A New 20 CPS-50 KC Wave Analyzer
with High Selectivity and Simplified Tuning

In the audio frequency range one of the basic measuring instruments is the harmonic wave analyzer. In essence, this instrument is a frequency-selective heterodyne voltmeter which measures the amplitude and frequency of the individual components of harmonic or complex waveforms. It is valuable where information is needed about the specific harmonics produced by amplifiers and other transducers, about the intermodulation products generated in multiple frequency systems, about the amplitude of voltages in the presence of noise and the amplitude of voltages too small to be measured by other means, about vibration components in mechanical and electrical systems, and in general about the components of

any recurrent electrical phenomena or physical phenomena that can be converted into electrical waves.

For a wave analyzer to have maximum usefulness, it is basically desirable that it have high selectivity, but high selectivity by itself has often been a distinct handicap in actual practice. One reason for this has been that the stability of typical audio frequencies is often insufficient for the signal to remain within a high-selectivity passband for the time needed to make a measurement. The user is then forced to try to track the signal by hand. Moreover, when a measurement is to be made at a high frequency in the order of kilocycles, tuning a high-selectivity system to the signal has often been difficult, because resolution of tuning has been inadequate. When such a high-frequency
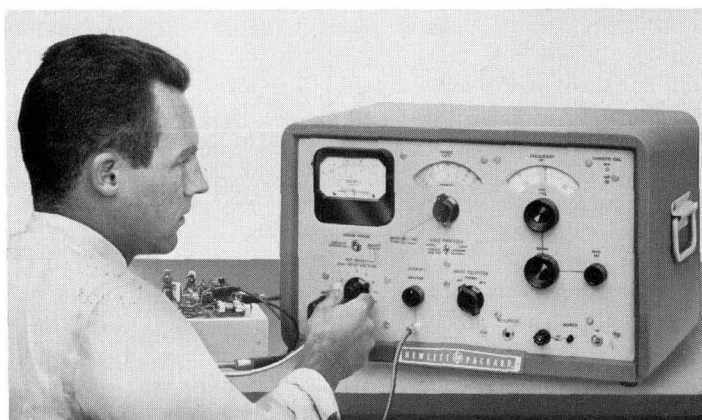

→| |← 6.6 cycles

Fig. 2 (above). *Dynamic plot of selectivity characteristic of typical 302A analyzer. Three db bandwidth can be seen to be less than 7 cycles. See also Figs. 6 and 7.*

Fig. 1 (at left). *New -hp- Model 302A Wave Analyzer measures from 20 cps to 50 kc and incorporates AFC circuit and linear tuning dial to simplify tuning. Voltage-measuring range extends below 10 microvolts. Instrument has sine wave output at dial frequency to facilitate transmission tests on external circuits.*
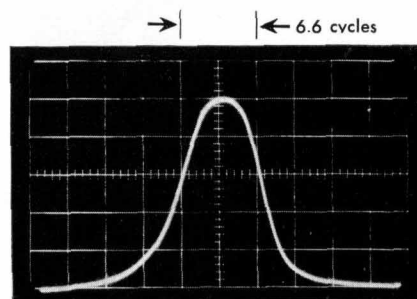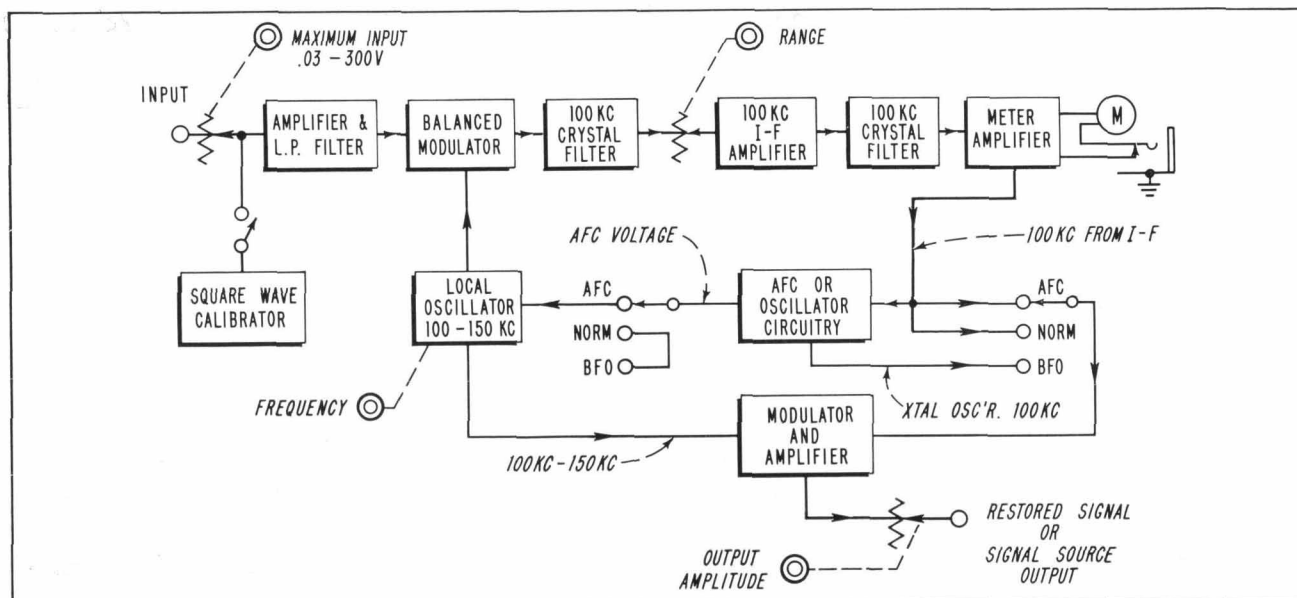
Fig. 3. *Basic circuit arrangement of -hp- Model 302A Wave Analyzer. Specially-developed tuning capacitor for local oscillator results in linear, constant-resolution tuning dial.*

signal then has instability, the measurement becomes doubly difficult, often impossible.

The Hewlett-Packard solution to this problem has been to provide an analyzer whose selectivity was adjustable* and could be suited to the measurement at hand. This arrangement permitted convenient measurement of typical signals, but there has been a demand for an instrument to measure frequency components higher than the top frequency of 16 kc possible with that instrument.

Consequently, a new analyzer has now been designed—one that has an upper frequency capability of 50 kc, the third harmonic of the highest usual audio frequencies. In this new instrument the advantages of high selectivity have been combined with the advantages of adjustable selectivity by incorporating an automatic frequency control arrangement into a high-selectivity instrument. When the instrument is then tuned to the component to be measured, the afc circuit locks to the component and typical frequency instabilities in the signal produce no observable effect in the measurement.

NEW OUTPUTS

Voltage-wise, the new analyzer measures from 30 microvolts full scale to

*Brunton Bauer, "-hp- Distortion Measuring Equipment," Hewlett-Packard Journal, Volume 2, No. 12, August, 1951.

300 volts full scale in 3:1 ranges. Measurements can be made either directly in voltage ("absolute") or as a percentage of the amplitude of the fundamental component ("relative"). The instrument has also been designed so that it has no tune-up procedure typical of analyzers in the past and so that it provides two special outputs, which may be selected by choice, in addition to an output for operating a dc recorder. One output is a signal whose frequency is the frequency being measured such that, where complicated or non-harmonically-related components are being investigated, an external frequency counter can be used to measure the component frequencies to high precision. In vibration analysis, for example, this feature provides an easy method for analyzing complicated spectra.

The second output is a constant-amplitude voltage whose frequency is the frequency to which the analyzer is tuned. This output is valuable as a signal source for checking the transmission of external devices. Since this output and the analyzer tuning are tracked together, the need for an external test oscillator in transmission measurements is normally disposed of, while the actual testing of external equipment becomes much simpler than when an external oscillator is used.

A number of additional design im-

provements have been included in the analyzer, three of which should be mentioned here. First, the tuning system is linearly calibrated in frequency so that resolution is constant. Secondly, a 100:1-reduction gear drive of a quality commensurate with a high-selectivity instrument has been used in the tuning system to insure adequate resolution. Thirdly, the analyzer is fully transistorized so that it has no warm-up time, can be battery operated, if desired, and has half the size and weight of the earlier design.

CIRCUIT ARRANGEMENT

Fig. 3 shows the general form of the analyzer circuitry. An input waveform to be analyzed is applied through an attenuator to a high-performance pre-amplifier which is designed so that its harmonic contribution is about 90 db below its maximum operating level. Following the pre-amplifier and a 50 kc cut-off low-pass filter, the waveform is mixed with the output of a tunable local oscillator in a balanced modulator to translate whichever waveform component is being measured to precisely 100 kc, the i-f frequency. The balanced modulator is designed to be linear over a range in excess of 80 db and, because of the low thermal levels achieved in the instrument from the use of semiconductor devices, is much freer of unbalance effects than previous designs.
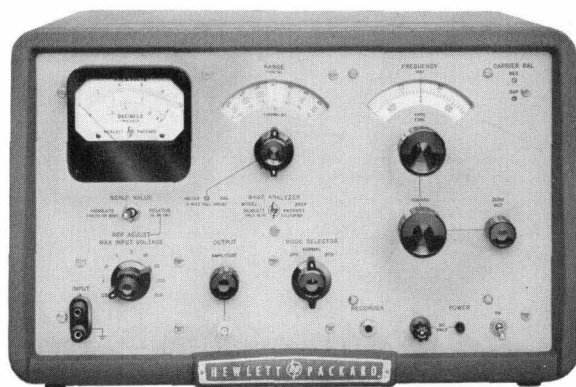
Fig. 4. *Panel view of analyzer. Constant-resolution tuning dial appears in right-hand panel window. Fine tuning control drives tuning capacitor through 100:1 reduction gear train giving dial length of more than 50 feet.*

Fig. 6. *Typical selectivity of new analyzer near peak of response characteristic. Curve obtained by averaging selectivities of 10 production instruments.*

Consequently, the controls that refine modulator balance are made available in this intrument only as screwdriver controls available from the panel instead of as panel operating controls. Modulator linearity and balance and the selectivity of ensuing amplifiers are such that modulation products other than the component being measured are maintained at least 75 db below the peak output level of the modulator, as is hum pickup.

To accommodate an input frequency range from 20 cps to 50 kc with an i-f of 100 kc, the local oscillator is arranged to be tunable from 100 to 150 kc and has been designed with high frequency stability. A straight-line-frequency capacitor of special design has been used to achieve a linear frequency scale,* which is discussed later.

The 100 kc component appearing at the modulator output is passed through a two-section crystal filter separated by

*B. M. Oliver, "Gamma-Derived Capacitors," letter to Proc. I. R. E., Volume 47, No. 9, Sept., 1959, p. 1654.

Fig. 5. *Signal source output simplifies testing external circuits since analyzer input is tracked with this output. A measured frequency output is alternatively available to enable complicated spectra to be plotted with frequency counter.*

an attenuator, which is the range control on the panel, and an isolating amplifier. After additional amplification, the component is rectified and applied to the dc meter circuit. A dc output is taken from the meter circuit to permit an external dc recorder to be used. A sample of the i-f signal is also taken from the meter amplifier and applied to the discriminator circuitry to provide an automatic frequency control voltage for the local oscillator.

INPUT SIGNAL AND SIGNAL SOURCE OUTPUTS

The two signal outputs which add a new degree of usefulness to wave analyzer instrumentation are obtained as follows, considering first the output that is the waveform component being measured ($F_{measured}$). When an external wave is analyzed, the *MODE* switch in Fig. 3 will be in the *AFC* or *NORM*(al) position. A sample of the 100 kc i-f frequency from the meter amplifier is then mixed with the local oscillator frequency ($F_{measured}$+ 100 kc) in a second modulator to subtract precisely 100 kc from the local oscillator frequency and thus to recover the measured frequency $F_{measured}$. This signal is amplified and applied to the output terminal at a maximum level of at least 1 volt, its actual amplitude being related to the amount of deflection occurring on the indicating meter. When a complicated input spectrum is being investigated, this output can be used for accurate analysis of the spectrum. When measuring the frequency of this output with an external counter, it should be noted that the output is obtainable both when the AFC circuit is being used and when it is not. However, better frequency accuracy in this out-
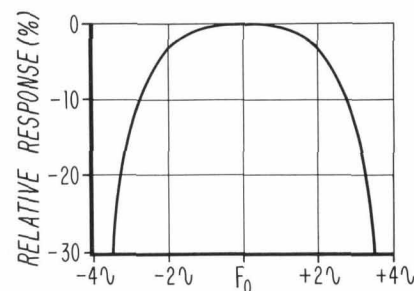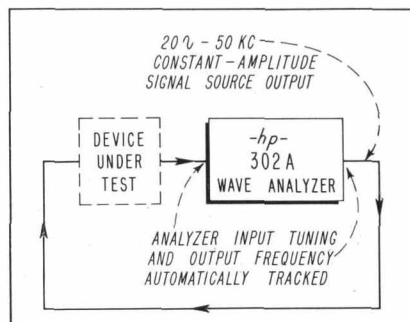
put signal will usually be obtained when AFC operation is used because of the accuracy of tuning that AFC operation provides.

The second signal output is the BFO or *signal source* output. This is a constant-amplitude signal whose frequency is always the frequency to which the analyzer is tuned. It can thus be tuned over a range from 20 cps to 50 kc by tuning the analyzer. Circuitwise, the signal is obtained by converting the AFC discriminator circuitry to form a 100 kc oscillator whose frequency is crystal-controlled. This 100 kc frequency is then subtracted from the local oscillator frequency to which the analyzer is tuned. It will be seen that this signal source output differs from the measured frequency output in that it is not derived from the measured component itself, although it is equal in frequency to a component which will be measured by that particular frequency setting of the analyzer. The measured frequency output, on the other hand, depends on an applied component and has an amplitude related to the amplitude of the component.

The value in use of the signal source output is substantial. Where frequency response measurements are being made, especially of devices that may have a wide response range such as filters, this

output is a considerable convenience for the reasons noted earlier. As a further convenience the signal source output is constant within a db over the 20 cps to 50 kc range, while its level can be selected with the Amplitude control up to at least 1 volt open circuit.

CALIBRATOR

A voltage calibrator circuit is also included in the system for occasions when it may be desirable to check the analyzer's voltage calibration. The analyzer's overall stability is high, however, and such a check is not a typical operating necessity. The calibrator consists of a free-running multivibrator whose voltage excursions are fixed by zener diodes at a value corresponding to a full-scale meter deflection. It operates at approximately 5 kc so that, when checking calibration, the indicating meter should indicate precisely full scale when the analyzer tuning is peaked in the vicinity of 5 kc. Calibration can be adjusted for optimum agreement with the calibrator by a screwdriver control accessible from the front panel.

SELECTIVITY CHARACTERISTIC

As indicated in Fig. 3, the selectivity of the new analyzer is established by a two-section crystal filter, which employs a total of three high-quality crystals whose resonant points are staggered for optimum flatness of the peak of the overall selectivity characteristic. A typical resulting selectivity is shown in the oscillogram of Fig. 2, while the average selectivity near the peak of 10 production instruments is shown in
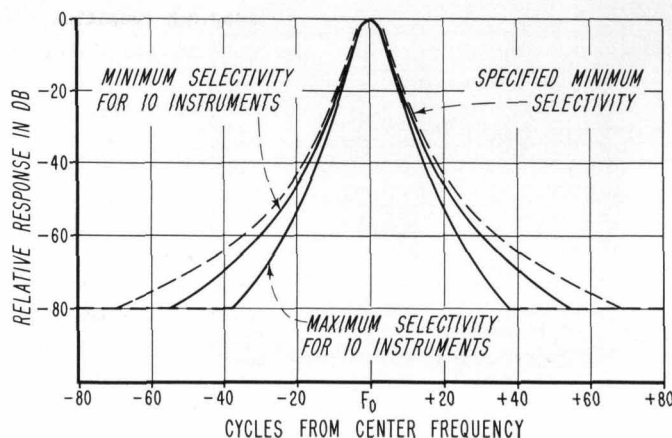
Fig. 7. *Typical overall selectivity in the form of maximum and minimum selectivities from group of 10 production instruments.*

Fig. 6. Typically, the top of the curve is virtually flat for a width of 2 to 2½ cycles (± 1 to $\pm 1\frac{1}{2}$ cycles from center). At 3 to 3½ cycles from center, the response is 3 db down.

Fig. 7 shows the overall selectivity characteristic of the analyzer in the form of the maximum and minimum selectivity from a group of 10 production instruments. The passband has an 80 db or more range with a narrow-skirted characteristic which reaches the 80 db attenuation level at no more than 70 cycles from center.

CONSTANT RESOLUTION TUNING SYSTEM

One of the major considerations in the design execution of a wave analyzer is the tuning system, in which tuning resolution becomes of particular concern. Typically, the approach to this problem is to use an expanded type mechanical drive to produce a long scale length. While this approach is basic and

in itself advantageous, the combination of drive and tuning capacitor usually produce a frequency dial in which for frequencies above a few hundred cycles the calibration has inadequate resolution. To try to determine with a typical tuning system whether a measurement is being made of a 60- or a 120-cycle sideband of a signal at even a few kc, for example, is usually difficult.

In the design of the new analyzer, a special tuning capacitor with an accurate straightline frequency characteristic has been used in the local oscillator. This is combined with a quality 100:1 gear reduction drive system to provide a tuning scale length greater than 50 feet for the 20 cps to 50 kc range. Because this drive is used with a capacitor that is accurately straight-line, it has the distinguishing feature that it has been possible to calibrate the vernier scale directly in frequency to achieve constant resolution for the complete range. With this feature it becomes as convenient to separate and measure a hum sideband at 50 kc as at 1 kc. The degree of resolution that the tuning system provides can be determined from the fact that the vernier dial is calibrated at 10-cycle intervals which have a spacing of $\frac{1}{8}$ inch. One complete vernier rotation produces a 1 kc change in the analyzer tuning or a change in the main tuning dial of 1 division. There are thus 5,000 calibration points in the instrument's tuning range.

With further reference to the oscillator, it is interesting to examine the data in Fig. 8 from which can be seen
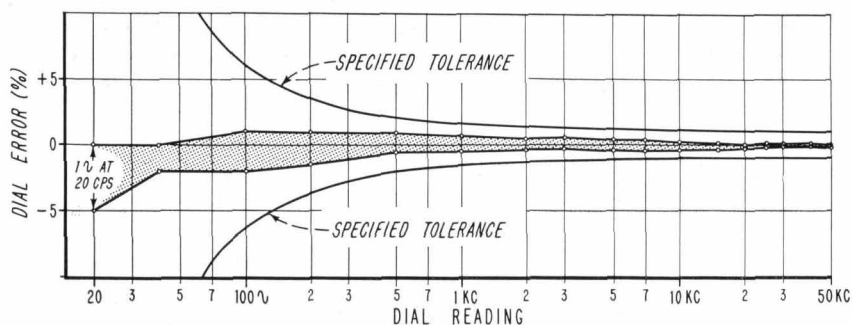
Fig. 8. *Extremes of frequency dial error from group of 10 production instruments. Curve shows spread of error among all instruments so that each unit is better than error limits shown. Dial calibration is linear; curve thus also shows that departure from linearity is small.*

in the one curve both oscillator linearity and typical accuracy of calibration. The curve shows the maximum dial error from a group of 10 instruments together with rated error limits. On a percentage basis the rated error limits appear large at low frequencies because of the 5 cps component in the rated tolerance [± (1% + 5 cps)], but this component represents only a 0.005% error in the local oscillator frequency of 100 kc.

VOLTAGE RANGE INDICATOR

To serve its intended purpose, an audio wave analyzer must have, at least from the input through the selective circuits, a wide dynamic range (75 db in this case), but for readability at the indicating meter this range must be divided into smaller ranges with an attenuator. In addition, to accommodate an even wider range of external signal levels (an additional 80 db for this instrument), an attenuator is re-

quired at the input terminals. Thus, an actual measurement of voltage involves the use of two attenuators, and previously the operator has been presented with the necessity for multiplying or otherwise mentally manipulating two calibrations to obtain the value of the voltage range in use.

In the new instrument, however, a mechanical multiplying arrangement has been used such that the full scale

MEASURING MICROWAVE TUBE ELECTRODE COEFFICIENTS WITH AN AUDIO WAVE ANALYZER

A common problem in applying microwave tubes is establishing performance requirements for power supplies, since power supply ripple usually appears in the tube output as unwanted frequency modulation. The diagram below indicates how the new -hp- Model 302A Harmonic Wave Analyzer (described in accompanying article) was used as the heart of an arrangement for measuring the voltage coefficient of frequency of the various elements, including the heater, of a backward-wave oscillator tube.

In the setup the signal source output from the analyzer was singly applied through an isolating transformer to the various terminals of the tube at a low level of a few millivolts. The tube's output frequency was then translated to the kilocycle range with a Model 540 Transfer Oscillator and applied to a counter-type discriminator whose input is amplitude-limited with a zener diode. This type of discriminator provides an output consisting of a constant-charge pulse for each cycle of the applied frequency. By filtering this output with a suitable low-pass filter, which can consist merely of a capacitor, it is easy to obtain a voltage whose amplitude is proportional to the deviation in the BWO output. The amplitude of this signal, and therefore the amount of f-m in the BWO output, is then

measured with the analyzer. With the coefficients of the tube elements thus established, a realistic basis is available for specifying power supply performance.

An advantage of the arrangement is that the BWO or other tube need not be operating from a high-performance supply during the measurement, since the analyzer provides the necessary discrimination against the supply ripple frequency and measurements can be made by setting the analyzer frequency a suit-

able amount away from the supply's ripple frequency. The arrangement also permits the influence of frequency on the coefficients to be investigated easily.

The above method is a variation of that described in an earlier article* but has the additional advantage of enabling coefficients to be established.

—*Harley L. Halverson*

*Duane Marshall, "A New 3 cps—100 kc Electronic Frequency Meter with Discriminator Output and Expandable Scale," Hewlett-Packard Journal, Volume 7, No. 1, Sept., 1955.

value for the voltage range to which the instrument is set is always directly indicated on a range dial on the panel. The possibility of reading errors is thus significantly reduced, especially when readings are being made by non-engineering personnel. An additional property of the mechanical arrangement is that it locks out voltage ranges which are inapplicable for a particular setting of the input attenuator. This feature thus prevents operating errors which formerly could be caused by an improper combination of the two attenuators.

AFC OPERATION

At first glance it might seem unrewarding from a design viewpoint to incorporate an AFC circuit into a high-selectivity instrument, since the rise time of the selective amplifier is inherently long and the amplitude response is a tremendously rapid function of the frequency departure from center (-50 db at $f_o \pm 25$ cycles).

While these and other matters do indeed introduce significant design problems for an AFC system, the results obtained are a substantial convenience from a usage standpoint. With the instrument's AFC circuit in use, for example, a measured component can drift up to a specified maximum amount of ± 100 cycles from center (± 150 cycles is a more typical maximum) before AFC control is lost. This characteristic is the value termed "frequency hold-in range" in the specifications.

The "pull-in range," i.e., the amount by which the instrument will initially tune itself to tune to a signal, is not nearly as large as the hold-in range, since, if it were, there would be undue danger of measuring an unwanted component when two components were close together. In an analyzer, as in a radio receiver, it is desirable to have the AFC lock to a desired component without being influenced by a larger component lying nearby. A high degree of discrimination has been achieved for the analyzer in this respect and, typically, a component spaced 30 cycles from a desired component and of an amplitude 40 db above the desired component does not pull the analyzer tuning from the desired component once

it has been tuned in. The speed of AFC pull-in action is measurably slower than that one may be accustomed to in receivers, but this is virtually unnoticed in use and has not been found an inconvenience.

TUNABLE AUDIO VOLTMETER

Possibly because of its name, an audio wave analyzer is often overlooked as a valuable tunable voltmeter—one in this case with a measuring range in excess of 150 db and a sensitivity well under 10 microvolts. Thus, besides wave analysis, the instrument is valuable for measuring the amplitude of small signals in the presence of noise and for measuring large attenuations, as in filters. Similarly, for measuring loop-gain characteristics the sensitivity is adequate for measurements even in low-level systems, while the upper frequency capability of 50 kc permits loop investigations to be made in gain-cross-over regions previously inaccessible. For many of these measurements the signal source output is a significant convenience, while the measured signal output enables the instrument to be used as a tunable narrow-pass filter. In addition, the ability to measure hum components to 75 db below the signal level is often of substantial value.

Finally, an interesting case where the new analyzer is used as a tuned voltmeter in an unusual situation is described in the accompanying article.