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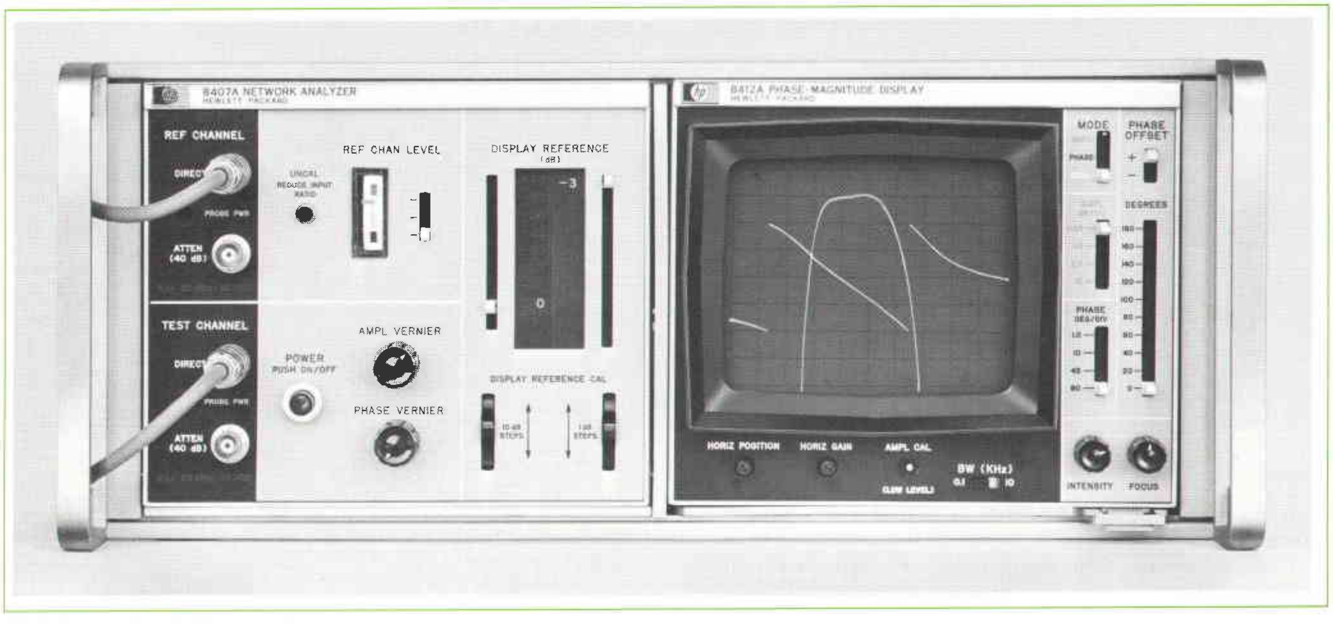
Network Analysis in the Range 100 kHz to 110 MHz

With speed and convenience, a new Network Analyzer presents swept display of amplitude response as great as 80 dB, yet achieves 0.05 dB resolution. Phase-measuring capability is comparable.

By William A. Rytand and David R. Gildea



NETWORK ANALYSIS HAS REVOLUTIONIZED DESIGN METHODS in microwave engineering. The big change resulted from the introduction of easily-operated wideband network analyzer equipment[1,2] in 1967. This equipment made it convenient and economical to make swept measurements over large frequency and dynamic ranges, displaying both magnitude and phase information simultaneously. The information could be read out easily in appropriate form for further computer manipulation. Together these capabilities have led to the near-demise of point-by-point design methods in microwave engineering.

Only recently has network analysis become similarly possible in the very important range 100 kHz to 110 MHz. There have been efficient, direct ways to measure magnitude and phase point by point across these bands;[3] separation of the real and the imaginary components of impedance, similarly on a point-to-point basis, can be accomplished without lengthy nulling or calculating functions.[4] Combinations of earlier equipment could make some valuable swept measurements.[5]

Only now, however, has a measuring method for this range combined the following list of desirable capabilities:

- Measure as much as 80 dB circuit gain or loss on a single swept display
- While thus showing magnitude, simultaneously display phase relations ±180°.
- Reject responses to signal-source spurious and harmonic signals
- On a swept CRT display, resolve amplitude to 0.05 dB, phase to 0.2°
- Achieve accuracies, in swept measurements, equaling and in some cases exceeding those previously common with CW methods.

The instrumentation is the Hewlett-Packard Network Analyzer, Model 8407A and associated equipment (Fig. 1 and Table I). The network analyzer requires one of two sweep sources. This may be either HP Model 8601A[6] or HP Model 8690B/8698B.

Fig. 1. *Network analyzer system for range 0.1 to 110 MHz includes optional plug-in displays. Two are shown here, Model 8412A Phase-Magnitude (partly installed) and Model 8414A Polar (above). In the foreground (left) is a new directional bridge with more than 40 dB directivity across the band of concern. Also shown are power splitter, passive probe and divider, parts of the transducer kits designed for the system.*

TABLE I

MODEL	FUNCTION	RANGE
	Mainframe	
8407A	Network Analyzer Mainframe, with Plug-in position for optional displays. Converts RF test frequencies to a low, constant IF, at which all measurements are made. Tracks only the fundamental of swept test signal.	0.1–110 MHz
	Sources	
8601A	Generator/Sweeper	0.1 to 110 MHz
8690B/ 8968B	Sweep Oscillator/Plug-in RF Unit	0.4 to 110 MHz
	Transducers	
11651A	Transmission kit. Power splitter receives swept signal from source, delivers equal signals to *reference channel* of 8407A Mainframe, and to input of device under test. Interconnecting test cables are matched for phase shift to avoid need for line stretcher or compensating calculations. See Fig. 3.	0.1–110 MHz
11652A	Transmission-reflection measuring kit Power splitter, as above, directional bridge, calibrating short, precision termination, and interconnecting cables matched for ϕ shift. Same facility for measurements as 11651A, plus capability for swept return loss (VSWR) and reflection coefficient complex impedance measurements. See Fig. 4.	0.1–110 MHz
11654A	Passive probe kit. Especially useful for circuit breadboards or circuits not in 50-ohm transmission line. Includes two each of probe cables, current probe tips, voltage probe tips, and a variety of accessories for grounding and getting at circuitry details.	0.1–110 MHz
	Displays	
8412A	Plug-in rectangular CRT readout, able simultaneously to show log amplitude vs frequency as one trace, and phase vs frequency as the other trace. Especially useful for transmission gain or loss measurement, and return loss (VSWR) measurements.	**Amplitude:** 10 dB/div (80 dB on-screen range) to 0.25 dB/div (resolving 0.05 dB on CRT). **Phase:** 90°/div (±180° on screen) to 1°/div (resolving 0.2° on CRT display).
8414A	Plug-in polar display with round-screen CRT to show amplitude and phase. Especially useful for complex impedance with Smith chart overlay, or reflection coefficient measurement.	**Amplitude:** Normalized in 0.2-of-full-scale gradations. **Phase:** 10° increments over 360° range.
8413	Plug-in analog meter readout of phase in ° or gain in dB, with rear outputs simultaneously for each, proportional to reading, for 'scope, X-Y recorder, or digital meter. Especially useful for CW measurements, but may be slowly swept for X-Y recording.	**Frequency:** 0.1 to 110 MHz or any segment thereof. **Amplitude:** Full scale to 60 dB. **Phase:** Full scale ±6° to ±180°.

Cover: *Model 8407A Network Analyzer System reveals transmission characteristics of a multi-pole bandpass filter, displays amplitude and phase response. Capabilities formerly confined to microwave equipment are brought to the range 0.1 to 110 MHz by the new system. Story begins on page 2.*

In this Issue:

Measuring Method

No matter if the measurement is of transmission (Fig. 2) or reflection (Fig. 3), one signal is taken as reference and fed to the *reference* channel of the instrument while a second signal, taken from the test device, connects to the *test* channel of the instrument. The measuring function is to compare the two in amplitude and phase.

Frequency range displayed by the Analyzer for any given measurement is determined by the setting of the associated swept signal source; sweeps may be narrow or the full 110 MHz range of the instrument. Perhaps the most notable of its characteristics, however, is its breadth of range in displaying gain (or attenuation) and phase. With the 8412A Phase-Magnitude readout it is possible to see 80 dB of dynamic range on the screen, accurately calibrated at 10 dB per division. If high resolution is needed, rather than great range, the amplitude-response setting may be as fine as 0.25 dB per division at which the eye can easily resolve differences as small as 0.05 dB on the CRT. This, it may be noted, is possible in *swept* operation. At the same time and on the same screen, with a separate trace, phase versus frequency may be shown. The range can be 90° per division, so ±180° is viewed all at once, or it can be as fine as 1° per division. At this setting the eye can plainly resolve differences as small as 0.2°. Still higher resolution is possible if the rear outputs, each proportional to measurement, are read with such auxiliary devices as an X-Y recorder or a digital voltmeter.

Theory of Operation

Fig. 4 shows a block diagram of the system. The frequency conversion principle used in the Network Analyzer is fundamental mixing. This principle is also used in both HP sweepers which are usable with the system (Models 8601A and 8690B/8698B). In the sweeper a voltage-tuned oscillator (VTO) is tuned from approximately 200 to 310 MHz and mixed with a 200 MHz crystal oscillator (XO). The result is a swept output to 110 MHz. This output is split, one part connected to the analyzer's reference input, the other to the device under test. The signals in both channels are converted to 278 kHz (IF) by the input converters, which preserve both amplitude and phase. Tracking AGC amplifiers are used to normalize the level of the test channel signal to that in the reference channel.

After passing through a precision attenuator, the test channel is split into two, one to test *phase* and the other to test *amplitude*. In the Model 8412A plug-in the test-phase signal is amplified and limited. Two functions are accomplished:

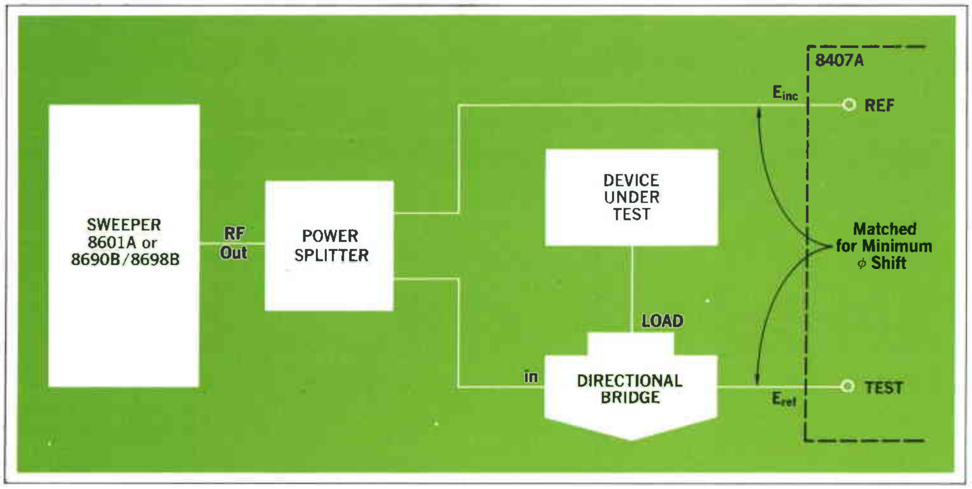


Fig. 2. *Transmission characteristics of test device are anaistics of test device are analyzed by comparing signal directly from source with signal which has passed through the device.*

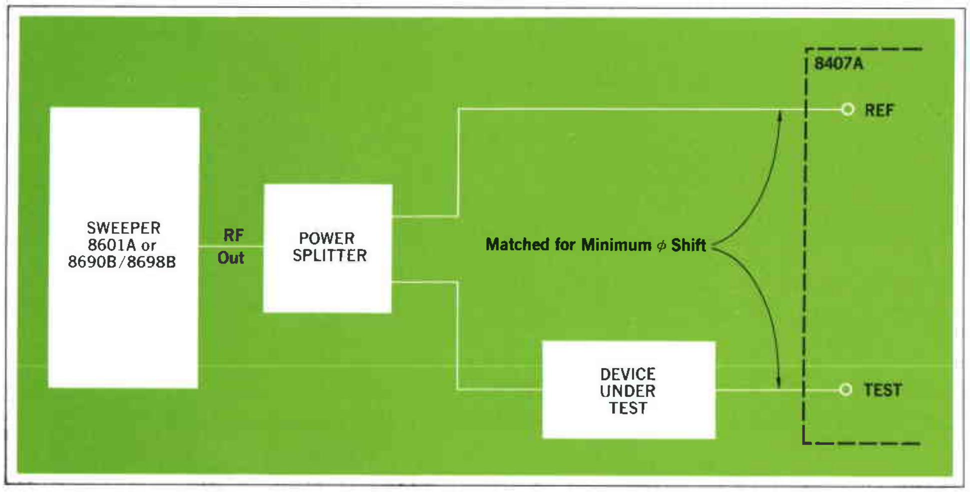


Fig. 3. *Before measuring reflection, the system is calibrated by having an open on the* **load** *port of the bridge, and adjusting the display to 0 dB and 0°. Upon connecting the test device, return loss and phase are shown directly on the 8412A Phase-Magnitude Display, or complex impedance may be read directly if the 8414A Polar Display is used with a Smith Chart overlay.*

1) A very fast zero crossing is obtained, which is used for the phase measurement.
2) A square wave constant-amplitude drive is obtained, which is used to drive the amplifier detector.

The test-*amplitude* signal is amplitude-detected using this drive. The detected signal is converted to decibels by a log converter.

The reference phase channel goes through a phase offset control, and then is applied to the phase detector where it is compared with the limited signal from the test-phase half of the test channel. The output of the phase detector is a dc voltage proportional to phase.

Now there is a signal proportional to the log of amplitude, and a signal proportional to phase. These are multiplexed for display on the CRT. Horizontal sweep for the display comes from the sweep circuit of the signal source.

The IF is maintained at 278 kHz by mixing the incoming RF signals with a frequency that is held equal to RF plus IF. To accomplish this, an internal phase-locked oscillator (PLO) is maintained at 200 MHz *minus* IF (278 kHz), or 199.722 MHz. This, in turn, is subtracted from the sweeper's VTO. The result is a signal that is always 278 kHz *higher* than the test frequency. A phase lock loop compares the generated IF with a crystal oscillator at 278 kHz, and the resulting error signal locks the PLO.

Frequency Response

The frequency-response flatness of the analyzer, typically ±0.05 dB, is largely a by-product of the dual channel design.

Since the channels are very similar, their responses tend to be common. Any deviation from flat frequency response that is common to both channels will be canceled by the IF circuits.

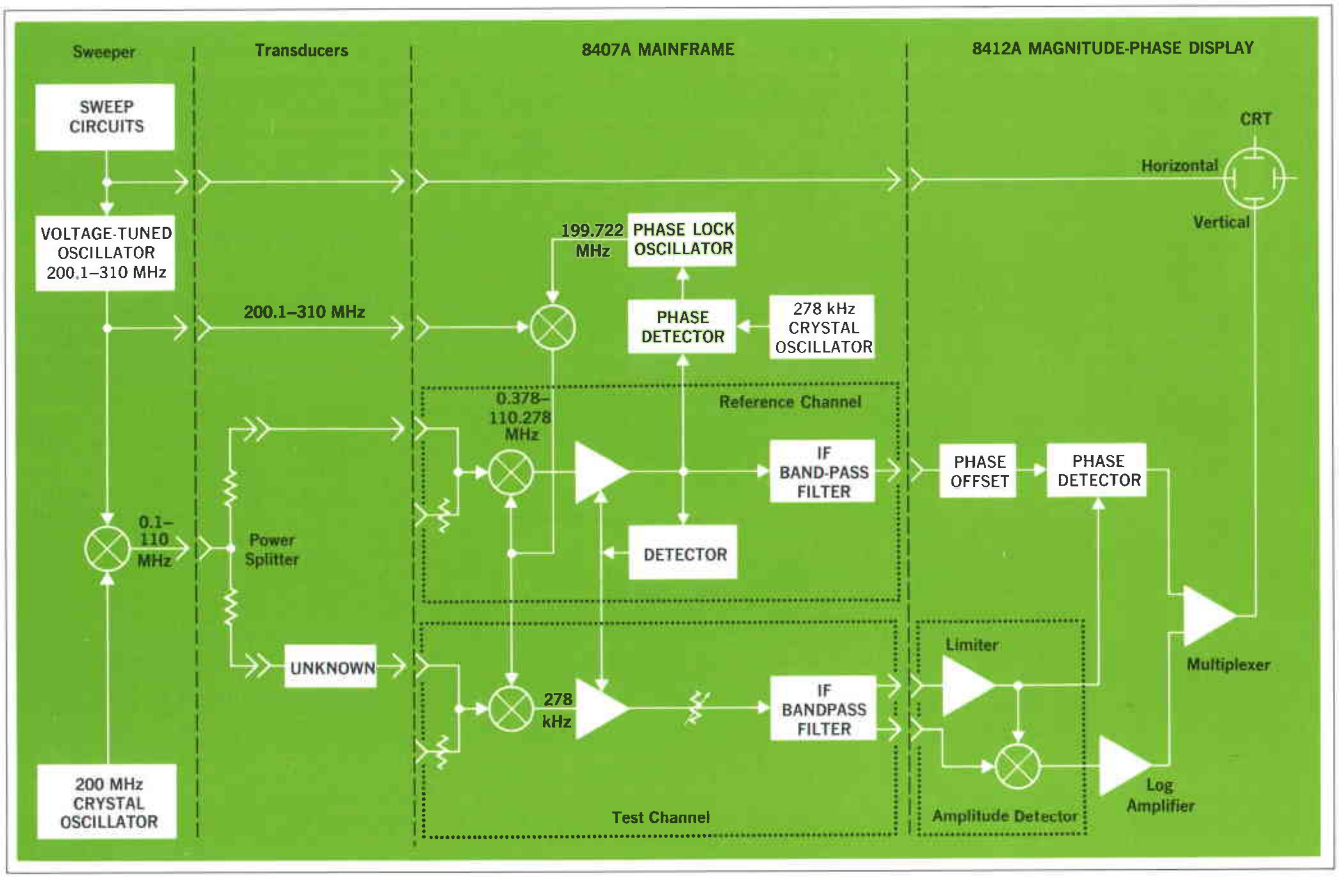


Fig. 4. *HP Model 8407A Network Analyzer System block diagram.*

Amplitude Measurement

The designers aimed at the usually incompatible combination of wide dynamic and display range with high accuracy and resolution.

The system's more than 100 dB dynamic range (the ratio of the largest to the smallest signals the system can measure) depends upon good sensitivity, on the one hand, and large power-handling capability on the other.

Good sensitivity was attained by combining 1) tracking design, 2) fundamental mixing, and 3) a noise-resistant detection scheme.

Even when sweeping more than 100 MHz the system has the effect of a 10-kHz filter always tuned to the RF; this tracking filter reduces the input noise by 40 dB compared to that obtainable with a broadband detector. Fundamental mixing is employed, rather than sampling. Some tracking detectors use sampling and phase-locked loops to obtain their IF. The fundamental mixing method inherently can yield a lower noise figure, so input sensitivity can be improved. The detection scheme (Fig. 4) employed in the Model 8412A display actually will largely ignore noise until it is higher than the signal. As a result, useful measurements can be made all the way down to the noise level.

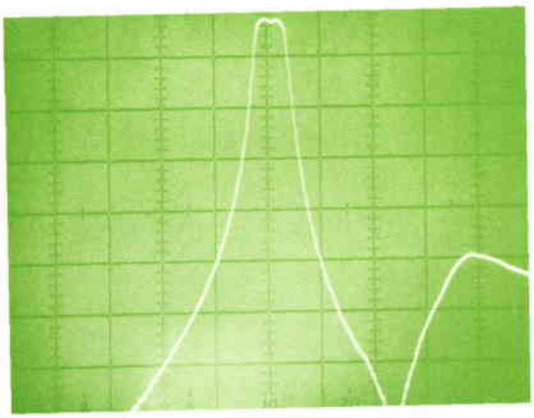
To provide large power capability, a self-contained RF attenuator is provided. Signals as high as 100 mW thus may be observed without driving the input mixers out of their linear range.

The 80 dB display range (the range over which the test-to-reference ratio may vary and still be displayed) is obtained without sacrificing accuracy (typically a few tenths of a dB over a 40 dB range) or resolution (0.05 dB).

This display results from the detection scheme employed. A transistor mixer converts the 278 kHz IF to dc. A transistor feedback log amplifier then converts the dc from linear to log. This detector operates over the entire display range of 80 dB, but is not plagued by the cyclic error patterns—due to successive approximations—from which most wide-range detectors suffer. The detection is as accurate as the log characteristics of a transistor. Accuracy of better than 0.01 dB is obtainable over a 30 dB range.

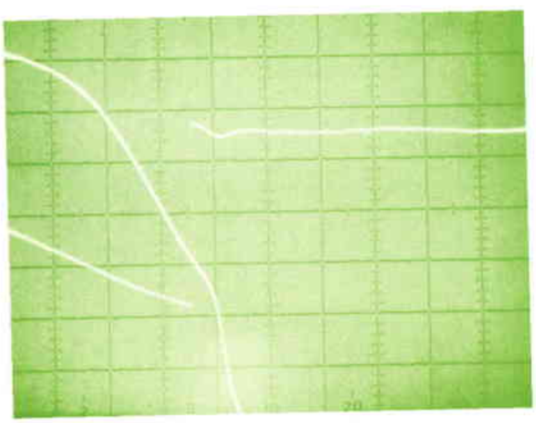
Great resolution is possible by amplifying the center

Network Analyzer Applications



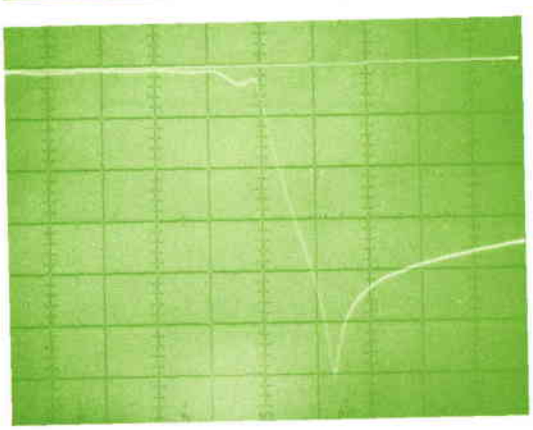
Bandpass Filter

Frequency response curve centered on 50 MHz, vertical scale 10 dB per division. Directly on the CRT it can be seen that the −60 dB points are 35 and 63 MHz. Even at 80 dB down, response is unobscured.



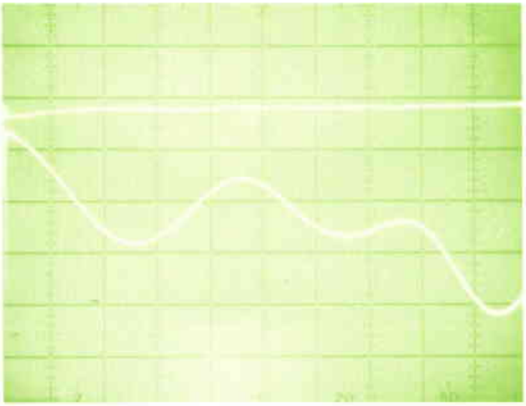
Feedback Amplifier

Plotting the open-loop phase-gain margin of a feedback amplifier leads quickly to optimum design for stability vs. gain. With the Analyzer, adjustments may be made while sweeping, with immediate view of broadband effects. Open-loop response is at left, vertical scale 2.5 dB/div for amplitude, 100°/div for phase. Horizontal is 5 MHz/div, centered on 25 MHz.



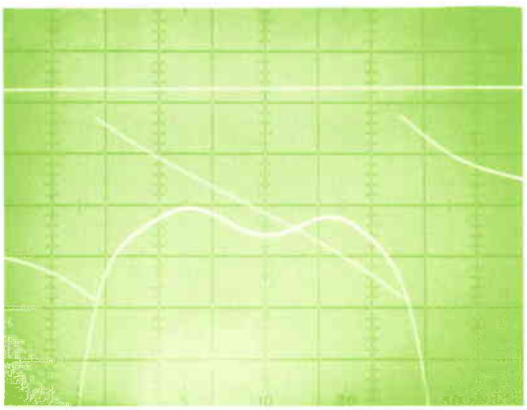
Low-pass Filter

Sweeping from 1 to 100 MHz at 10 MHz/div, displaying 80 dB vertically at 10 dB/div, display shows response of 4-pole Chebyshev low-pass filter. Note the notch at −60 dB; neither a crystal detector nor a broadband log detector could faithfully measure it. Trace is unambiguous, free of responses to source harmonics or spurious signals.



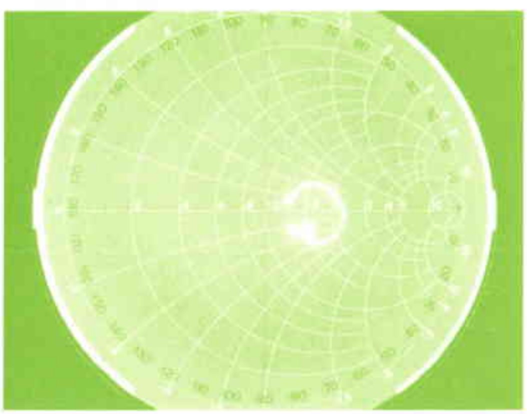
Fine Structure of Passband Response

Sweeping from 1 to 40 MHz at 4 MHz/div, centered on 20 MHz, with vertical response *0.25 dB per division,* insertion loss and passband ripple of Chebyshev filter are measured within hundredths of a decibel.



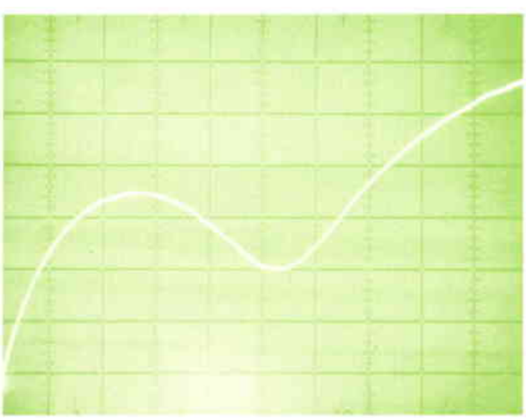
Tweaking a Tunable Filter

Looking at the peak of filter's response at 1 dB/div vertically (100°/div for phase), sweeping from 45 to 55 MHz at 1 MHz/div, filter is quickly adjusted for flattest amplitude response and linear phase through passband.



Measure Antenna Complex Impedance

FM antenna is swept over 88–108 MHz range, using Polar Display with Smith Chart overlay. The characteristic input Z is a point exactly at the center of the display. Antenna's variations from inductive through capacitive through sweep range are visible. Values of complex impedance can be read directly on Smith Chart.



Measure Cable Return Loss

A length of cable is seldom a near-perfect transmission line of specified constant Z. Return loss over 110-MHz swept range is displayed here for a cable which showed 40 dB at 1 MHz, but 25.5 dB at 110 MHz. Corresponding VSWR is quickly calculated, if desired.

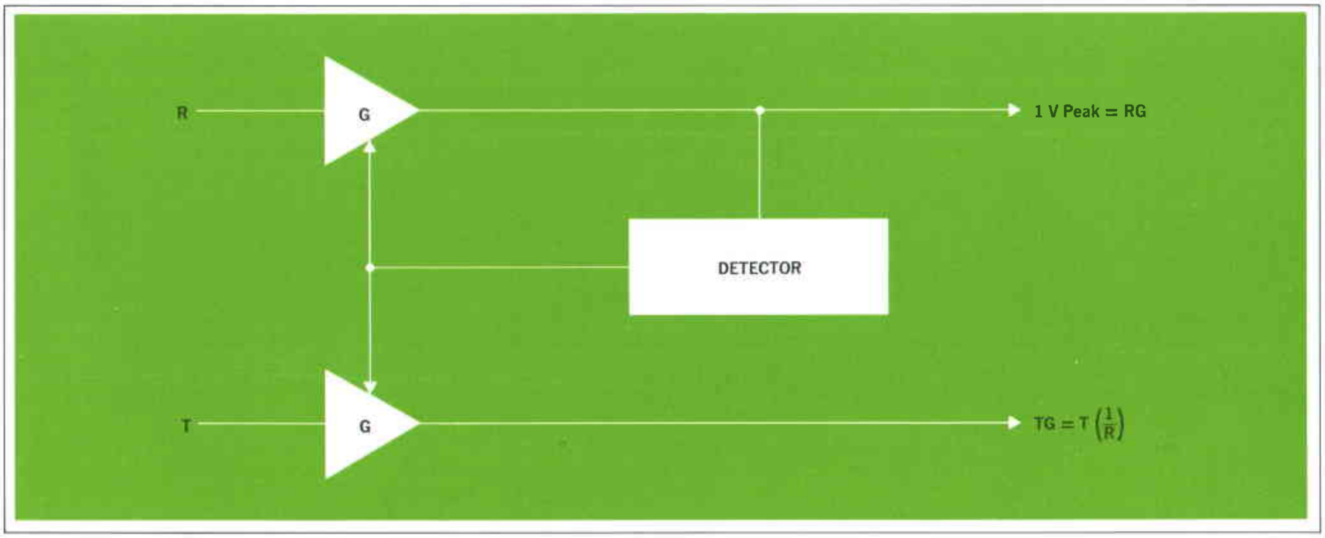


Fig. 5. *Reference and test channels of analyzer are a master-slave pair. As a consequence, channels need only be alike, not necessarily flat in response, for overall amplitude response to be flat.*

portion of the detector's range, and the IF attenuators make it possible to move the signal into this region. Attenuators for performing IF substitution are provided in both 10 and 1 dB steps.

Phase Measurement

Phase measurements are another consequence of the dual channel design of the Model 8407A/8412A. The swept RF test and reference signals are converted to IF signals in the Model 8407A. Because the same local oscillator is used in the conversion of both channels, the phase relationship between the two signals is the same at IF as it was at RF. Now the phase measurement may be made at constant IF, thus with inherently greater accuracy than would have been possible at swept RF.

In phase measurements, as in amplitude measurements, the Model 8407A/8412A system allows both wide dynamic display range and high accuracy and resolution. Phase-measuring accuracy of a few degrees, and resolution of 0.2° are possible by using the phase offset.

The phase offset arrangement in the Model 8412A Display provides IF phase substitution much as the IF attenuator provides IF amplitude substitution. Feedback is employed to give a precise offset so that the resolution obtained is meaningful.

Transducers

Because of the accuracy and range of the instrument, it proved necessary to develop cables and transducers with improved characteristics. Special cables have adequate shielding and are matched for electrical length. A small precision power-splitter was designed. A new directional coupler has 40 dB directivity over two frequency decades (1 to 110 MHz). To verify the 40 dB directivity, a new precision 50-ohm termination was developed.

The mainframe is equipped with a powered socket to connect HP active probes, such as the 1120A described elsewhere in this issue.

Operation

To observe with high resolution or to examine noisy signals, a bandwidth control is provided. This control reduces the display bandwidth from 10 kHz to 0.1 kHz.

A display reference calibration is incorporated into the mainframe. The display reference control permits the operator to 'zero' his IF gain control (IF attenuator) when he sets his measurement calibration reference. Then when the operator makes his measurement he can use IF substitution and the instrument will 'remember' his calibration.

Overload indicators on the Model 8407A warn when a mixer is being overdriven.

A swept CRT display and the display controls are an integral part of the system when the Model 8412A Phase-Magnitude Display option or the Model 8414A Polar Display is chosen. The Model 8412A provides resolution controls calibrated for both dB/division and degrees/division, eliminating any need for an intermediate calculation.

Specifications

HP Model 8407A
Network Analyzer

TEST INPUT: Direct, −10 to −90 dBm; Attenuated, +20 to −50 dBm; Impedance 50Ω, VSWR <1.08.

REFERENCE INPUT: Direct, required level −10 to −60 dBm; Attenuated, required level +20 to −20 dBm; Impedance 50Ω, VSWR <1.08.

AMPLITUDE ACCURACY: Frequency response (may be calibrated out): For test inputs >−60 dBm, ±0.2 dB, 0.1 to 116 MHz, ±0.05 dB over any 10-MHz portion. Typically 0.05 dB for −10 dBm direct reference input and direct test input.
DISPLAY REFERENCE: <0.05 dB per 1-dB step, total error does not exceed 0.1 dB; <0.1 dB/10 dB step, total error does not exceed 0.25 dB.

PHASE ACCURACY: Frequency response (may be calibrated out): for test inputs >−60 dBm, ±5° from 0.1 to 116 MHz, ±2° over any 10-MHz portion from 1 to 110 MHz. Typically ±2° for −10 dBm direct reference input and direct test input.
DISPLAY REFERENCE: <0.2° per 1-dB step; total error does not exceed 1°. <0.5° per 10-dB step; total error does not exceed 3°.

POWER REQUIRED: 115/230 vac ±10%, 50–60 Hz, 65 W.

WEIGHT: 32 lb (14,5 kg).

PRICE: $2950.00.

HP Model 8412A
Phase-Magnitude Display

AMPLITUDE ACCURACY: Display, 0.08 dB per dB; Rear Output, 0.03 dB per dB. Temperature coefficient typically <0.05 dB per °C at midscreen

PHASE ACCURACY: Display, 0.065° per degree; Rear Output 0.015° per degree. Phase offset, 0.3° per 20-degree step, total error does not exceed 3° for 360° change, positive or negative. Vs displayed amplitude, <1° per 10-dB, total error 4° for 80 dB. Temperature coefficient typically <0.1° per °C.

POWER REQUIRED: 23 W (supplied by 8407A).

WEIGHT: 17 lb (7,8 kg).

PRICE: $1575.00.

HP Model 8414A
Polar Display

GENERAL: Normalized polar coordinate display. Magnitude calibration is in 0.2-of-full-scale gradations, full scale determined by DISPLAY REFERENCE setting on 8407A. Phase calibration is in 10° increments over a 360° range.

ACCURACY: All errors in amplitude and phase due to display are contained within a 3-mm circle about the measurement point.

POWER: 35 W (supplied by 8407A)

WEIGHT: 13 lb (5,9 kg).

PRICE: $1250.00.

HP Model 11652A
Reflection-Transmission Kit

GENERAL: Reflection-Transmission Kit, contains power splitter, directional bridge, two precision 50Ω terminations, calibrating short, BNC adapters and matched, low-leakage cables.

DIRECTIONAL BRIDGE: 50Ω, 6 dB coupling in main and auxiliary arm. Frequency response ±0.5 dB, 0.1 to 110 MHz (may be calibrated out). Directivity >40 dB, 1 to 110 MHz. Return loss at LOAD port is >30 dB (ρ <0.03).

POWER SPLITTER: 50Ω, 6 dB loss through each arm.

50Ω TERMINATION: Return loss >43 dB.

WEIGHT: Net, 1.5 lb (0,7 kg).

PRICE: $300.00.

HP Model 11651A
Transmission Kit

GENERAL: Transmission Kit, contains power splitter (6 dB loss through each arm) and matched, low-leakage cables.

WEIGHT: Net, 1.5 lb (0,7 kg).

PRICE: $80.00.

HP Model 11654A
Passive Probe Kit

GENERAL: Passive probe Kit, contains a pair each of six resistive divider probes, current probes, and variety of adapters.

WEIGHT: Net, 2 lb (0,9 kg).

PRICE: $225.00.

MANUFACTURING DIVISION: HP MICROWAVE DIVISION
1501 Page Mill Road
Palo Alto, California 94304

N-Port Power Flow Measurements

In wideband work, and where frequencies are so high that transmission line techniques are appropriate, measurement and analysis in terms of scattering parameters [7, 8, 9, 10, 11] have proved to be enormously powerful. 'S' (scattering) parameters are reflection and transmission coefficients, conceptually like 'h' or 'y' or 'z' parameters, but based upon referencing to standard input and output terminations rather than to shorts or open circuits. Treatment of modern design methods with 's' and other reflection and transmission coefficients is, of course, beyond the scope of this article. It is important to note, however, that the 8407A Network Analyzer is able quickly and conveniently to measure these parameters. Its use for this purpose will certainly, in many laboratories, be its principal application.

Acknowledgments

The authors wish especially to acknowledge the contributions of Phil Spohn and Al Seely to the system design, and the contributions of Ned Kuypers and Jerry Manock to industrial and product design. Important contributions were also made by Jerry Ainsworth to IF circuits, Scott Anderson to the AGC system, Ken Astrof to the frequency convertors, Rich Bauhaus to the transducers' design, Dick Lee to the high-frequency circuits, Larry Ritchie to the front-panel PC switches, Gary Shramek to the PLO, Steve Sparks to the final circuit development, and Roger Wong to the transducers' development.

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David R. Gildea

Dave Gildea received his BSEE from Stanford in 1966 and is working on his Master's. He joined HP as a production engineer on the 8410 Microwave Network Analyzer and aided in the development of the 8413A Display Unit. Dave designed the 8412A and served as project supervisor during the development of the transducers for the 8407 System. He enjoys many of California's outdoor sports, including skiing, back packing, swimming and especially sailing (he races both an El Toro and a Contender).

William A. Rytand

After receiving his BSEE from M.I.T. in 1965, Bill Rytand joined HP to work as design engineer for the 8414A Polar Display and as project supervisor for the 8407A. He has attended Stanford since coming to HP; Bill received his MSEE in 1967 on the HP Honors Cooperative Program and is working towards a Ph. D. A native San Franciscan, Bill plays tennis and is looking for a squash court (a game similar to handball which he learned in the East).

High Impedance Probing to 500 MHz

Intended for use with spectrum analyzers, counters, oscilloscopes, and network analyzers when the signal cannot be brought to the instrument on a 50-ohm line, a new dc–500 MHz voltage probe has an input impedance of 100 k ohms shunted by less than 3 pF or, with slip-on voltage dividers, less than 1 pF.

By Joel Zellmer

IN RECOGNITION OF THE DIFFICULTY OF CONDUCTING HIGH-FREQUENCY SIGNALS on anything but transmission lines, instruments for high-frequency measurements commonly have 50-ohm inputs. There are times, however, when it is necessary to 'look at' a signal at a point where it is not possible to bring the signal out on a 50-ohm line. High-impedance voltage probes are commonly used for this purpose.

In using voltage probes, care must be exercised because of the capacitance they introduce into a circuit, which often degrades high-frequency circuit performance. A 10 pF probe, for example, has an impedance of only 150 ohms at 100 MHz; circuit impedance at the test point must be much less than this if the probe is not to affect circuit behavior.

A new active Probe (Fig. 1) has been designed to alleviate this situation — it has a capacitance of less than 3 pF, and this can be reduced to less than 1 pF, with 1 megohm input, by slip-on voltage dividers furnished with the Probe. The Probe (Hewlett-Packard Model 1120A) is basically an impedance converter that translates its 100 k ohm/3 pF input impedance to 50 ohms with unity voltage gain.

The linear dynamic range of the new Probe is 1 volt peak-to-peak, but it can be overloaded up to ±100 V without damage to the circuits. The Probe's ±0.5 V 'window' can be offset 5 volts above or below ground to allow high-sensitivity observation of small signal variations on a relatively large dc bias. Dynamic range and offset can be increased proportionately with the 10:1 and 100:1 slip-on voltage dividers, which also increase allowable input voltage to 350 V.

Probe noise is only 1.5 mV, as measured with a 1 GHz Sampling Scope, allowing measurements on low-level signals.

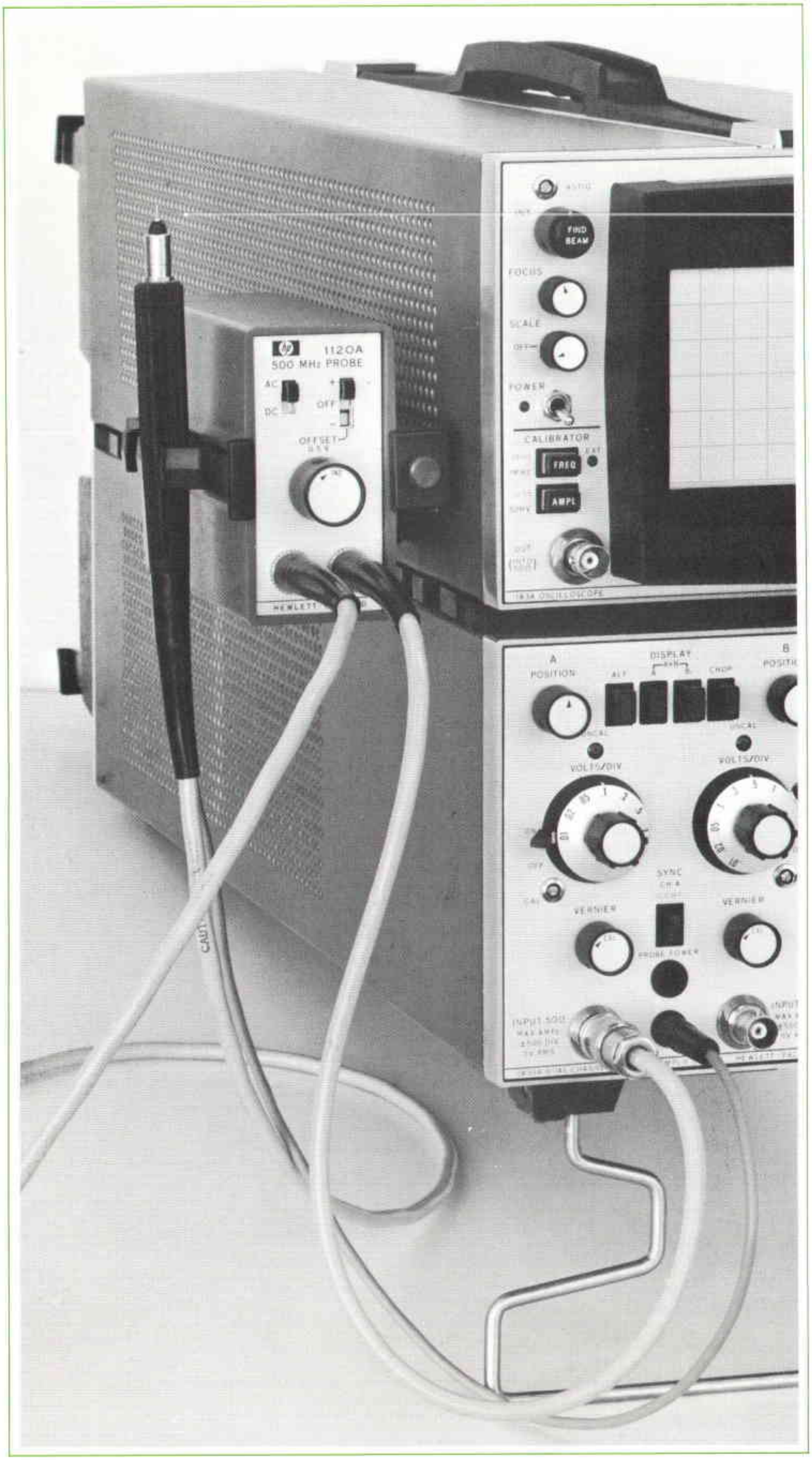

Fig. 1. *New 500 MHz Probe connects to amplifier box through 4 ft. cable. Box mounts to side of instrument with versatile bracket supplied, and obtains power either from Probe Power jacks on instrument as shown, or from optional Probe Power Supply.*

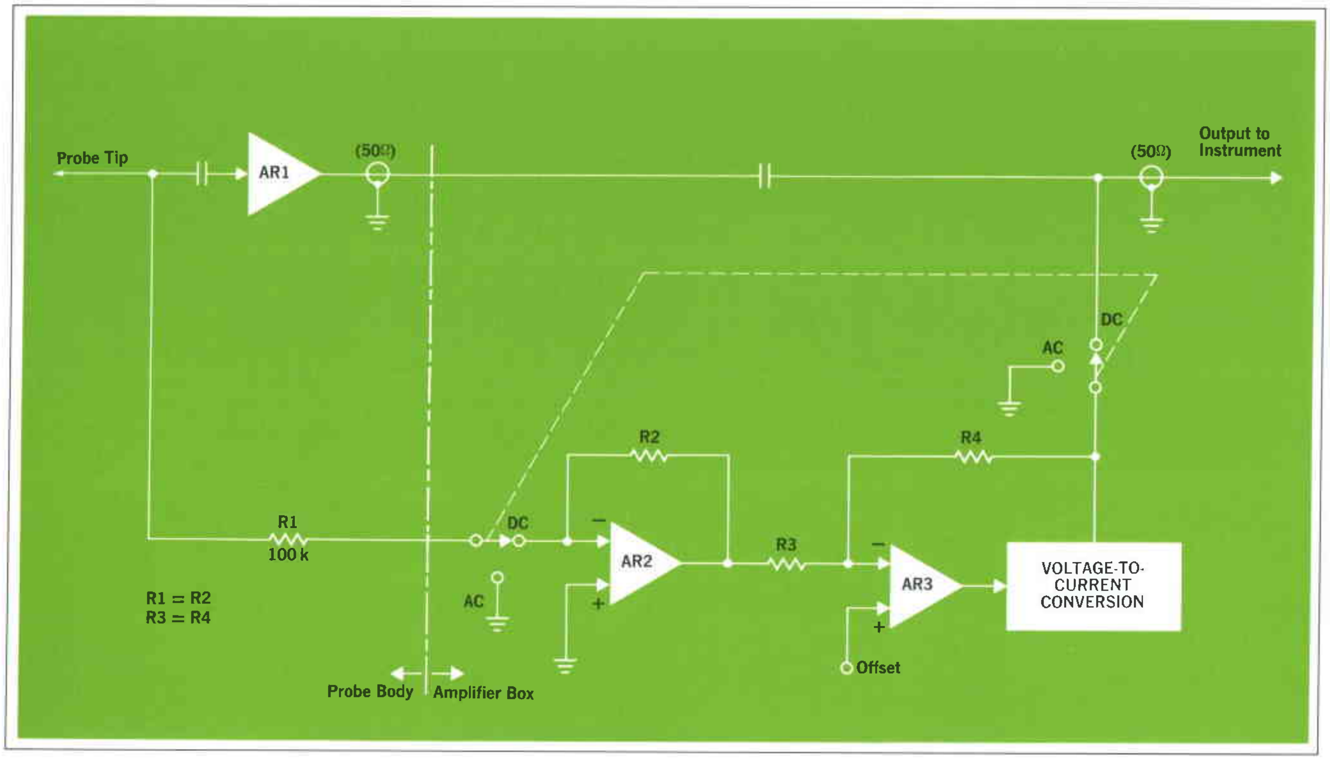

Fig. 2. *Block diagram of 500 MHz Probe. AC path is through AR1, dc through AR2. AR3 compares outputs of AR1 and AR2 in lower part of frequency spectrum, reinserts low frequencies into output signal where AR1 output differs from AR2.*

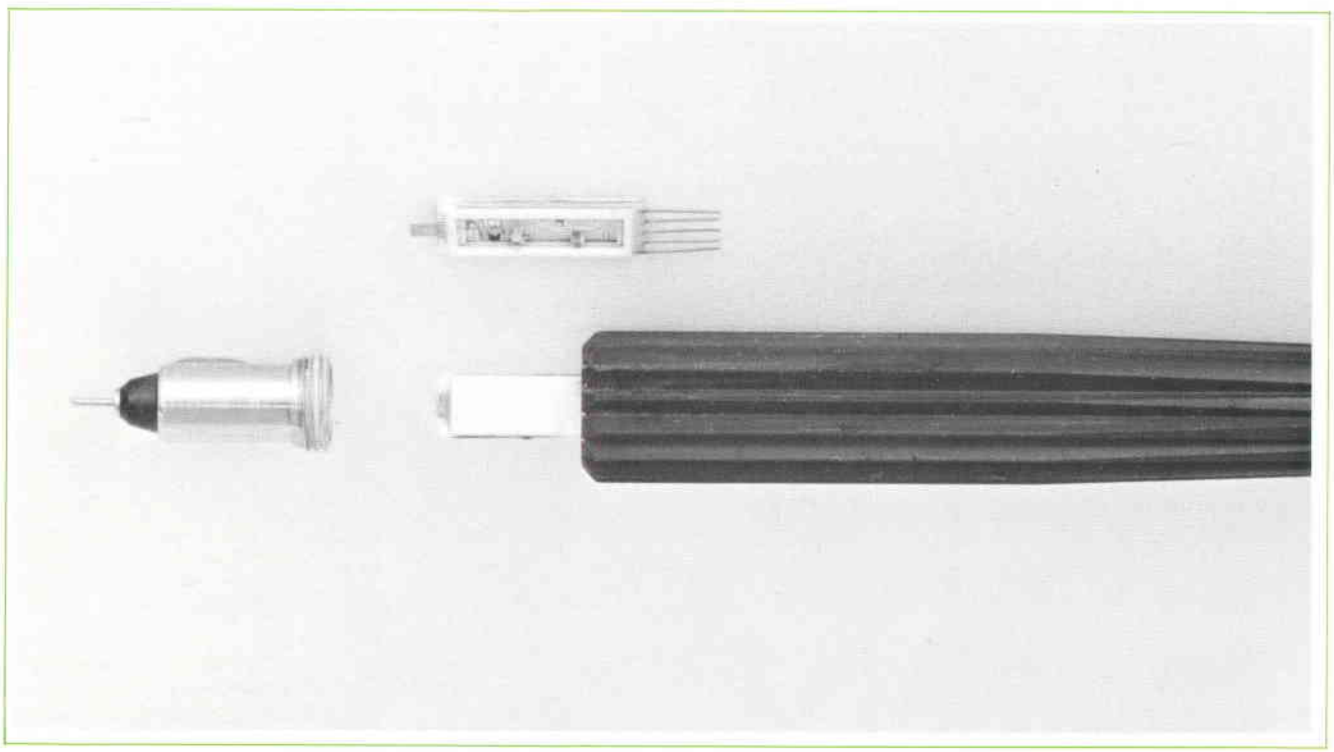

Fig. 3. *Probe input is to hybrid microcircuit (rectangular unit shown detached at top). Probe tip connects to microcircuit, when installed at front of probe, through shock-absorbing contact which prevents damage to microcircuit.*

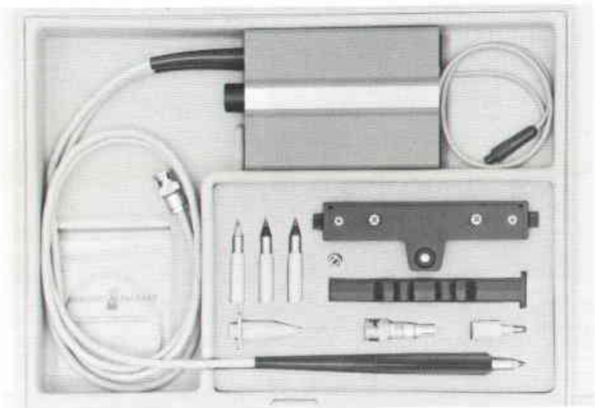

Fig. 4. *Model 1120A 500 MHz Probe is supplied in kit with accessories, including 10:1 and 100:1 1-pF voltage dividers, 27-MHz bandwidth limiter, 2½ inch ground lead, hook tip, spanner tip, BNC adapter, and mounting brackets.*

Fig. 5. *Model 1122A Probe Power Supply, for use where instruments are not equipped to power Probe, furnishes power for up to four Model 1120A Probes.*

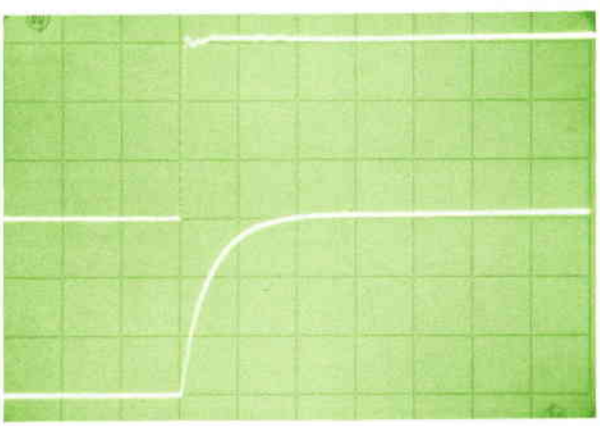

Fig. 6. *Upper trace shows response of 500 MHz Probe to 0.35 ns, 300 mV step in circuit with 50Ω source impedance. Probe response time here is 0.75ns (sweep time: 10 ns/cm). Lower trace shows Probe response to same signal in circuit with 1kΩ source impedance.*

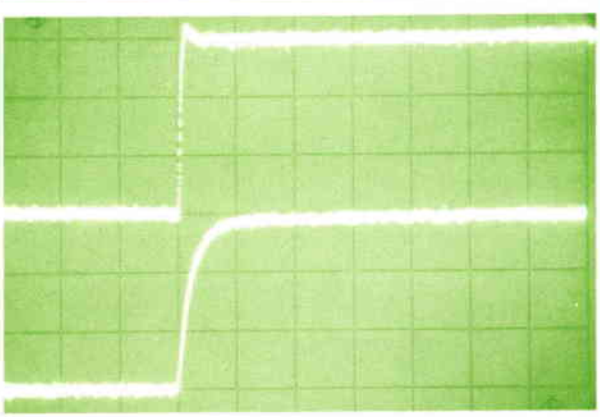

Fig. 7. *Probe response with 10:1 voltage divider added to probe tip. Upper trace was made with Probe in 50Ω circuit. Lower trace was made in 1kΩ circuit and shows fast response time of Probe when used with divider to probe higher impedance circuits. (All scope photos were made with 4 GHz sampling scope.)*

Probe Construction

The low-capacitance input is achieved by use of a FET-input microcircuit amplifier at the very front of the stainless steel probe barrel. As shown in the block diagram (Fig. 2), the amplifier input is ac coupled to the probe tip and its output is ac coupled to the instrument cable. DC-coupling is by way of resistor R1 and the circuits in the amplifier box. Frequency response of the dc path overlaps the low-frequency rolloff of the probe tip amplifier (1.5 kHz) to give broadband performance from dc to 500 MHz.

AC coupling of the probe-tip amplifier minimizes dc drift from changes in temperature, which has often been a problem with hand-held active probes. This approach allowed greater freedom in optimizing the amplifier for high-frequency performance. The dc amplifiers in the box can thus be low-bandwidth monolithic operational amplifiers which have good temperature stability. Drift is less than 0.1 mV per degree C change at the Probe, and less than 0.2 mV per degree C change at the box.

Power for the Probe (+15 V, 110 mA; −12.6 V, 70 mA) is normally obtained from the instrument with which it is used. When the instrument is not equipped with a probe power connector, power can be supplied by the Model 1122A Probe Power Supply.

Mechanical Considerations

The microcircuit connects to the probe tip with a shock-absorbing contact that prevents accidental damage to the circuit. The Probe connects to the amplifier box through a 4-foot cable, and the box attaches to the side of an instrument with the mounting bracket supplied.

Acknowledgments

Many people provided helpful suggestions during design of the 1120A Probe. Product design was by Jay Cedarleaf and Robert Montoya, industrial design by David Eng. Ed Prijatel designed the low-capacitance dividers. The author would also like to thank Alan J. DeVilbiss for helpful advice, and the HP Colorado Springs Division microcircuits lab for their many hours of intense work.

SPECIFICATIONS
HP Model 1120A
500 MHz Probe

BANDWIDTH
DC-coupled: dc to >500 MHz.
AC-coupled: <1.5 kHz to >500 MHz.

PULSE RESPONSE: Risetime, <0.75 ns; perturbations, <±5% measured with 1 GHz sampler.

GAIN: 1:1, ±5%.

DYNAMIC RANGE: ±0.5 V with ±5 V dc offset.

NOISE: Approximately 1.5 mV (measured tangentially with 1 GHz sampler; with Model1830A 250 MHz Vertical Amplifier, approximately 0.8 mV (measured tangentially).

DRIFT: Probe tip, <±100 μV/°C; amplifier, <±200 μV/°C.

INPUT IMPEDANCE: 100 k ohms; shunt capacitance <3 pF at 100 MHz. With 10:1 or 100:1 Dividers, 1 MΩ; shunt capacitance <1 pF.

MAXIMUM INPUT: ±100 V (±350 V with 10:1 and 100:1 Dividers).

WEIGHT: Net, 2¼ lb (1,0 kg).

POWER: +15 V ±2%, 110 mA and −12.6 V ±2%, 70 mA, supplied by instruments so equipped or by Model 1122A Probe Power Supply. (Model 1122A, $225, powers up to four Probes.)

CABLE LENGTH: Overall, 4 ft; with option 006, 6 ft (add $25).

ACCESSORIES FURNISHED: 10:1 Divider, 100:1 Divider, hook tip, 2.5-inch ground lead, spare probe tips, BNC probe adapter.

PRICE: Model 1120A, **$350.00.**

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Joel Zellmer joined the Hewlett-Packard Colorado Springs Division in 1966, going to work on the 220A/221A Square Wave Generators and the Model 1120A 500 MHz Probe. Joel, who hails from Saint Paul, Minnesota, earned his MSEE degree in 1966 from the University of Minnesota, where he had been a teaching associate. Outside of working hours, he skis, plays tennis, and makes furniture in his woodworking shop. Joel is a member of Eta Kappa Nu.

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