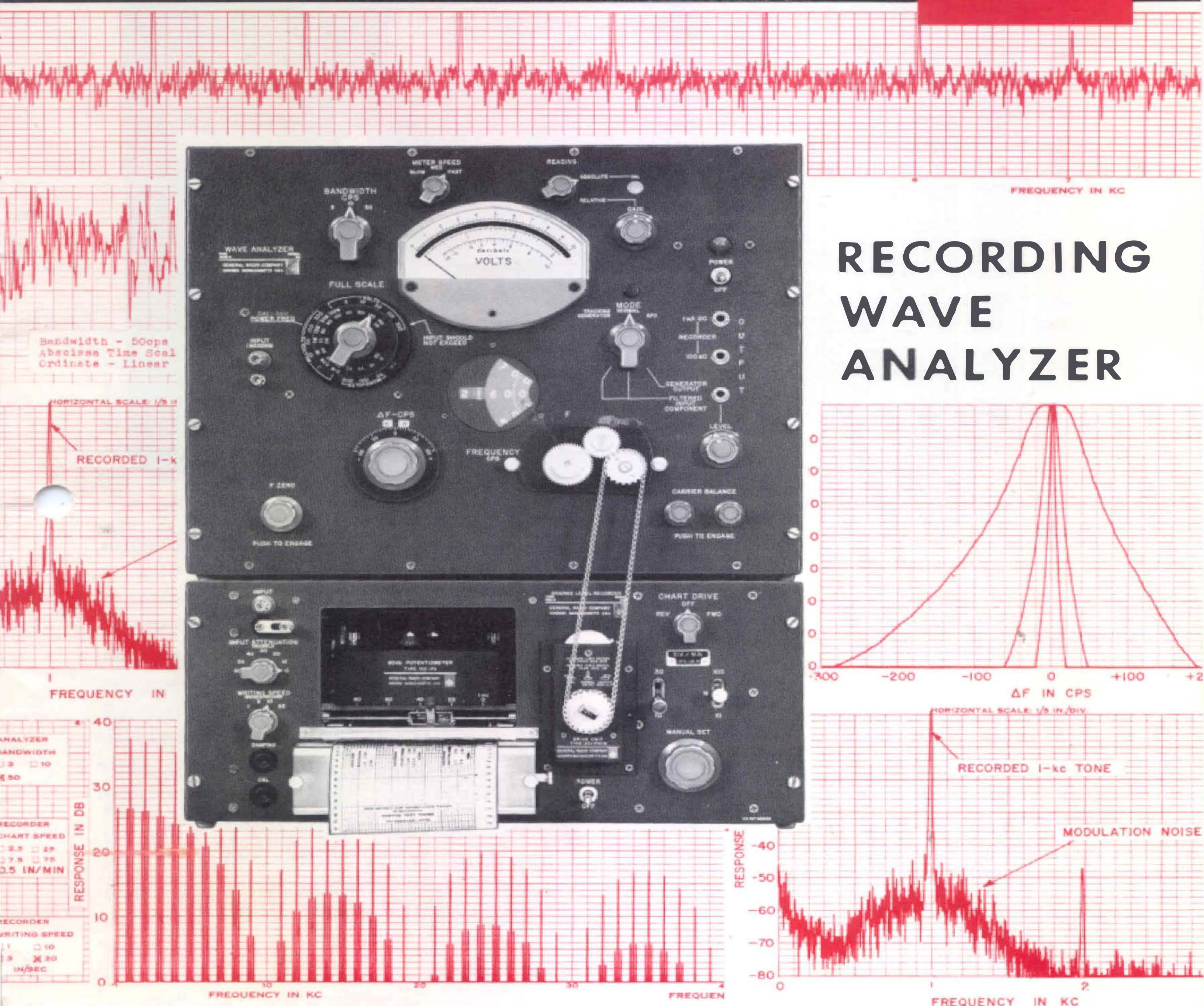
THE GENERAL RADIO
EXPERIMENTER



RECORDING WAVE ANALYZER

VOLUME 38 NUMBER 4 APRIL 1964

IN THIS ISSUE

New Wave Analyzer
SWIEEECO

Figure 1. Panel view of the Type 1900-A Wave Analyzer.

NEW WAVE ANALYZER HAS 3 BANDWIDTHS, 80-DB DYNAMIC RANGE

The new TYPE 1900-A Wave Analyzer, shown in Figure 1, is one of the most versatile measuring instruments ever devised.

In its primary function as an electric-wave analyzer or selective voltmeter over the range from 20 to 54,000 cps, it provides three different bandwidths — 3, 10, and 50 cps — and a wide sensitivity range to cover a variety of spectrum-analysis requirements.

Its three meter speeds, together with the three bandwidths, make it exceptionally useful for noise analysis.

CONTENTS OF THIS ISSUE

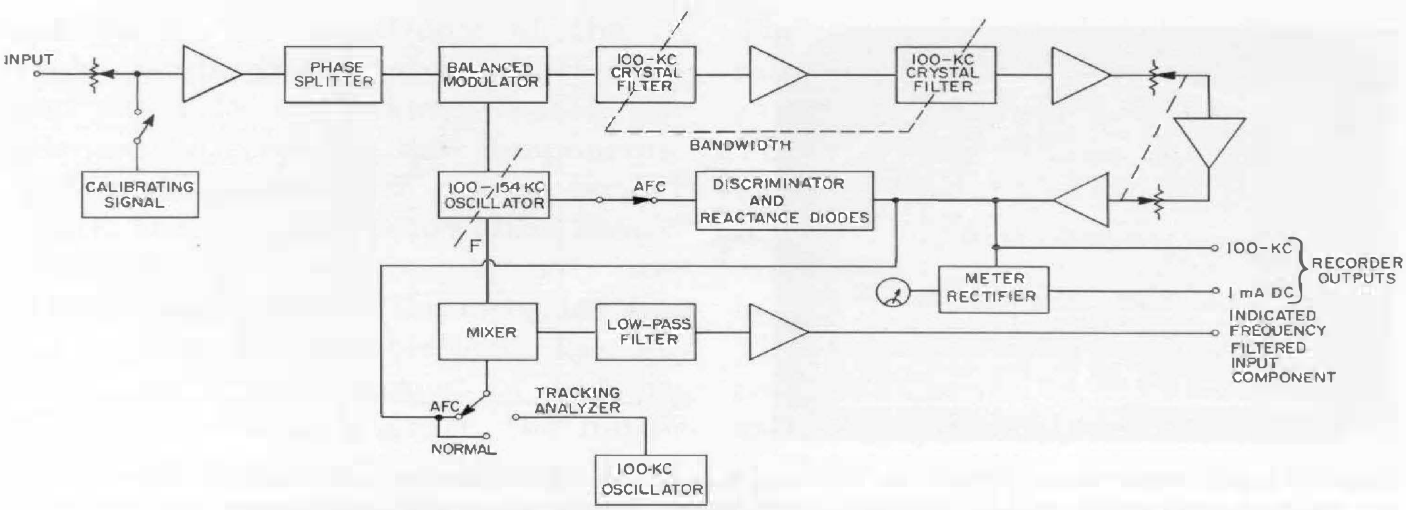


Figure 2. Block diagram of the analyzer.

The linear frequency scale, the three bandwidths, and a high-level, 80-db-dynamic-range output make the combination of a TYPE 1521 Graphic Level Recorder and TYPE 1900-A Wave Analyzer a recording analyzer of outstanding usefulness. Another output for use with 1-ma dc recorders is also included.

The analyzer also functions as a tunable filter, and it has a generator output that tracks the tuning of the analyzer, thus providing both a power source and a tuned-voltmeter detector for network measurements.

The additional features of a large, mirror-backed meter, in-line frequency readout, precise frequency settability, excellent frequency stability, a constant one-megohm input impedance, automatic frequency control, and a quick calibration test make the analyzer easy to use.

DESCRIPTION

General

The TYPE 1900-A Wave Analyzer is a heterodyne type of analyzer. As can be seen from the block diagram, Figure 2, the main filter is a 100-kc quartz-crystal filter. Any frequency in the range from 20 to 54,000 cps can be heterodyned with the local oscillator, which is tunable from 100 to 154 kc, to produce a 100-kc difference frequency, which is applied to the filter. The amplified output of the filter drives a metering circuit and supplies a voltage for recording.

This basic analyzing system is arranged to include the features necessary for a wide variety of measurement applications; these important features will be described in relation to typical applications.

INPUT CIRCUIT

The input control for the instrument is a constant-input-impedance, 1-megohm attenuator. A 54-kc low-pass filter in the input amplifier reduces the response to signals beyond the operating frequency range of the instrument. This filtering is essential to minimize responses at the 100-kc filter frequency and at image frequencies. These responses could otherwise lead to serious errors, particularly in the measurement of wide-band noise.

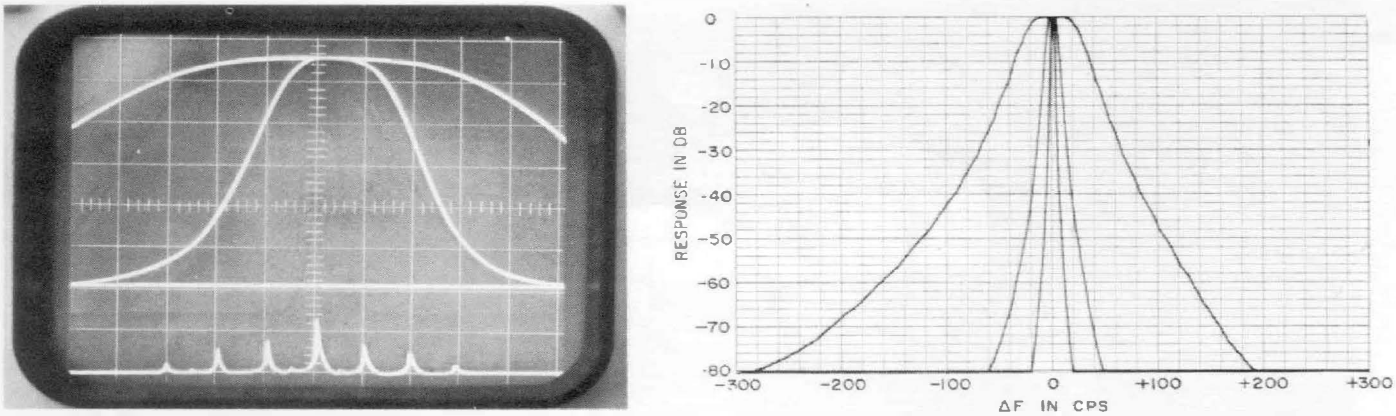


Figure 3 (*right*). Filter characteristics for the three bandwidths (3, 10, and 50 cps) as plotted automatically on the Type 1521 Graphic Level Recorder. (*left*) Photo of trace on storage oscilloscope, showing detail of 3-cycle and 10-cycle bands. Frequency source was a Type 1162-A Coherent Decade Frequency Synthesizer. Markers are 1 cps. Vertical scale is linear.

LOCAL OSCILLATOR

The oscillator uses the series-tuned Vackar circuit[1] with a large, high-Q, universal-wound coil and stable capacitors to achieve a high degree of frequency stability. The frequency-control capacitor of the oscillator is shaped so that the frequency is a linear function of the dial rotation. The linear scale makes possible the use of a combination of dial and counter to get high resolution and an in-line readout. But, more importantly, when the analyzer is tuned manually, this linearity makes the transient behavior the same over the full range of the dial. When a recording is made and the dial is driven at a constant rate, the behavior is again uniform, and the fastest speed of sweep suitable for a given bandwidth is appropriate over the full frequency range. The resulting chart has a linear frequency scale, which has important advantages for analysis. This feature will be discussed more fully below.

The series tuning arrangement of the oscillator circuit has made possible a new circuit for a calibrated cycles-increment control that is useful over the entire tuning range of the oscillator. This control covers the range of ±100 cps with respect to the setting of the main frequency-control dial. The cycles-increment control is particularly helpful when the 3-cycle bandwidth is used in the measurement of components that are closely spaced in frequency, as for example, low-frequency side-band components about a carrier. It is also useful as a vernier adjustment during recording.

QUARTZ-CRYSTAL FILTER

The use of four low-temperature-coefficient quartz crystals has made possible the development of a filter that can be switched to three different bandwidths and which has excellent characteristics over a relatively wide range of ambient temperatures. The bandwidths selected are 3, 10, and 50 cps, which are adequate for almost any analysis problem. Typical response characteristics are shown in Figure 3.

The importance of being able to select any one of three bandwidths is easily demonstrated by some simple examples. If the components in the spectrum to be measured are only 10

[1] J. K. Clapp, "Frequency Stable LC Oscillators," *Proceedings of the IRE*, August, 1954.

cps apart, the selectivity of the 3-cycle bandwidth is essential; the 10- and 50-cycle bandwidths would not adequately separate the components. If the components are spaced farther apart, the broader bandwidths should ordinarily be used, because any frequency instability of the incoming signal is then less troublesome. For example, in a measurement of the distortion of a tape recorder, the flutter may make the pointer of the analyzer meter fluctuate violently as an attempt is made to tune in the component in a narrow band, and no satisfactory measurement is possible. But the 50-cycle bandwidth will tolerate the fluctuations encountered in any good tape recorder, and the measurement is easy.

Time saving is another important advantage of the wider bandwidths.

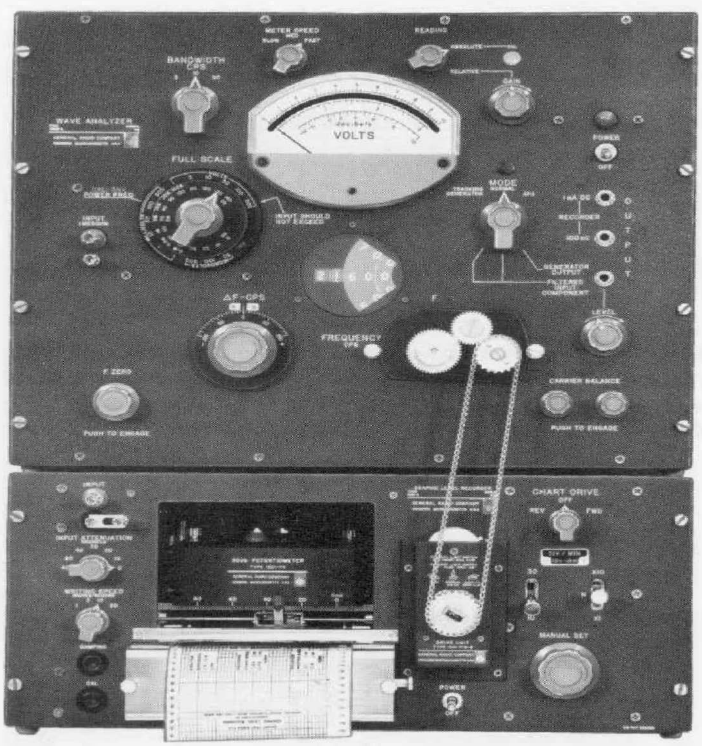


Figure 4. View of the Type 1910-A Recording Wave Analyzer, consisting of the Type 1900-A Wave Analyzer and the Type 1521 Graphic Level Recorder.

The speed with which a given frequency range can be swept varies in the limit as the square of the filter bandwidth. Thus, if the 50-cycle bandwidth provides adequate resolution, the effective response speed over a given frequency range can be as much as 25 times as fast as it is for the 10-cycle bandwidth. This increased speed can be very important in recording, but it is also both useful and apparent when the analyzer is tuned by hand. For noise signals, the differences in time required for analysis by the different bandwidths are even more significant. This point is discussed further in the section on noise analysis.

VOLTAGE CALIBRATION

A voltage from the power line is clipped and compensated to provide a component at the fundamental power-line frequency whose amplitude is essentially constant over a wide range of input voltage and ambient temperature. This fundamental component is used as the reference calibrating signal, so that the sensitivity of the instrument can be easily checked at any time. The calibrating signal is always at the power-line frequency so that it can be located without difficulty.

OUTPUTS FOR RECORDING

The new analyzer has a number of outputs, two of which are specifically provided for recording purposes. The most important is the 100-kc filtered-and-amplified signal for driving the Type 1521 Graphic Level Recorder. This output has an 80-db dynamic range and enough power so that the full capabilities of the recorder can be utilized, and the recorder and the analyzer, shown in Figure 4, make a remarkably useful combination, which is available as the TYPE 1910-A Recording Wave Analyzer.

Dynamic Range

The 80 db or more of dynamic range in the filtered output is obtained for signals of 0.3 volt or higher. The term "dynamic range" is used here to signify the linear range from maximum output to the noise level without readjustment of the controls. This range in many other instruments is significantly less than the analysis range one obtains by resetting the attenuator that controls the meter reading. In this analyzer the two are similar, since the meter attenuator covers a 70-db range, which combines with a 20-db range of the meter to give a 90-db analysis range.

Writing Speed and Bandwidth

When the output of the analyzer is recorded, much detailed information about the spectrum of a signal can be obtained automatically. The detail that can be obtained is illustrated by the charts reproduced in Figure 5. In one instance more than 3400 components of a particular signal were recorded, and each of the components was clearly defined.

Such a recorded analysis can proceed with little attention after it is once set up. But it often pays to consider carefully how the analysis should be done, because the time required varies greatly with the bandwidth and with the recorder characteristics. When a periodic

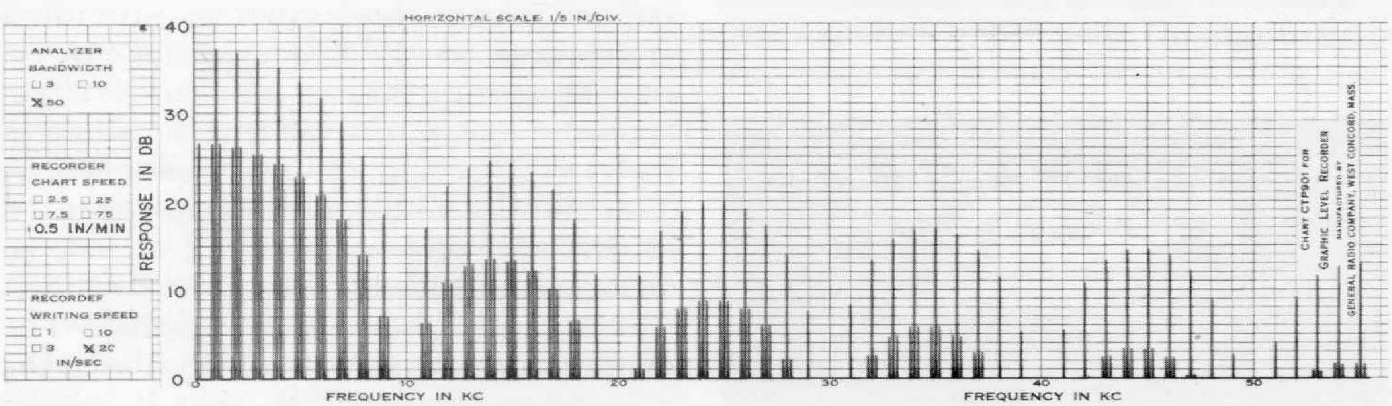
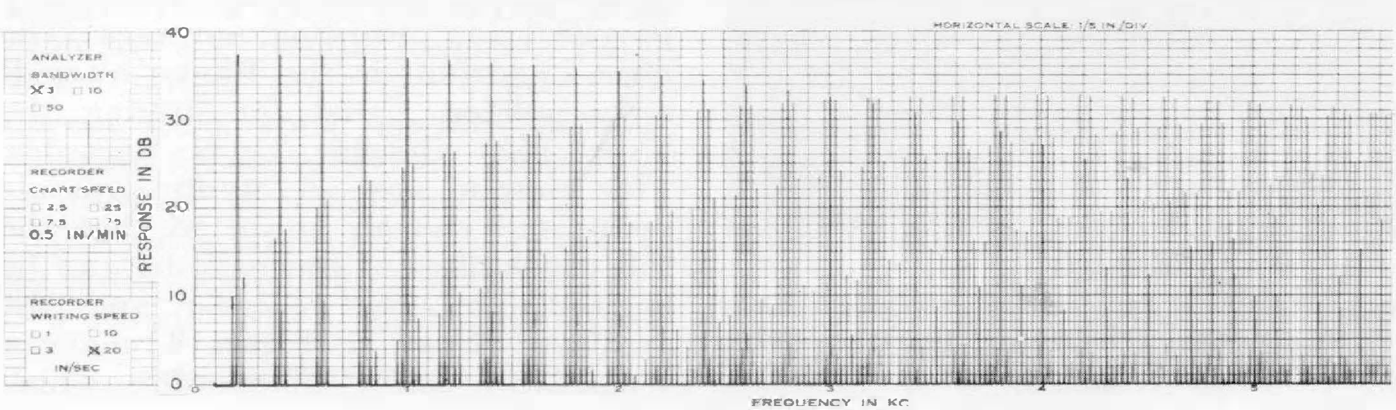


Figure 5. Plots of pulse waveforms made on the recording analyzer: (a, *above*) 100-μsec pulse at 1-kc repetition rate. Pulse was amplitude modulated from ¼ to full amplitude by a 200-cycle, non-coherent sine wave. (b, *below*) 20-μsec pulse at an average repetition rate of 200 cps. The pulse was position modulated at a 25-cycle rate.



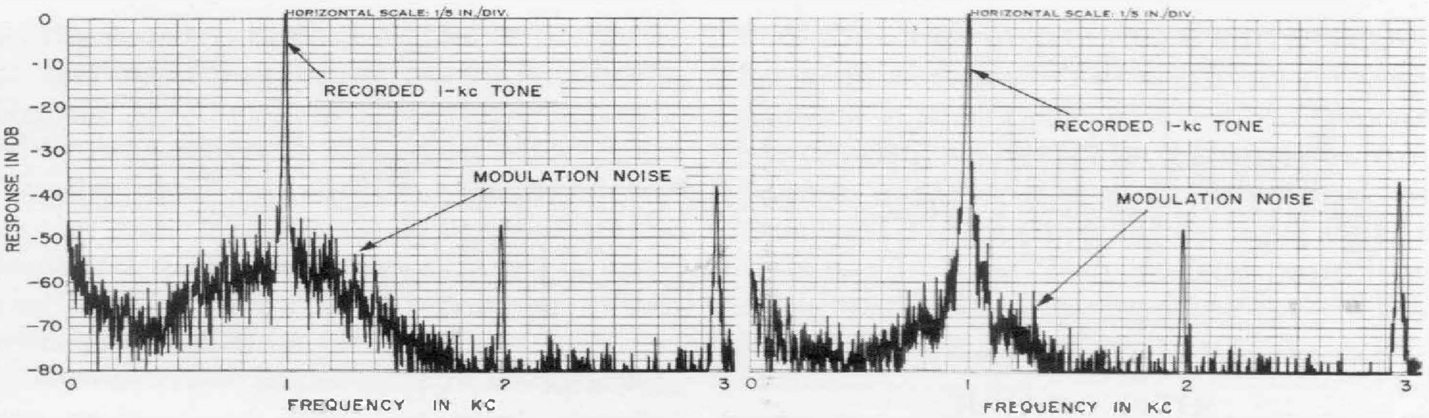


Figure 6. Charts of modulation noise on a 1-kc tone for two different types of magnetic tape. Note that one is about 10 db better than the other. Such measurement can be made easily with the recording analyzer, owing to the 80-db dynamic range. For these records, chart speed was 2.5 inches per minute; writing speed, 10 inches per second; bandwidth, 10 cps.

signal is analyzed, the recorder's fastest writing speed should be used to speed up the recording. Its fast writing speed makes the TYPE 1521 Graphic Level Recorder particularly useful.

The widest bandwidth that provides adequate selectivity should also be used, since the inherent response time of the filter is inversely proportional to the bandwidth. Here the three bandwidths make possible a near-optimum choice for most analyses. The time required to analyze over a 25-kc range is approximately 2 minutes, 20 minutes, and 2 hours for the 50-, 10- and 3-cycle bandwidths, respectively.

Linear Scale

The recorded display from the TYPE 1900-A Wave Analyzer is linear in frequency. This linear display has the important advantage that harmonic components of a periodic signal are uniformly spaced, so that the harmonic relations are obvious. If the signal is more complex, for example, a modulated carrier or other combinations of signals, where there are component frequencies that are sums and differences of other component frequencies, such relations are also readily apparent on a linear frequency scale.

DC Output

The second output for recording is in series with the indicating meter so that a simple, 1-ma dc recorder can be used. This arrangement provides a convenient method of recording, but the recording is seriously limited in speed and in dynamic range, compared to the one made from the 100-kc output.

NOISE ANALYSIS

Meter Speed

The new analyzer is well suited for the analysis of noise. The slow meter response is one essential feature, and the choice of bandwidths and the linear frequency scale simplify many noise analyses.

Three different meter speeds are provided. The fastest time constant is essentially that of the meter alone, about 1/6 second. This speed is always used for measurement of components of periodic signals. The slowest time constant provided is about 5 seconds, and this and the intermediate value are used for noise measurements. The im-

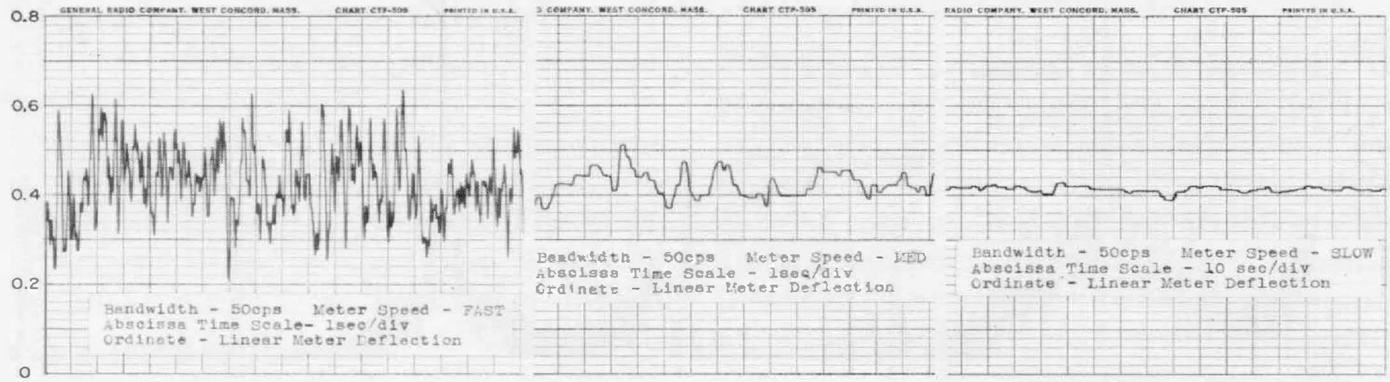


Figure 7. Chart of analyzer meter current (dc output) as a function of time for random noise, with 50-cycle bandwidth, as recorded with FAST, MEDIUM, and SLOW meter switch settings.

portance of these slower responses for noise measurement can be readily appreciated when the problems associated with noise analysis are reviewed.

The indicated meter reading produced by an applied random-noise signal, whether it is electrically generated noise or acoustic noise transformed by a microphone into an electrical signal, fluctuates considerably. These fluctuations reflect the irregularities in the process of noise production. In fact, all signals contain some random-noise energy, and many contain enough so that the indication is not at all steady.

The charts of Figure 7 show graphically the behavior of the pointer of the indicating instrument as a function of time when samples of the same random noise were measured with the 50-cycle bandwidth and the three different meter speeds. It is clear that the average value is essentially the same for each sample, but the fluctuations are markedly greater for the faster meter speeds than for the slow one, and these differences are inherent in the nature of the measurement. It is obviously much easier to obtain a good estimate of the average value with the slow meter speed. The charts illustrate also that a maximum or minimum reading for a noise signal has little significance. The extent of the fluctuations does have some significance, however, with regard to the statistical estimate of the confidence to be given to the selected average value.[2,3]

Bandwidth

If the narrower bandwidths are used, the fluctuations are even greater, and only the slower meter speeds can be used to obtain a satisfactory average value. A relatively simple principle applies here. The narrow bands are used to get fineness of detail. The finer the detail that is desired, the more time is needed to obtain the result to a certain degree of confidence. The averaging time required is essentially inversely proportional to the bandwidth.

If the analyzer is swept through a range of frequencies in order to observe the spectrum, it is necessary to stay in each bandwidth along the frequency span long enough to get a satisfactory measurement. This factor combines with the averaging time to make the required total sweep time inversely proportional to the square of the band-

[2] R. B. Blackman and J. W. Tukey, *The Measurement of Power Spectra*, Dover, New York, 1958.
[3] R. P. Rona, "Instrumentation for Random Vibration Analysis," pp 7–27 to 7–30 in *Random Vibration*, edited by S. H. Crandall, Technology Press, Cambridge Massachusetts, 1958.

width, again pointing up the importance of having three bandwidths available. If only the detail of the 50-cycle bandwidth is needed, a relatively short time for the analysis suffices. If the detail of the narrower bands is necessary, the required time is correspondingly longer, and a fast scan is useless or, even worse, misleading.

Unless these aspects of noise analysis are understood, one can easily be led into using an analyzer that is entirely unsuitable to the problem, using an analyzer incorrectly, accepting data that are misleading, or even rejecting useful data.

Spectral Density

In order to compare measurements of random noise made with different bandwidths, it is customary to convert the measured value to an equivalent one for a bandwidth of one cycle per second. This equivalent value is often called the spectral density. The conversion for a measurement made on the wave analyzer is simple, because it is independent of the center frequency and depends only upon the particular bandwidth used.

AUTOMATIC FREQUENCY CONTROL

In one mode of operation of the analyzer, the local-oscillator frequency is controlled by the filtered signal by means of a quartz-crystal discriminator and reactance diodes. When a component has been tuned in, it can be locked by means of this automatic frequency control to stay within the pass band of the analyzer over a wider frequency range than the normal pass band. The characteristics of the control circuit, however, limit the rate at which the frequency can change without dropping out of lock to a relatively slow one, and the control circuit is not effective for a noise signal. Thus, whenever possible, it is preferable to use the 50-cycle bandwidth rather than automatic frequency control. If a component is to be observed for a long time and might drift beyond the 50-cycle pass band, the afc is useful in compensating for such a drift.

TUNABLE FILTER

The analyzer also functions as a tunable, selective filter and amplifier. This type of operation is achieved by a second heterodyne operation in which the amplified and filtered signal at 100 kc is beat with the local oscillator to restore the filtered component to its original frequency. The tunable filter has the excellent selectivity characteristics of the particular bandwidth chosen, and the output amplitude is proportional to the component amplitude.

The applications for this mode of operation are generally those for a highly selective filter, for example, separating out an individual component of a complex signal for study. The study may consist of an accurate determination of the component frequency stability by means of a digital frequency meter (counter), or it may simply be determining the existence of a particular component in the midst of interfering components.

If a signal from the Type 1390 Random-Noise Generator is applied to the input of the analyzer, the output will be a narrow band of noise. The center frequency of this noise can be set by means of the analyzer frequency control. When this type of noise is made audible by means of a loudspeaker, it can be used for acoustical transmission

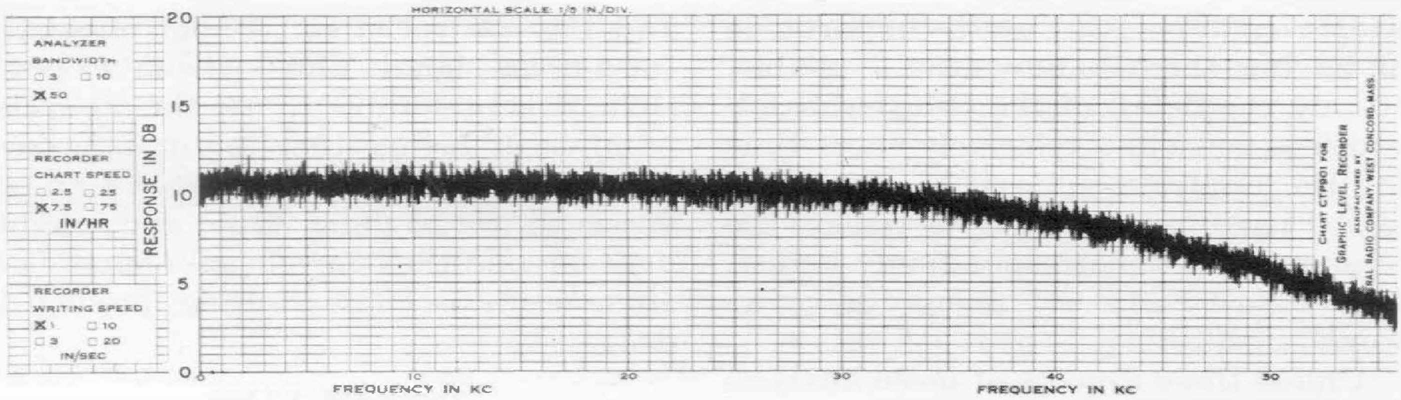


Figure 8. Chart of 0- to 20-kc output of Type 1390 Random-Noise Generator as recorded with 50-cycle bandwidth.

tests, for reverberation measurements, and for some psychoacoustical tests.

TRACKING GENERATOR

In one mode of operation the local-oscillator voltage is heterodyned with a 100-kc crystal-oscillator voltage to produce a beat signal whose frequency is always the same as that to which the analyzer is tuned. As the local oscillator is tuned from 100 to 154 kc, the frequency of the beat signal varies from zero to 54 kc. This beat signal is amplified to provide a maximum of at least 2 volts across 600 ohms. This output can be used to drive a network, amplifier, tape recorder, impedance bridge, or other system to be tested. The output of the device to be tested can then be measured by the analyzer, and the analyzer will stay in tune to the fundamental component as its frequency is varied. In this way the effects of hum, distortion, and noise are essentially eliminated from the measurement.

When an accurately known signal must be applied to the device under test, the output from the generator is sufficient to drive a Type 546-C Audio-Frequency Microvolter. Alternatively, the wave analyzer can measure its own output but, of course, not at the same time as it measures the output of the device under test.

The 100-kc output for driving the Type 1521 Graphic Level Recorder can be used at the same time that the tracking-generator output is used. Thus, the response characteristic of a device can be plotted automatically with the wave analyzer supplying the signal, the detector, and the output for recording.

SUMMARY

The Type 1900-A Wave Analyzer, with its three highly selective filter bandwidths covering the frequency range from 20 to 54,000 cps, its high sensitivity, its high and constant input impedance, its three meter speeds for noise analysis, its linear frequency scale, its tunable filter, its tracking generator, and its afc, provides a new degree of versatility in measuring instruments that will make it one of the most widely used analyzers in electronics.

— Arnold Peterson

CREDITS

The author wishes to acknowledge the many contributions made by others in the design of this instrument and, in particular, the assistance of R. J. Ruplenas in the circuit development. — Editor

TYPE 1910-A RECORDING WAVE ANALYZER

The Recording Wave Analyzer consists of the following items:

Type 1900-A Wave Analyzer
Type 1521 Graphic Level Recorder
Type 1521-P10B Drive Unit
Type 1900-P1 Link Unit
10 Rolls Type 1521-9464 Chart Paper
10 Rolls Type 1521-9465 Chart Paper
Type 1521-P3 80-db Potentiometer*

Both bench and rack models are available. The bench model is shipped completely assembled. The rack model is supplied with supports for installation in a standard 19-inch rack.

* A 40-db potentiometer is installed in the recorder. The 80-db unit is supplied in addition.

SPECIFICATIONS

TYPE 1900-A WAVE ANALYZER

FREQUENCY

Range: 20 to 54,000 cps. The frequency is indicated on a counter and a dial with a linear graduation, 1 division/10 cps.

Accuracy of Calibration: ± (½%+5 cps) up to 50 kc; ± 1% beyond 50 kc.

Incremental-Frequency Dial (△F): ± 100 cps. Accuracy is ± 2 cps below 2 kc, ±5 cps up to 50 kc.

Automatic Frequency Control: At frequencies below 10 kc, total range of frequency lock is 400 cps for the 50-cycle band and 150 cps for the 10-cycle band, as defined by 3-db drop in response from full-scale deflection. At 50 kc, the lock ranges decrease to one-half these values.

SELECTIVITY: Three bandwidths (3, 10, and 50 cps) selected by switch.

3-Cycle Band: At least 30 db down at ±6 cps from center frequency, at least 60 db down at ±15 cps, at least 80 db down at ±25 cps and beyond.
10-Cycle Band: At least 30 db down at ±20 cps, at least 60 db down at ±45 cps, at least 80 db down at ±80 cps and beyond.
50-Cycle Band: At least 30 db down at ±100 cps, at least 60 db down at ±250 cps, at least 80 db down at ±500 cps and beyond.

Effective bandwidth for noise equal to nominal bandwidth within ±10% for 10- and 50-cycle bands and ±20% for 3-cycle band.

INPUT

Impedance: One megohm on all ranges.

Voltage Range: 30 microvolts to 300 volts full scale in 3, 10 series. A decibel scale is also provided.

Voltage Accuracy: After calibration by internal source, the accuracy up to 50 kc is ±(3% of indicated value + 2% of full scale) except for the effects of internal noise when the attenuator knob is in the maximum-sensitivity position. In that position the internal noise is about 5% of full scale for the 3- and 10-cycle bands and 10% of full scale for the 50-cycle band. From 50 to 54 kc, the above 3% error becomes 6%.

OUTPUT

100-kc Output: Amplitude is proportional to amplitude of selected component in analyzer input signal. With the TYPE 1521 Graphic Level Recorder connected through the adaptor cable supplied, at full-scale meter deflection output is at least 3 volts. Dynamic range from overload point to internal noise is >80 db with attenuator knob fully clockwise.

Recording Analyzer: The analyzer in combination with the TYPE 1521 Graphic Level Recorder produces continuous, convenient records of frequency spectra over the complete range of the analyzer. The end frames of the bench models can be bolted together to form a rigid assembly.

DC Output: One milliampere in 1500 ohms for full-scale meter deflection, one side grounded.

Filtered Input Component: Output at least 1 volt across 600-ohm load for full-scale meter deflection with output control at maximum.

Tracking Generator: 20 cps to 54 kc; output is at least 2 volts across 600-ohm load with output control at maximum.

GENERAL

Residual Modulation Products and Hum: At least 75 db down.
Terminals: Input, TYPE 938 Binding Posts; output, telephone jacks.
Power Requirements: 105 to 125 (or 210 to 250) volts, 50 to 60 cps, approximately 40 watts.
Accessories Supplied: TYPE 1560-P95 Adaptor Cable Assembly, phone plug, TYPE CAP-22 Power Cord, spare fuses.
Other Accessories Available: TYPE 1900-P1 Link Unit for coupling to TYPE 1521 Graphic Level Recorder.

SPECIFICATIONS (Cont)

Cabinet: Rack-bench.

Dimensions: Bench model — width 19, height 16¼, depth 15¼ inches (485 by 415 by 390 mm), over-all; rack model — panel 19 by 15¾ inches (485 by 400 mm), depth behind panel 13¼ inches (340 mm).

Net Weight: 56 pounds (26 kg).

Shipping Weight: 84 pounds (39 kg).

TYPE 1910-A RECORDING WAVE ANALYZER

Dimensions: Bench model — width 19, height 25¼, depth 15¼ inches (485 by 645 by 390 mm), over-all: rack model — width 19, height 24½ (485 by 625 mm), depth behind panel, 13¼ inches (340 mm).

Net Weight: 116 pounds (53 kg).

Shipping Weight: 190 pounds (87 kg).

Type		*Price*
1900-AM	**Wave Analyzer**, Bench Model	$2150.00
1900-AR	**Wave Analyzer**, Rack Model	2150.00
1910-AM	**Recording Wave Analyzer**, Bench Model (for 60-cycle supply)	3500.00
1910-AR	**Recording Wave Analyzer**, Rack Model (for 60-cycle supply)	3500.00
1910-AMQ1	**Recording Wave Analyzer**, Bench Model (for 50-cycle supply)	3500.00
1910-ARQ1	**Recording Wave Analyzer**, Rack Model (for 50-cycle supply)	3500.00
1521-9464	**Chart Paper**, 0–10 kc, 100-foot roll	2.75
1521-9465	**Chart Paper**, 0–50 kc, 100-foot roll	2.75

USEFUL FORMULAS, TABLES, AND CURVES FOR RANDOM NOISE

Under the above title we have prepared a 6-page publication listing relationships and data that are commonly used in working with random noise. It will be found particularly useful by those who deal with noise phenomena only occasionally and need a handy reference to refresh their memories. Free on request; ask for publication IN-103.

CORRECTION

Several eagle-eyed readers have pointed out that the schematic of a pulsed bias supply for use in transistor measurements (*Experimenter*, February, 1964, page 7) shows that the bias source is shorted when the relay operates. This is quite true, but, as used by Clark Division, National Semiconductor Corporation, who devised the circuit, the shorting does no harm since they use a constant-current bias supply, rather than a battery.

We apologize to our puzzled readers for omitting this fact.

SWIEEECO

This ancient Apache rallying cry stands for Southwestern IEEE Conference and Show, now in its 16th year. General Radio will be there, in booths 301-302-303. On display will be the new instruments shown at IEEE — New York and described briefly in the March issue of the *Experimenter*. General Radio engineers will be on hand to welcome you and to demonstrate the new equipment.

Dallas Memorial Auditorium **April 22-24, 1964**

General Radio Company
WEST CONCORD, MASSACHUSETTS, U.S.A.

PRINTED IN U.S.A.