



A New Microwave Modulator

A NEW modulator has been designed which substantially simplifies the task of amplitude-modulating microwaves in the range from 800 to 2400 megacycles. Basically, the new modulator is an electrically-variable attenuator whose attenuation can be changed

SEE ALSO:

Sensing magnetic fields, p. 7
The Smith Chart with negative Z, p. 8
New Prefixes, p. 8

very rapidly. Its properties include fast rise and decay times of less than 20 nanoseconds, an on-off ratio of 80 db, and the fact that it is solid-state. It will handle up to one watt of microwave power and can also be used at low level,

since internally-generated noise is small. Modulation can be obtained from internal or external pulses or square waves or from external sine waves. The internal circuits include delay and width circuits which are adjustable down to 0.1 microsecond and which are jitter-free.

The new modulator operates by absorbing the microwave energy applied to it, as opposed to other solid-state modulators which reflect it. The instrument thus minimizes the difficulties associated with reflection. Reflections can, for example, pull the frequency of tightly-coupled microwave oscillators and therefore cause frequency modulation. Large reflections can also permanently damage some sources such as traveling-wave-tube amplifiers.

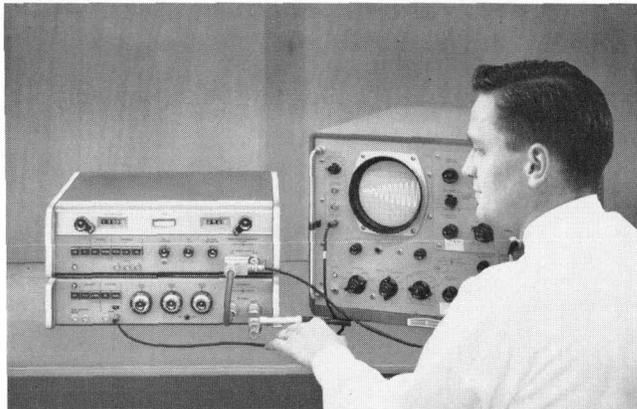


Fig. 1. New -hp- Model 8714A Modulator gives wide versatility in modulating waves in the 0.8–2.4 Gc range and greatly reduces incidental FM and other effects. Trace on scope shows build-up of 1 Gc RF pulse, is described further on p. 4.

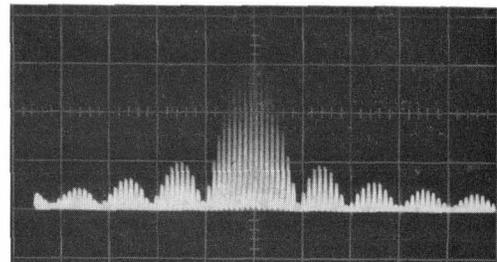


Fig. 2. Spectrogram taken of 2 μ sec RF pulse produced by new modulator. Symmetry of side lobes is a measure of freedom from incidental FM in RF pulses produced by modulator. Also see Fig. 6.

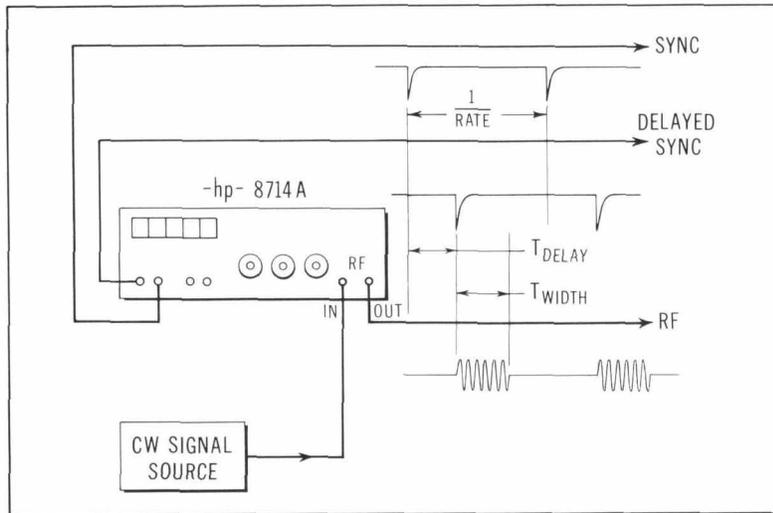


Fig. 3. Diagram indicating operating principle of new modulator. Modulation can be from internal pulses as indicated or by external pulses or sine waves.

The new device also has many advantages over the generally-used method of switching on and off a klystron oscillator. For example, the change in klystron cavity loading with consequent frequency instability during oscillation build-up is greatly reduced, as is jitter due to klystron starting irregularities. Also, rise time is shortened from about .1 μ s to under .02 μ s.

PRINCIPLE OF OPERATION

A typical example of the modulator in use is shown in Fig. 3. A microwave signal, normally CW, is fed into the RF input jack. In the various pulse modes of operation this signal is absorbed at all times except during the pulse itself. If an external sine wave is applied for modulation,

the absorption of the RF wave occurs in accordance with the instantaneous amplitude of the modulation waveform.

The modulator consists of the attenuator and the solid-state circuits necessary for flexible modulation by the attenuator. The attenuator is comprised of *p-i-n* diodes mounted in shunt across a strip transmission line.

P-i-n diodes resemble ordinary semiconductor diodes except that an intrinsic or *i* layer is interposed between the *p* and *n* sides. Charge storage in this layer makes the diodes poor rectifiers above a few Mc and they act as linear resistors at microwave frequencies. When reverse-biased, the diodes are an open circuit except for their small capacity and

cause negligible attenuation to microwave signals traveling down the 50-ohm transmission line. When forward-biased, the resistance decreases to as little as 30 ohms, causing considerable attenuation. The attenuating array is tapered in the amount of attenuation (or resistance) per diode so that maximum attenuation (minimum resistance) occurs at the center of the array and the ends attenuate enough to absorb reflections from the high-attenuation center portion. At 80 db of attenuation, the VSWR looking into either RF port is less than 2:1. At minimum attenuation, the VSWR is less than 1.5:1. Additional design information is available from Hunton and Ryals.¹

CIRCUIT ARRANGEMENT

A simplified block diagram of the circuits included in the modulator is shown in Fig. 5. Since considerable charge is stored both in the *p-i-n* diodes and on the transmission line which holds the diodes, it is necessary to move this charge rapidly to achieve fast variations in RF level. For this reason the video pulses applied to the diodes via the transmission line are shaped to have large amounts of overshoot and undershoot. For amplitude modulation or for continuous attenuation control by external signals, a converter is included to protect the *p-i-n* diodes

1. J. K. Hunton and A. G. Ryals, "Microwave Variable Attenuators and Modulators Using P-I-N Diodes," IRE PGMTT Transactions, Vol. 10, No. 4, July, 1962, p. 262.

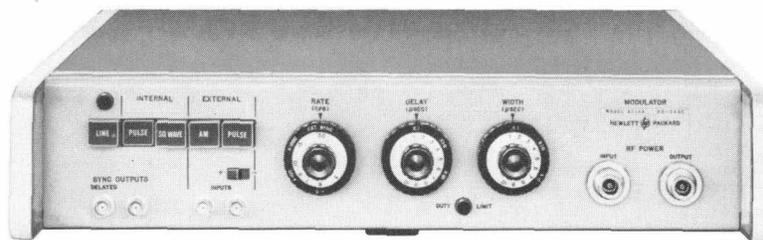


Fig. 4. New -hp- Model 8714A Modulator accommodates RF levels to 1 watt. Rise time on pulse modulation is 20 nsec; on-off ratio is 80 db.

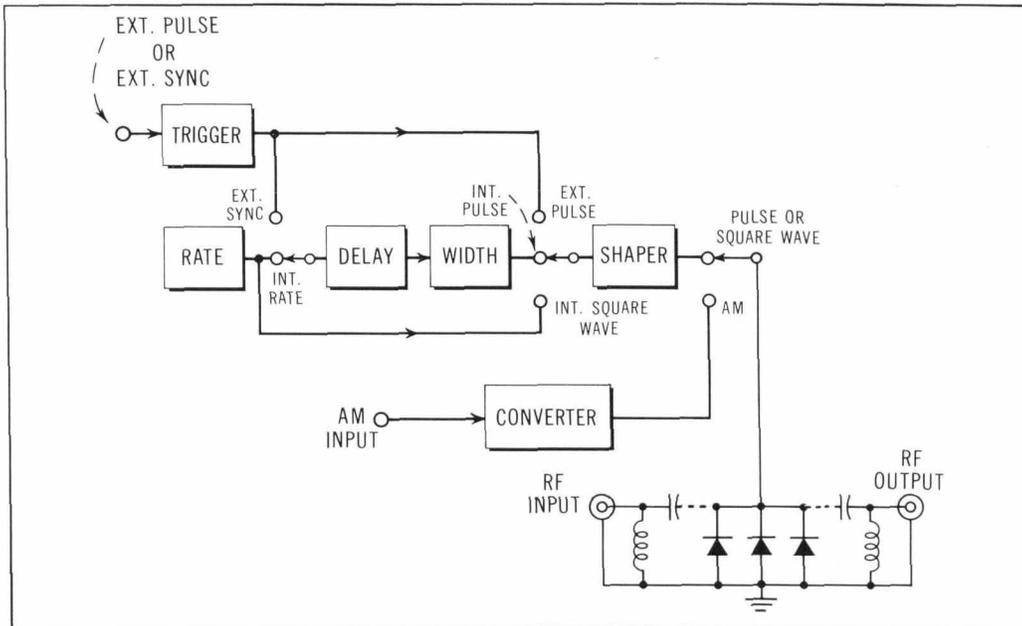


Fig. 5. Basic circuit arrangement of hp-Model 8714A Modulator. Modulating mechanism is an array of *p-i-n* diodes acting as an electrically-controlled microwave attenuator.

from being accidentally overdriven and to present a more convenient input impedance instead of the very low impedance level of the forward-biased diodes. The remaining portions of the block diagram indicate the logic involved to achieve maximum utilization as a pulse modulator.

The circuitry and other aspects of this instrument were designed to cover as many modulation require-

ments as possible. A very flexible Schmidt trigger is used for external pulse and external sync applications. A choice of triggering on positive or negative signals or on positive or negative portions of a sine wave is available. Protective circuits are also included at the input so that input voltages up to 50 volts will not damage the fast and sensitive circuits. The input jack is dc-coupled to permit low frequencies or dc to be used

to switch the *p-i-n* diodes from minimum to maximum attenuation. The dc coupling also allows a sequence of irregularly-spaced pulses to be applied to the external modulation jack with no integration effects common to most ac-coupling techniques.

PULSE SPECTRUM

It is of interest to examine the oscillograms of a spectrum analyzer presentation of the modulator output

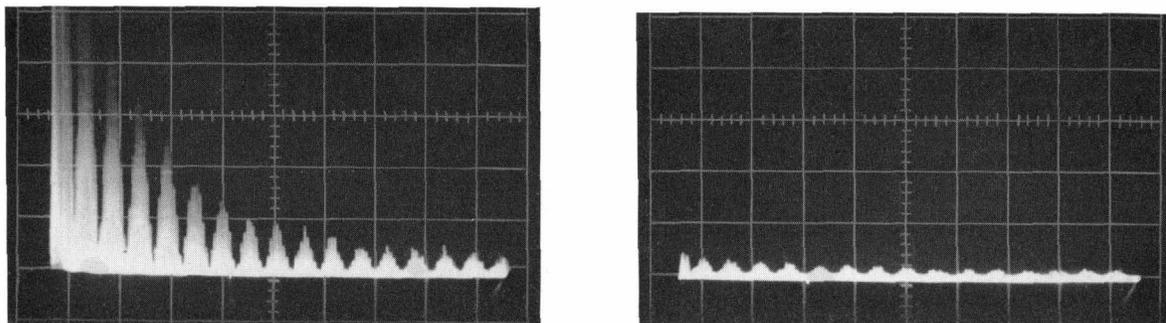
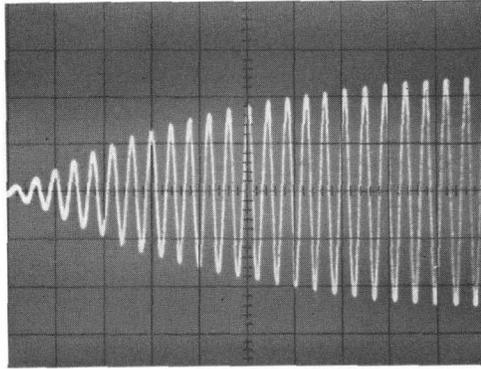


Fig. 6. Spectrogram of same 2 Gc, 2 μ sec RF pulse in Fig. 2 showing 33 side lobes, indicative of fast rise and decay of pulses produced by modulator.



RF PULSE CHARACTERISTICS

The unusual oscillogram appearing above shows the fast rise of the RF pulse produced by the new modulator described in the accompanying article. The oscillogram is that of the growth, cycle by cycle, of the RF pulse. The RF wave is a 1 Gc (kMc) sine wave, and is displayed by an *-hp-* Model 185B Sampling Oscilloscope.

To obtain the oscillogram, the external sync mode of operation was used in which the oscilloscope was synced from

the 1 Gc signal. The counted-down sync output of about 100 kc from the oscilloscope was then used to sync the internal video-pulse-generating circuits of the modulator. Since many hundred samplings are used to form the trace on the sampling oscilloscope, it is evident that the modulator circuits, as well as the oscilloscope countdown circuits, have a very small amount of jitter ($\ll 1$ nsec). Otherwise a photograph such as that above would be impossible.

in Fig. 2 and 6. Fig. 2 shows the pulse rate, pulse width, and also the lack of frequency modulation during pulse time. If an appreciable amount of FM existed, the spectral response would not be symmetrical about the carrier frequency. Fig. 6 shows the first 33 side lobes of spectral response. Such an extensive portrayal of side lobes is only possible with very rectangular pulses. The special photographs thus indicate the fast rise and decay times of the RF signal.

CONTINUOUS MODULATION

Continuously-variable modulation is possible by varying the control current through the diodes. Even though the attenuation in db varies linearly with the bias current, the assumption of linear modulation of RF voltage with video current presents small errors in most amplitude modulation requirements. Fig. 7 shows the envelope distortion when

a sine-wave-modulated signal from the modulator was passed through a linear detector. It is also possible, by using a rear panel control, to modulate about any desired attenuation level. Thus a setting of the control to about 6 db attenuation allows equal excursions of RF voltage

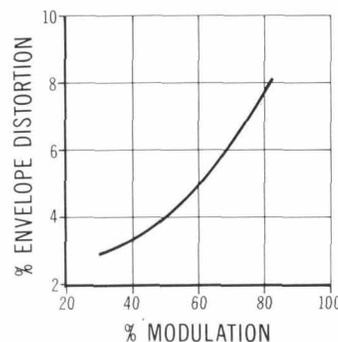


Fig. 7. Typical performance of new modulator as to envelope distortion on sine-wave modulation.

above and below the half voltage point. Setting the control to minimum attenuation and having no input to the AM jack gives minimum attenuation or a CW mode of operation. The variable attenuator is also useful in leveling applications where the attenuator is part of a feedback loop which is controlled in such a way that the attenuator output power is constant. This is illustrated in Fig. 8.

The flexibility achieved by the ability to modulate with external pulses combined with the ability to amplitude modulate is indicated by the oscillogram in Fig. 9. Two modulators were connected in series. The first was operated in the external pulse mode of operation and was driven by pulses of different widths and unequal spacings. The second was operated in the AM mode and was driven by a sine wave oscillator which was synchronized with the pulse into the first unit. A close examination of the pulse tops shows portions of the sine wave used to amplitude modulate. Although it is not evident on this oscillogram, the rise and decay times of the pulses are still less than 20 nsec.

PHASE SHIFT INDEPENDENT OF ATTENUATION

Another outstanding feature of the modulator is its small phase shift as attenuation is varied. Preliminary

observations indicate phase shifts of 1° or less for attenuations of 20 db or more. Such small phase shift should be an important asset in applications where amplitudes of signals must be controlled independently of the phase.

RF HARMONIC GENERATION

RF harmonic generation by the *p-i-n* diodes used in the modulator is small. To date, the largest harmonic content experienced has been 30 db below the fundamental when the diodes were in their minimum attenuation condition. At maximum attenuation (at least 80 db) those harmonics whose frequency was within the instrument passband (0.8 to 2.4 Gc) were lower than the fundamental output and too small to be readily measured. Those harmonics that occurred above the passband (above 2.4 Gc) were at least 50 db below the fundamental input. The above measurements were made with 1 watt of fundamental input to the *p-i-n* diodes. As this fundamental power is reduced, the harmonic generation becomes an even smaller percentage of the fundamental input power.

NOISE LEVEL

The noise contributed to a system by the modulator is, in most cases, negligible. When the attenuator was used as a noise source, at 10 db attenuation, the noise output was less than 2 db above that of a passive termination at room temperature. At 80 db of attenuation the noise output was less than 5 db above that of a passive termination.

OTHER ADDED FEATURES

Several other features of the modulator deserve mention. The unit is capable of attenuating up to 1 watt of microwave energy without permanent damage. Radio frequency interference filters are included to prevent modulating signals containing high frequency components from

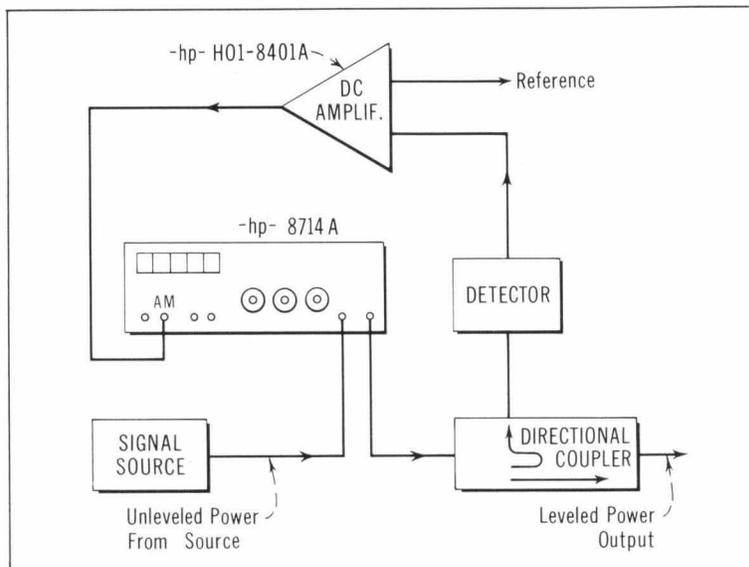


Fig. 8. Equipment arrangement for leveling power output from unleveled power sources.

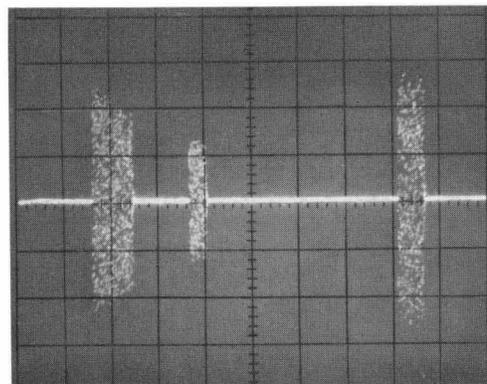
being transmitted to the ac power line. Included at each end of the *p-i-n* diode array are high-pass filters designed to keep the modulating signal off the RF terminals. The modulating signal at the RF ports is so small that attempts to measure it have proven futile. When in the 1000-cycle square wave mode of operation, it can safely be said that the 1000-cycle signal appearing at the

RF terminals when the microwave input is zero is less than $0.02\mu\text{v}$.

Finally, the frequency band is not sharply limited at either .8 or 2.4 Gc. Operation of a quality sufficient for many applications is available from about .5 to 3 Gc.

Similar modulators for higher microwave bands are in the design stage and will be announced later in the year.

Fig. 9. Oscillogram showing versatility of new Modulator in modulating with difficult waveforms. Envelope shown was obtained on 1 Gc carrier by operating two modulators in series. One was externally pulsed by unequally-spaced pulse train. Second was externally driven with sine wave. Sine wave envelope can be seen on pulse tops.



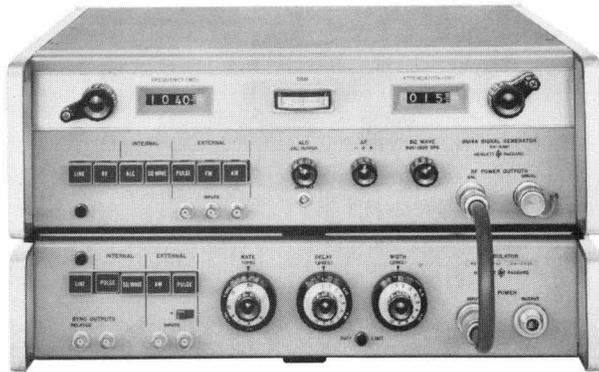


Fig. 10. -hp- 8714A Modulator (lower unit) shown with new -hp- 8614A 0.8-2.4 Gc Signal Generator to be described in future issue.

ACKNOWLEDGMENT

The author is indebted to J. Keith Hunton and Auber G. Ryals for their work on the attenuator design and also to those people mentioned in their article¹ who helped develop *p-i-n* diodes. Others who participated in the development of the in-

strument were John C. Shanahan, Douglas A. Gray, Wayne A. Fleming, Lawrence B. Renihan, and Thomas K. Werrick. Thanks must also be given to Dr. George W. C. Mathers for his many suggestions and constant guidance.

—Nicholas J. Kubn

SPECIFICATIONS -hp- MODEL 8714A MODULATOR

FREQUENCY RANGE: 800 to 2400 Mc.

INSERTION LOSS: Minimum 1.2 ± 0.5 db. Maximum: more than 80 db.

RF INPUT POWER: Maximum 1 watt.

SWR: 1.5 maximum at minimum attenuation. 2.0 maximum at 80 db attenuation.

INTERNAL MODULATION

SQUARE WAVE:

FREQUENCY: Continuously variable from 50 cps to 50 kc, 3 decade ranges.

SYMMETRY: Better than 40/60%.

RF PULSE: RISE TIME: Less than 20 nsec. DECAY TIME: Less than 20 nsec.

PULSE:

REPETITION RATE: Continuously variable from 50 cps to 50 kc, 3 decade ranges.

DELAY: Continuously variable from 0.1 μ sec to 100 μ sec, in 3 decade ranges between sync out pulse and RF output pulse.

WIDTH: Continuously variable from 0.1 μ sec to 100 μ sec in 3 decade ranges.

EXTERNAL SYNC

AMPLITUDE: 5 volts to 15 volts peak.

WAVEFORM: Pulse or sine wave.

POLARITY: Either positive or negative.

INPUT IMPEDANCE: Approx. 600 ohms, dc coupled.

RATE: 1 Mc maximum.

TRIGGER OUT:

SYNC OUT: 0.1 μ sec to 100 μ sec in advance of RF pulse, as set by DELAY control.

DELAYED SYNC OUT: Simultaneous with RF pulse.

AMPLITUDE: Approximately: 2.0 volts.

SOURCE IMPEDANCE: Approximately 500 ohms.

EXTERNAL MODULATION

PULSE INPUT:

AMPLITUDE AND POLARITY: 5 volts to 15 volts peak, either positive or negative.

REPETITION RATE: Maximum average PRF, 1 Mc/sec. Maximum peak PRF, 2 Mc/sec.

INPUT IMPEDANCE: Approx. 600 ohms, dc coupled.

MINIMUM WIDTH: 0.1 μ sec.

MAXIMUM WIDTH: $1/\text{PRF} - 0.4 \mu$ sec.

RF PULSE: RISE TIME: Less than 20 nsec. DECAY TIME: Less than 20 nsec.

CONTINUOUS AMPLITUDE MODULATION: MAXIMUM FREQUENCY: Approx. 10 Mc, sinusoidal.

LEVEL CONTROL: AM input is dc coupled, permitting control by bias of AM input; rear panel control for use with ac coupled modulation.

GENERAL

POWER REQUIREMENTS: 115 or 230 volts $\pm 10\%$, 50 to 1000 cps, approximately 10 watts.

DIMENSIONS: Cabinet Mount: $16\frac{3}{4}$ in. wide, 4 in. high, $18\frac{3}{8}$ in. deep, hardware furnished for conversion to 19 in. by $3\frac{1}{2}$ in. rack mount.

WEIGHT: Net 23 lbs. shipping 30 lbs.

PRICE: -hp- Model 8714A \$850.00.

Prices f.o.b. factory

Data subject to change without notice

A high sensitivity magnetometer probe now is available as an accessory to the -hp- 428A/B clip-on dc milliammeters. The probe can measure weak fields down to an inherent noise level equivalent to a reading of less than 10^{-5} gauss (1 gamma). This sensitivity is not impaired by temperature variations, which limit the low range performance of other types of magnetometers.

The new -hp- 3529A probe converts magnetic field strength at the

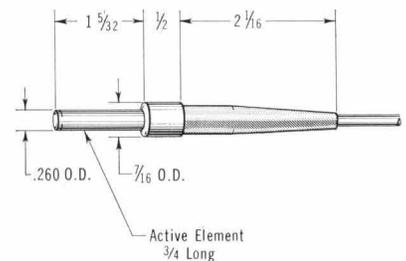
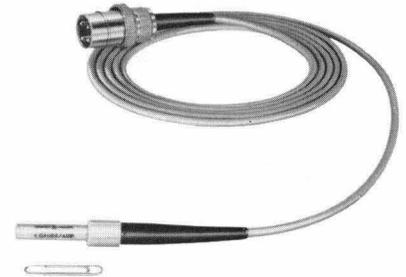


Fig. 1. -hp- Model 3529A Magnetometer probe measures magnetic field strengths of less than 1 milligauss.

probe tip to a meter deflection on a one gauss per ampere basis. Thus, a field strength of 1 milligauss deflects the meter full-scale to 1 milliamp on the most sensitive range of the 428B. The probe senses both dc and low-frequency ac fields and its maximum range is 10 gauss full scale.

Applications of this probe are

A CONVENIENT PROBE FOR SENSING MAGNETIC FIELDS



Fig. 2. Magnetometer probe being used to "sniff" external field from transformer. Waveform of ac field is displayed and measured on scope. DC fields are measured on -hp- 428B Milliammeter (upper unit).

many and varied. In amplifier design, for instance, the probe locates the area of minimum hum field for placement of sensitive signal transformers. Leakage fields from power transformers can be examined to determine how the transformers should be oriented for minimum interference with sensitive circuits. Furthermore, the magnetometer supplies information in meaningful numbers which are useful for specifying maximum permissible values of transformer leakage fields.

The high sensitivity enables small amounts of residual magnetism to be detected, such as in magnetically susceptible impurities in wattmeter eddy current damping discs (which could affect wattmeter performance). Because of the high sensitivity, the earth's field alone, about 400 milligauss, can overload the instrument on the *six* lowest ranges. To avoid earth's field effects, the probe

is clamped on a stand and oriented perpendicular to the earth's field by nulling the meter reading. The device to be checked is then rotated in front of the probe. If the device has residual magnetism, there is one maximum and one minimum meter deflection for each 360° of rotation. Two maxima and two minima during each 360° rotation show that the



Fig. 3. Probe operates in conjunction with -hp- 428B Milliammeter.

device is not magnetized but is permeable, "gathering" the flux lines of the earth's field.

In essence, the probe is a magnetic chopper which "gates" the ambient flux by periodic saturation of the magnetic core material. This gated flux induces an ac signal proportional to the ambient field in a sensing coil.

DC negative feedback from the 428A/B opposes the ambient field in the probe coil, resulting in high linearity and stability. Without any calibration, the instrument reads magnetic field strengths to an accuracy of 5% and when calibrated with a standard field, it reads with 3% accuracy.

Although designed for measuring dc fields, the probe is sensitive to low-frequency ac fields up to 80 cps. An output jack on the 428B enables examination of the low frequency ac components of a field with an ac voltmeter or oscilloscope.*

—Arndt Bergh

*D. E. Barkley and A. Bergh, "Broader Information Capabilities in the Clip-On DC Milliammeter," Hewlett-Packard Journal, Vol. 13, No. 3-4, Nov.-Dec., 1961.

SPECIFICATIONS

-hp- MODEL 3529A MAGNETOMETER PROBE

RANGE (with -hp- 428B milliammeter): 0.1 milligauss to 10 gauss. Nine full scale ranges from 1 milligauss to 10 gauss in 1, 3, 10 . . . sequence (0.3 milligauss to 1 gauss in 6 ranges with 428A).

CONVERSION FACTOR: 1 milligauss/milliamper (1 gauss/amp).

ACCURACY: ±3% of full scale from 0°C to +55°C (±5% if not calibrated with individual 428A/B).

OPERATING TEMPERATURE RANGE: -20°C to +55°C.

STORAGE TEMPERATURE RANGE: -40°C to +65°C.

OUTPUT FREQUENCY RANGE (with 428B): DC to 80 cps.

COMBINED NOISE AND SHORT TERM DRIFT: Typically less than ±.01 milligauss, peak-to-peak.

PROBE DIMENSIONS: 3-11/16 in. long; 1/4 in. diameter at probe tip, 7/16 in. maximum diameter. Cable: 7 feet long.

PRICE: -hp- 3529A Probe alone: \$75.00.

Prices f.o.b. factory

Data subject to change without notice

USING THE SMITH CHART WITH NEGATIVE REAL-PART IMPEDANCES OR ADMITTANCES

In high-frequency design work, impedance charts such as the Smith Chart are widely used to simplify design problems. The Smith Chart, though, since it is a plot of the right half of the complex impedance plane, does not include negative real-part impedances. Hence, to plot negative-impedance devices such as the Esaki diode thereon, a transformation must be used to transform the left half of the plane into the Smith Chart. Several transformations have been proposed in the literature which do this but they suffer from one or more disadvantages which make them difficult to use. The transformation described here allows the Smith Chart to be used directly without any modification or relabeling.

The rules for using the chart with negative real part impedances or admittances are:

1. Change the sign of the real

part of the impedance (admittance) only.

2. Normalize the impedances (admittance) in the usual way and plot on the chart.

3. The magnitude of the true reflection coefficient is the reciprocal of that read on the chart.

4. The true angle of the reflection is the angle read on the chart.

These rules may be justified by considering the equation which plots the Smith Chart:

$$\rho = \frac{\bar{z} - 1}{\bar{z} + 1}$$

where: ρ is the reflection coefficient

$\bar{z} = \frac{Z_L}{Z_0}$ is the complex normalized load impedance.

Let ρ' be the quantity that results if \bar{z} is replaced by $-\bar{z}$.

Thus:

$$\begin{aligned} \rho' &= \frac{-\bar{z} - 1}{-\bar{z} + 1} = \frac{\bar{z} + 1}{\bar{z} - 1} \\ &= \frac{1}{\rho} = \frac{1}{|\rho|} \end{aligned}$$

When working with lossy lines, it is necessary to draw a spiral increasing instead of decreasing as in the case of positive real part impedances.

Using two pencils with different colors, one Smith Chart can be used to represent the complete Z plane. Instead of going out of the chart, change the color of pencil and use the circle $r = 0$ as a reflector.

Impedances measurements can be made in the normal way with slotted line techniques.

$$VSWR = \frac{1 + |\rho'|}{1 - |\rho'|}$$

-Luiz Peregrino
and Harley L. Halverson

NEW SUBMULTIPLE PREFIXES

The National Bureau of Standards has announced that it will follow the International Committee on Weights and Measures in adopting two new prefixes for submultiples of numerical units. The new prefixes are *femto* (10^{-15}) and *atto* (10^{-18}).

Pronunciations of a few previously-adopted prefixes were also altered slightly. The present full list with pronunciations is given at right. These prefixes and symbols will also be standard in the *Hewlett-Packard Journal*.

Multiple/ Submultiple	Prefix	Symbol	Pronunciation
10^{12}	tera	T	tēr' à
10^9	giga	G	jì' gâ
10^6	mega	M	mĕg' à
10^3	kilo	k	kíl' ò
10^2	hecto	h	hĕk' tò
10	deka	da	dĕk' à
10^{-1}	deci	d	dĕs' ĭ
10^{-2}	centi	c	sĕn' tĭ
10^{-3}	milli	m	mĭl' ĭ
10^{-6}	micro	μ	mĭ' krò
10^{-9}	nano	n	năn' ò
10^{-12}	pico	p	pĕ' cò
10^{-15}	femto	f	fĕm' tò
10^{-18}	atto	a	ăt' tò