of the Synchronizer and associated instruments. The signal and Transfer Oscillator frequencies are compared in a harmonic mixer (which is part of the Transfer Oscillator circuitry) in the same manner as a manual comparison. However, the mixer output, which is at 30 mc, is fed directly to the Synchronizer instead of to the video (output) amplifier in the Transfer Oscillator.

The mixer output is amplified in the Synchronizer in a wide band i-f amplifier and limiter and applied to a balanced cosine phase detector. The limiter eliminates any a-m that may be present, which would otherwise contribute to unwanted f-m on the Transfer Oscillator signal. Adequacy of limiting is indicated on the front panel LEVEL SET meter, which also provides an indication of proper signal level adjustment. A broad green area on the meter scale indicates the satisfactory level. A front panel control enables the i-f gain to be adjusted to correspond with associated signal coupling equipment.

Fig. 7 shows a more detailed block diagram of the Synchronizer and associated instruments. The signal and Transfer Oscillator frequencies are compared in a harmonic mixer (which is part of the Transfer Oscillator circuitry) in the same manner as a manual comparison. However, the mixer output, which is at 30 mc, is fed directly to the Synchronizer instead of to the video (output) amplifier in the Transfer Oscillator.

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EXTRACTING RESIDUAL F-M
In addition to frequency and drift measurements, useful information about the f-m present on the signal can be obtained as a result of the tight lock between the signal and the Transfer Oscillator. This occurs because frequency variations are converted to voltage in the Synchronizer phase detector and applied to the Transfer Oscillator to correct its frequency. This voltage is thus a useful analog of frequency—its ac component indicates the presence of f-m on the signal. Hence, a pair of front panel terminals labeled Deviation Output are provided on the Synchronizer to make this voltage externally available. These terminals then enable an oscilloscope or vtvm to be connected for measuring both the amount and the components of f-m in the initial
The 10 mc reference signal from the counter is amplified in a separate channel and tripled in frequency to generate a 30 mc signal reference. A delayed agc loop in this channel maintains a constant reference level into the phase detector. When sufficient i-f signal is also applied (as indicated by the Level Set meter) to produce limiter action, the detector sensitivity is constant and independent of signal and reference level variations.

Detector output is indicated on the meter and, after passing through a direct-coupled cathode follower, is available as a frequency control signal for the Transfer Oscillator. The output is a cosine function of phase difference and has a peak value of 7 volts. A dc adjustment of the cathode follower output enables setting the average output level at zero.

DETERMINING HARMONIC NUMBER

Since the transfer oscillator range is from 100 to over 200 mc, the possible number of harmonics that could be used to zero-beat with the signal frequency is at least equal to the signal frequency divided by 200 mc, e.g., at 12 gc/s there are more than 60 harmonics available. The number can be doubled because the Synchronizer can be locked with an oscillator harmonic either 30 mc above or below the signal frequency. This results in pairs of lock-in points separated by 60/N mc on the oscillator dial. This "pairing" of lock-in points provides an easier means of determining the harmonic in use than is possible without the Synchronizer. The operator notes the frequency reading on the counter at each of a pair of lock points, and divides their difference into 60 to obtain the harmonic number. The signal frequency is the counter reading multiplied by the harmonic number, plus or minus 30 mc/s depending on whether the upper or lower frequency is used.

TRANSFER OSCILLATOR FREQUENCY CONTROL

A minor modification to the automatic frequency control system of a standard -hp- 540A or 540B Transfer Oscillator provides an increased range of control for use with the DY-5796 Synchronizer. (A modification kit, available from Dymec, includes the necessary components and a new frequency dial that reflects the change in the upper frequency of the transfer oscillator from 220 mc to 210 mc.)

CAPTURE AND LOCK RANGE PARAMETERS

The ±7 volt control voltage from the Synchronizer produces at least ±0.05% change at 100 mc and ±0.2% at 200 mc in a modified Transfer Oscillator. The reduction in control at the low frequency end is due to a swamping effect caused by the higher tuning capacity, and points out the desirability of using the highest possible tuning range to obtain the greatest control range. The control range, expressed as a percentage, also defines the signal frequency lock range; thus, ±0.2% at 12.4 gc corresponds to a 50 mc range. A typical curve of lock range versus dial setting is shown in Fig. 7.

Whenever feedback is employed in a control system, the effect of loop gain and bandwidth variations on stability must be considered by the designer. In this system, the loop gain is a function of the harmonic used, since the i-f frequency is obtained by comparing the signal with an oscillator harmonic. Stable control loop design requires the capture range to be less than the open-loop bandwidth of the system. However, the lock-in range \( f_l \) can be made much greater than the open-loop bandwidth, and is expressed as follows:

\[
 f_l = 2K_1K_2N
\]

where \( K_1 \) is the detector sensitivity in volts per radian

\( K_2 \) is the oscillator control slope in mc per volt

\( N \) is the harmonic number

Typical values are

\( K_1 = 7 \) volts per radian

\( K_2 = 0.1 \) mc/s per volt (at 200 mc dial setting)

\( N = 60 \) (at 12.4 gc)
This results in a maximum lock-in range of about ±40 mc at 12.4 gc. Because of control slope non-linearity and conservative rating practices, a lock-in range of ±25 mc (±0.2%) is guaranteed at 12.4 gc. The capture range is limited to a value less than the system bandwidth, or typically 1 mc.

To capture a signal and obtain synchronization, the Transfer Oscillator must be tuned so that the difference frequency is very close to 30 mc. Normally, it is tuned through the proper point in order to capture the signal and then settled back into the wide lock-in range. The lock-in range is centered by tuning the Transfer Oscillator to indicate center frequency. F-M MEASUREMENTS

The amount and nature of incidental f-m in the measured frequency range can be obtained from the oscillator control voltage made available at the Deviation Output terminals on the front panel. The sensitivity of this measurement is directly related to the slope of the oscillator frequency control circuit. At a dial setting of 200 mc, the slope is about 100 kc per volt. The signal deviation is determined by multiplying the oscillator deviation by the harmonic number. The oscillator control slope can easily be measured by using a variable voltage source and the -hp- 524/525 Counter/Converter at various dial settings.

One error source should be considered in applying this technique. The measured f-m is slightly less than the signal f-m, because the control loop gain is finite and a function of oscillator and modulating frequencies as well as harmonic number. The f-m, measured at dial settings around 200 mc, will be within 5% of the signal f-m for modulating frequencies below 7 kc and harmonics above the first. The 5% error limit increases to 50 kc as the harmonic number reaches 60. (This is approximately proportional to the root of the harmonic number.) The maximum f-m deviation that can be handled without loss of synchronization is obtained when the oscillator is tuned for zero phase error indication, thus centering the f-m in the lock range. In this condition, f-m at rates up to 1000 cps can be measured to the full limits of the lock-in range of ±0.2%. Above 1000 cps, the maximum permissible deviation is reduced by 20 db per decade.

The minimum measurable f-m is limited by the residual f-m of the Transfer Oscillator itself. This is typically 150 cps peak deviation at dial settings around 200 mc, or less than ±0.001%. This occurs principally at a 60 cps rate.

ACKNOWLEDGMENT

The design of the Synchronizer was based on a technique developed by Duane Marshall in the -hp- Frequency and Time Engineering Department. The design group at Dymec included John Hasen, who performed the circuit development, and Kenneth G. Wright, who performed the mechanical design.

—Albert Benjaminson

OVERALL SPECIFICATIONS

(Transfer Oscillator plus Counter plus Synchronizer)

Frequency Range: 0.2 to 12.4 gc.

Sensitivity: -10 dbm minimum signal input at 12.4 gc, increasing to -40 dbm at 200 mc.

Lock-On Range: ±0.2% of signal frequency maximum. (Depends on Transfer Oscillator setting, see Fig. 7 in text.)

Accuracy: ± Stability ± resolution; see following entries.

Stability: 3/10° short term, 5/10° per week.

May be used with external frequency standard, e.g., -hp- 103AR for 5/10° per day.

Resolution: ±1 count at transfer oscillator frequency equivalent to 5/10° with 1-second counter gate, or 5/10° with 10-second gate (at 200 mc oscillator setting).

F-M Measurement: Deviations up to lock-on range at rates to 1 kc. Above 1 kc deviation limit reduced at 20 db/decade to maximum of 0.001% of 200 kc.

SPECIFICATIONS

DYMEC MODEL 5796 SYNCHRONIZER

Input Requirements:

30 mc Input: 150 µv rms minimum (front panel BNC).

100 mc Input: 0.8 µv rms minimum (front panel BNC).

Error Signal Output: ±7v maximum for full lock-on range (rear panel BNC).

Deviation Output: 14v peak-to-peak at modulation rates up to 1 kc. Decreases at 20 db/decade to rates to 200 kc. (Available at front panel binding posts).

Search Voltage Input: Capture point may be varied over desired part of lock range by application of dc to 60 cps signal, ±7v peak maximum. (Rear panel binding posts.)

Power Required: 115/230v ± 10%, 50-1000 cps, 35 watts.

Dimensions: 19" wide, 5½" high, 9½" deep.

Weight: 14 lbs. net, 22 lbs. shipping.

Price: DY-5796 Transfer Oscillator Synchronizer (rack mount) $585.00

All prices f.o.b. Palo Alto, California

Data subject to change without notice

Dymec

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