THE GENERAL RADIO

Experimenter

New 70-MHz Solid-State Frequency Synthesizer

Narrow-Band Wave Analyzer 1% Bandwidth

VOLUME 40 · NUMBER 9 / SEPTEMBER 1966

Volume 40 • No. 9
September 1966

the GR Experimenter

Published monthly by the General Radio Company

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70-MHz SYNTHESIZER JOINS THE FAMILY

Figure 1. Type 1164-A7C.

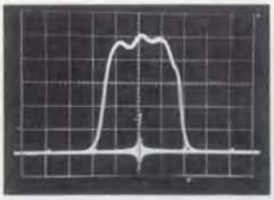
The newest addition to the GR synthesizer line, the TYPE 1164-A Coherent Decade Frequency Synthesizer (Figure 1), offers greatly expanded frequency coverage, extending well beyond the normal high-frequency, radio-communications bands and including the popular intermediate frequencies. All the features of the low-frequency models[1,2] — modular construction, in-line readout, provision for sweeping, continuously adjustable decade (CAD), programmability,[3] ac and battery operation — have been retained, and a few new ones added.

The frequency synthesizer, a relatively recent development, is nonetheless well established as an important instrument in the laboratory and in countless frequency-control applications. Also well established is GR's 1160 family of coherent decade frequency synthesizers, which have until now supplied frequencies up to 12 MHz. Now a new member—the 1164—extends coverage to 70 MHz and thus brings the considerable advantages of this type of instrument to many more users.

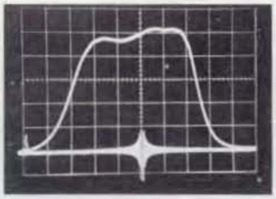
To review the chief characteristics of the 1160 line briefly: Each synthesizer can contain up to seven plug-in digit modules, each controlled by a front-panel rotary switch, plus a continuously adjustable decade (CAD). By the push of a button, the CAD can be electrically substituted for one or more of the step-digit modules. The output level is adjustable up to 2 volts and is monitored by a panel meter. The synthesizer can be locked to an external frequency standard, can be swept, and, with appropriate plug-in modules, can be programmed.

Because of the modular construction, the 1160 series can be provided in a great many variations to suit customer requirements. One can, for instance, buy a synthesizer with as few as three of the maximum seven digits, adding more later as more resolution is needed. The programmable option further increases the number of available models. For the

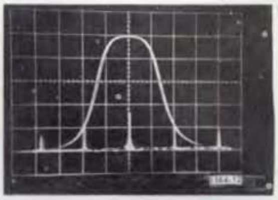
[1] A. Noyes, Jr., "Coherent Decade Frequency Synthesizers," *General Radio Experimenter*, September 1964.
[2] A. Noyes, Jr., "12-Mc Coherent Decade Frequency Synthesizer," *General Radio Experimenter*, November-December 1965.
[3] G. H. Lohrer, "Remote Programming for GR Synthesizers," *General Radio Experimenter*, May 1965.



Communications receiver i-f with 455-kHz center frequency and 1.5-kHz mechanical filter. Horizontal scale: 500 Hz/cm. Marker frequency: 455.00 kHz. The CAD was in the 1-kHz position and was swept ± 2½ major divisions, or ± 2½ kHz.



Response of 50-MHz crystal filter. Horizontal scale: 2 kHz/cm. Marker frequency: 50.00000 MHz. The CAD was in the 10-kHz position and was swept ±1 major division, or ± 10 kHz.



Response of GR Type 1900 Wave Analyzer tuned to 10 kHz and set for 10-Hz bandwidth. Horizontal scale: 5 Hz/cm. Marker frequency: 10,000.00 Hz. The CAD was in the 10-Hz position and was swept ± 2½ major divisions, or ± 25 Hz.

Figure 2.
Oscillograms showing frequency response of various filters to swept output of synthesizer CAD.

1164 alone, twenty "standard" combinations are listed.

Applications

One of the most common uses for synthesizers is frequency control of communications transmitters and receivers. Used with a transmitter, a complete 70-MHz synthesizer is roughly equivalent to a bank of 7 million crystals that can easily be switched to change frequency. (There are 700 million readable frequencies when the CAD is used.) In a receiver, the synthesizer can serve as a highly stable local oscillator.

The 70-MHz upper frequency limit of the new synthesizer covers not only most of the commercial broadcasting spectrum but also intermediate frequencies of many vhf and uhf systems. Frequency-translation techniques can be applied, moreover, to provide useful frequencies for devices operating in the gigahertz region.

In a telemetry receiver, for example, a synthesizer can be used as a second- or third-conversion oscillator, automatically compensated for Doppler shift. The Doppler shift is sensed by an external phase detector, which in turn is used to control the synthesizer's CAD frequency. Or, in a nuclear magnetic resonance (NMR) study, the synthesizer frequency can be added to the output of a stable microwave source to produce a 70-MHz-wide microwave band under synthesizer control. Conversely, the NMR band can be beat against a stable microwave frequency and the beat frequency compared with the synthesizer output.

Of course, the synthesizer output itself can be multiplied, but, the higher the multiplier, the more noticeable any instability.

Sometimes it is desirable to divide the synthesizer frequency. In one application, for instance, an aerospace laboratory wished to measure the rotational speed of a satellite to eight significant digits, then to supply a corresponding frequency to the satellite. With the satellite rotating only 100 revolutions a minute, it was necessary to divide the synthesizer output by means of a 10^4 scaler; the synthesizer then served admirably to measure and to reproduce the satellite rotational frequency.

The sweep capability is all-important in many applications and is especially so in the measurement of the characteristics of crystal and other mechanical filters (see Figure 2). The CAD can be swept electrically over ± 5 major dial divisions, corresponding to a frequency span as wide as 1 MHz or as narrow as 10 Hz. The sweep can be centered on any point of the 12-division manual dial except on the 100-kHz functional position, where the limits for the frequency excursion are − 100 and + 1100 kHz.

Perhaps the single most important capability of a frequency synthesizer is programmability. In the TYPE 1164 synthesizer, output level as well as frequency can be programmed. This means, for instance, that in a frequency-response measurement, frequency and level can be simultaneously programmed to effect 3-dB, 6-dB, 10-dB, etc, level changes at selected frequencies.

The maximum programmable bandwidth of the TYPE 1164 synthesizer is at present 1 MHz. In other words, one can electrically control output frequency over any 1-MHz (or smaller) range, up to the 70-MHz frequency limit of the synthesizer. Frequency switching time is less than two milliseconds.

Constructional Features

The synthesizer consists of plug-in modules in a bench or rack frame with a panel only 5¼ inches high. Five of the seven digit modules in the TYPE 1164 are identical and interchangeable with one another and with corresponding modules in other GR synthesizers. The advantages of such modular construction in servicing are obvious. Less obvious, perhaps, but equally important are the manufacturing economies of this approach, which are translated into low prices.

All etched boards in the instrument are made of fiberglass, and the improved power supply uses all silicon transistors. The rear panel is an engineer's delight: in addition to the primary output (also available at the front panel), the following are available: 100 kHz, 1 MHz, 5 MHz, 5-5.1 MHz, 30 MHz, 42 MHz, 40-49 MHz, 50-51 MHz, 90 MHz, and +18V dc.

HOW IT WORKS

Figure 3 is a complete block diagram of the synthesizer.

The DI-1, CAD, and AFS-1 modules have been described in an earlier article.[1] The new modules are briefly described below.

DI-2, DI-3 Digit-Insertion Units

Figure 4 is a block diagram of the DI-2 unit. The frequency of the digit oscillator goes from 40 to 49 MHz in 1-MHz steps as its dial rotates from 0 to 9. The digit-oscillator frequency is rough-tuned to the proper frequency by a step switch controlled by the dial, and a voltage-control servo establishes phase lock with a multiple of the reference frequency. A gated or sampling-type phase detector is used here. The gate opens only during every 40th to 49th cycle (depending on the frequency selected) of the output frequency of the DI-2 unit (every 30th to 24th cycle of the DI-3) and stays open for only a small fraction of a period of the output frequency. If the phase of the output frequency is crossing zero while the gate is open, no voltage is placed on the holding capacitor, and therefore no correction voltage is applied to the digit oscillator. If the phase of the output frequency has passed zero in a negative direction when the gate opens, a negative voltage is placed on the holding capacitor; if the phase has not reached zero, a positive voltage is placed on the capacitor. With the proper phasing in the frequency-control loop of the oscillator, the phase error between the reference-frequency-controlled gate and the output frequency is minimized. The latter is thus locked at an exact multiple of the reference frequency.

[1] *Ibid.*

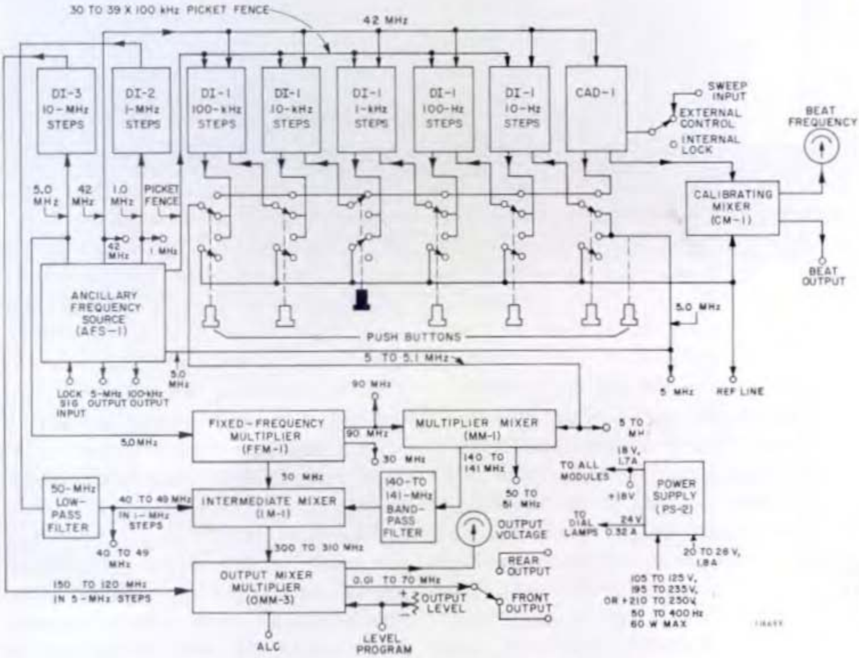


Figure 3. Block diagram of the synthesizer.

Any change in the output frequency is immediately sensed as a phase error and corrected.

Proper phase condition for phase lock exists whenever the digit-oscillator frequency is an exact multiple of the reference frequency. Rough-tuning to the approximate frequency by the digit dial determines which multiple is chosen. A dial-light warning system indicates failure to achieve stable phase lock. As in the DI-1's, the presence of any appreciable ac signal in the phase-control loop is sensed, causing the dial light of the affected unit to go out.

The DI-3 unit is identical to the DI-2 except that the frequency from the ancillary frequency source is 5 MHz, and the step-tuned oscillator goes from 150 MHz to 120 MHz in 5-MHz steps as its dial setting is changed from 0 to 6.

Fixed-Frequency Multiplier (FFM-1)

The fixed-frequency multiplier is shown in Figure 5. Undesired frequencies are rejected by frequency-selective amplifiers and by the connection of pairs of diodes in push-push for doubling and push-pull for tripling. Levels are kept relatively high to minimize noise.

Mixers MM-1 and IM-1

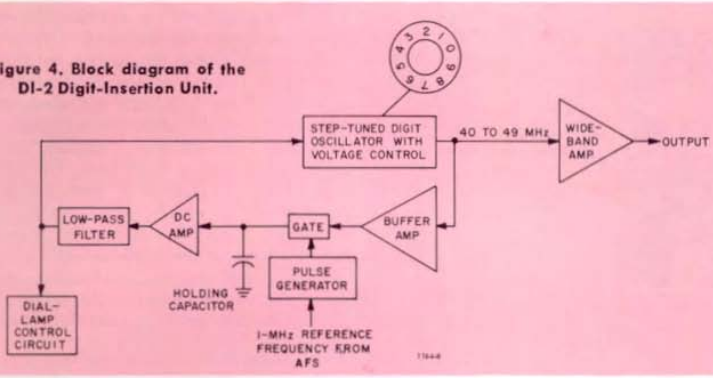
Figures 6 and 7 are block diagrams of the multiplier mixer (MM-1) and intermediate mixer (IM-1), respectively. In each, bandpass amplifiers reject frequencies outside the desired ranges. Each uses transistor frequency multipliers and double-diode balanced mixers (one in the MM-1, two in the IM-1).

Output Multiplier Mixer OMM-3

Figure 8 shows the output multiplier mixer in block form. The 150- to 120-MHz output of the DI-3 unit is amplified in a two-stage bandpass amplifier, doubled in frequency by a pair of diodes in a full-wave doubler, and filtered by a six-pole bandpass filter to provide the input to the final mixer, which produces the 10-MHz steps in the output. A four-diode double-balanced mixer is used to subtract this frequency from the 300- to 310-MHz output from the IM-1 unit to produce the final output frequency.

Signal levels at this mixer are kept low to minimize undesired mixing products within the output-frequency passband. A six-stage broad-

Figure 4. Block diagram of the DI-2 Digit-Insertion Unit.



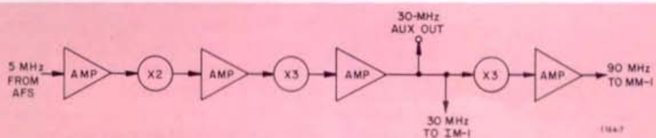


Figure 5. Block diagram of the Fixed Frequency Multiplier (FFM-1).

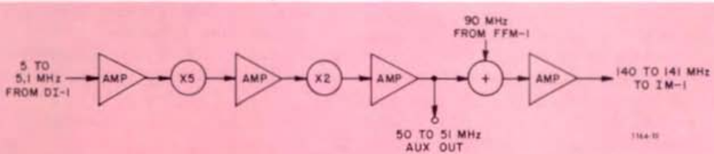


Figure 6. Block diagram of the Multiplier Mixer (MM-1).

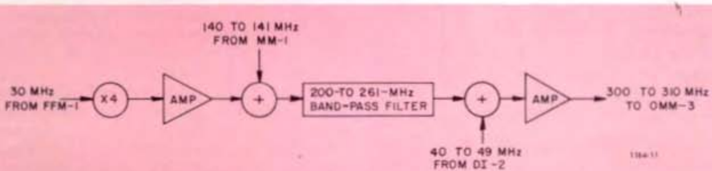


Figure 7. Block diagram of the Intermediate Mixer (IM-1).

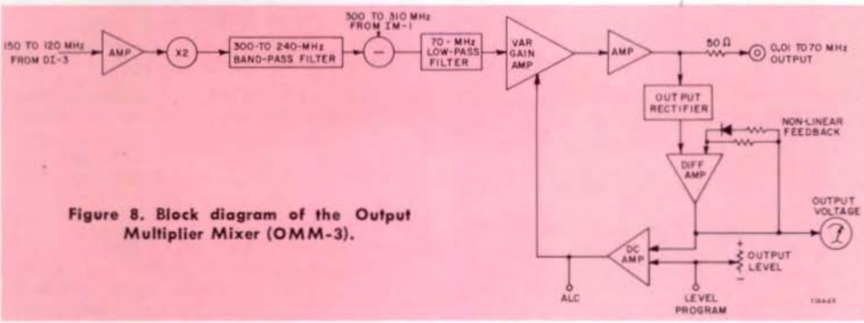


Figure 8. Block diagram of the Output Multiplier Mixer (OMM-3).

William F. Byers was graduated with high honors from Ohio University in 1943 with the degree of BSEE. He was a visiting lecturer in electrical engineering at Ohio University prior to coming to General Radio as a development engineer in late 1943. He is at present a Section Leader in the development group concerned with radio-frequency circuits, including standard-signal generators, oscillators, and frequency synthesizers. He is a member of the IEEE.

band amplifier covering the frequency range of 0.01 to 70 MHz follows the output filter of the mixer, increasing the level to a maximum of 2 volts behind 50 ohms. This level is maintained even with the output connector short-circuited.

Two of the earlier stages are variable in gain by diode-controlled emitter degeneration, permitting automatic output leveling. The last two stages are operated in push-pull, using complementary transistor pairs. Emitter, shunt, and feedback compensation are all used to achieve a reasonably flat response. The full-wave, peak-responding output rectifier senses voltage ahead of an accurate 50-ohm resistor to provide a 50-ohm source.

Following the output rectifier is a dc amplifier with a nonlinear feedback network, which makes the dc output a linear function of the ac signal applied to the rectifier. That is, it linearizes the rectifier characteristic over an ac-voltage range of 0.4 to 2 volts. This amplifier drives the level-control circuits and output meter. The linear scale on the output meter thus gives a true account of output level, and the voltage available for automatic level control is linear over this range. The automatic leveling circuit is completed by a difference amplifier, which compares the indicated output voltage with an adjustable voltage set by the output control or applied at the level program connector, and which delivers a control current to the variable-gain amplifier to minimize the difference. Enough gain variation is available so that any output level from 0.2 to 2.0 volts can be set. This level is then automatically maintained to within 0.3 dB for all load and frequency variations within the range of the instrument. An external detector can easily be connected to the automatic-level-control bus (internal control is disabled when the panel level control is turned to the off position).

Power Supply PS-2

The power supply is an improved version of the PS-1 used in earlier synthesizers. It can supply more current at 18 volts (regulated) to meet the demands of the 1164-A with a 200-mA reserve for accessories. The new, all-silicon-transistor power supply is completely short-circuit proof and current-limited.

A toroidal power transformer is enclosed in an A-metal case to minimize stray fields. A special input jack permits operation of the synthesizer from a battery, with the internal series regulator functioning to maintain normal operation with battery voltages from 20 to 28 volts.

— W. F. Byers

CREDITS

The present four GR Synthesizers are the result of the combined efforts of Atherton Noyes, Jr., Group Leader, G. H. Lohrer, C. C. Evans, and the author.

In the Type 1164-A, the primary responsibility for the new modules, IM-1 and PS-2, was that of G. H. Lohrer; for the new DI-2 and DI-3 modules, that of C. C. Evans. The primary responsibility for the remaining new modules, the FFM-1, MM-1, OMM-3, and the new chassis, as well as coordination of the effort, was that of the author.

SPECIFICATIONS

Frequency Range: 0.01 to 70 MHz.

Smallest Digital Increment: 10 Hz on step-digit controls; 0.1-Hz divisions on CAD dial (−A7C model).

Maximum Bandwidth Controllable by CAD: 1.2 MHz.

Frequency Accuracy: Same as that of 5-MHz driving signal. Internal oscillator, which can be readily phase-locked to an external standard, has temperature dependence of approx 2×10^{-7}/°C when operated without external lock, and can be adjusted, unlocked, approx $\pm 5 \times 10^{-6}$ by front-panel screwdriver control.

Spurious-Frequency Levels: Harmonic, at maximum output with 50-Ω load, −30 dB from 0.1 to 70 MHz, −25 dB from 0.01 to 0.1 MHz; discrete nonharmonic, −60 dB.

Output Impedance: 50 Ω.

Output Level: 0.2 to 2.0 V behind 50 Ω.

Levelling Characteristics: With 50-Ω load, ± 3% ± 0.02 V from 0.1 to 70 MHz, ± 5% ± 0.02 V from 0.01 to 0.1 MHz. At single frequency, level is held constant ± 0.02 V as load resistance varies from 0 to ∞.

Output Metering Accuracy: ± 5% from 0.1 to 70 MHz, +5 −10% from 0.01 to 0.1 MHz.

Digital Programming Characteristics (with remotely programmable units, RDI):
Method: 10-line circuit closure for each controlled digit.
Programmable Bandwidth: Any integral megahertz band (e.g., 49–50, 68–69 MHz), in steps as small as 10 Hz (−AR7 model).
Switching Time: <2 ms.
Relay Life: Over 5 × 10^7 operations.

CAD Sweeping and Programming Characteristics
Frequency Range: In 10-kHz or lower functional position, ± 5 major CAD dial divisions. The sweep can be centered on any manual dial setting except in the 100-kHz functional position, where the swept frequency limits are −100 and +1100 kHz.
Sweep Rate: Up to 1 kHz.
Control Voltage Required: −0.3 V per major CAD division.

Beat Output (difference between CAD frequency and that of replaced digit selectors, available at BEAT terminals; panel meter indicates zero beat)
Frequency: 10 kHz per major CAD division.
Frequency Range: 0 to 110 kHz.
Voltage: Greater than 0.5 V behind 3 kΩ.

Level Programming Characteristics
Level Range: 0.2 to 2 V, rms, behind 50 Ω.
Level Response Time: 10 ns for change 95% complete.
Level Programming Control: Either a 5- to 25-kΩ resistance or 6 to 10 V into 5 to 6 kΩ.

External-Frequency-Standard Requirements
Frequency: 5 MHz or any submultiple down to 100 kHz.
Minimum Level: 0.25 V, rms.
Input Impedance at Lock Input Connector: Approx 1 kΩ at minimum level, 50 Ω at 2 V or higher (max allowable level, 5 V).

Rear-Panel Connections
At locking GR874 connectors: 100 kHz and 5 MHz outputs.
At Subminiature Connectors: 1, 5, 5/5.1 and 5/5.1 reference, 30, 42, 40–49, 50/51, and 90 MHz; +18 V dc, outputs.
At BNC connectors: Main output, beat output, CAD control, level program.

Accessories Supplied: TYPE 874-R22LA Coaxial Patch Cord, bridging unit (substitute for DI-1 during maintenance) with panel insert, TYPE CAP-22 3-wire power cord, spare dial lamps and fuses.

Power Required: 105 to 125, 195 to 235, or 210 to 250 V, 50 to 400 Hz, 60 W, max; or 20 to 28 V dc, 1.8 A.

Cabinet: Rack-bench; end frames for bench mount and fittings for rack mount are included.

Dimensions: Bench model, width 19, height 5¼, depth 19¼ inches (485, 135, 490 mm); rack model, width 19, height 5¼, depth behind panel 17 inches (485, 135, 432 mm), over-all.

Net Weight: 45 lb (20.5 kg).

Shipping Weight: 52 lb (24 kg).

Catalog Number	*Type*	*Units Included*	*Smallest Step (DI only)*	*Price in USA*
1164-9597	**1164-A7C**	7DI + CAD	10 Hz	**$7065.00**
1164-9596	**1164-A6C**	6DI + CAD	100 Hz	**6620.00**
1164-9595	**1164-A5C**	5DI + CAD	1 kHz	**6175.00**
1164-9594	**1164-A4C**	4DI + CAD	10 kHz	**5730.00**
1164-9593	**1164-A3C**	3DI + CAD	100 kHz	**5285.00**
1164-9417	**1164-A7**	7DI	10 Hz	**6525.00**
1164-9416	**1164-A6**	6DI	100 Hz	**6080.00**
1164-9415	**1164-A5**	5DI	1 kHz	**5635.00**
1164-9414	**1164-A4**	4DI	10 kHz	**5190.00**
1164-9413	**1164-A3**	3DI	100 kHz	**4745.00**

PROGRAMMABLE MODELS*

Catalog Number	*Type*	*Smallest Programmable Increment*	*Price in USA*
1164-9527	**1164-AR7C**	10 Hz	**$7515.00**
1164-9526	**1164-AR6C**	100 Hz	**6980.00**
1164-9525	**1164-AR5C**	1 kHz	**6445.00**
1164-9524	**1164-AR4C**	10 kHz	**5910.00**
1164-9523	**1164-AR3C**	100 kHz	**5375.00**
1164-9507	**1164-AR7**	10 Hz	**6975.00**
1164-9506	**1164-AR6**	100 Hz	**6440.00**
1164-9505	**1164-AR5**	1 kHz	**5905.00**
1164-9504	**1164-AR4**	10 kHz	**5370.00**
1164-9503	**1164-AR3**	100 kHz	**4835.00**

*The X10 MHz and X1 MHz decade units are not programmable. However, these two decades can be programmed between whole 1-MHz steps (e.g., between 11 and 12 MHz, 50 and 51 MHz, etc).
US Patent No. 2,548,457. Patents applied for.

A ONE-PERCENT-BANDWIDTH WAVE ANALYZER

Figure 1. The Type 1568-A Wave Analyzer with the Type 1560-P40 Preamplifier connected to the input. When the preamplifier is used, the sensitivity of the analyzer is effectively increased by a factor of 10, giving a maximum full-scale sensitivity of 10 microvolts.

To be classed as a wave analyzer, an instrument must have a very narrow bandwidth filter to make possible the separation of closely spaced discrete frequency components. The filter must also have high initial-cutoff rate and high ultimate attenuation, so that it can resolve small frequency components in the presence of larger ones. It should be capable of "seeing" at least 70 dB into a spectrum. Further, its self-generated distortion should be so low that the analyzer itself, under normal conditions, cannot detect it. The new Type 1568-A Wave Analyzer, as well as most fixed-bandwidth-type analyzers, meets these requirements.

Narrow-band, constant-percentage-bandwidth analyzers are not generally classed as wave analyzers. They have traditionally been characterized by poor filter shape, inadequate stop-band attenuation, and limited dynamic range. Low ultimate filter attenuation, resulting from the use of twin-T filter circuits, has often limited analyzing range to no more than 30 or 35 dB.

The new Type 1568 Wave Analyzer, like the Type 1564,* (Figure 1) incorporates many recent advances in circuit

* W. R. Kundert, "New Performance, New Convenience with the New Sound and Vibration Analyzer," *General Radio Experimenter*, September-October 1963.

design to overcome these shortcomings. Chief among these advances is a new filter design. This and other performance features of the new analyzer are described below.

PERFORMANCE FEATURES

Filter Response (see Figure 2)

The bandwidth is narrow, 1% of the selected frequency. The filter, comprised of two resonant sections, has an initial attenuation rate of about 600 dB per octave, and attenuation at twice and at one half the selected frequency is at least 75 dB. The filter characteristic does not flatten in the stop band; rather, the attenuation rate approaches 12 dB per octave far from the center frequency, and attenuation is still increasing at the noise level of the instrument.

Sensitivity and Analyzing Range

Other features of the new analyzer include full-scale meter ranges from 100 microvolts to 300 volts (in 10-dB steps) and extremely low input-circuit distortion, so low that it cannot be detected by the analyzer itself, which can detect harmonic-distortion products as low as 0.01%. For manual analysis, the analyzing range is never limited by input-circuit distortion and rarely by lack of sensitivity. Sensitivity can be increased to 10 microvolts, full scale, at an input impedance equivalent to 6 pF shunted by 500 megohms, by use of a Type 1560-P40 Preamplifier. The preamplifier, shown in Figure 1, is designed to drive long connecting cables, permitting the analyzer to be operated remote from the signal source. Power for the preamplifier is supplied by the analyzer.

Calibration

A built-in, feedback-type calibrator can check amplitude calibration at any frequency. When greatest accuracy is required, the instrument can be calibrated at the frequency of each component in the spectrum being measured.

Dynamic Range—Automatic Recording

The Type 1568-A has a wide dynamic range, which is necessary for a wide analyzing range in automatic recording. Dynamic range, an often-misunderstood term, means the range between overload and noise level at any one setting of the attenuator controls

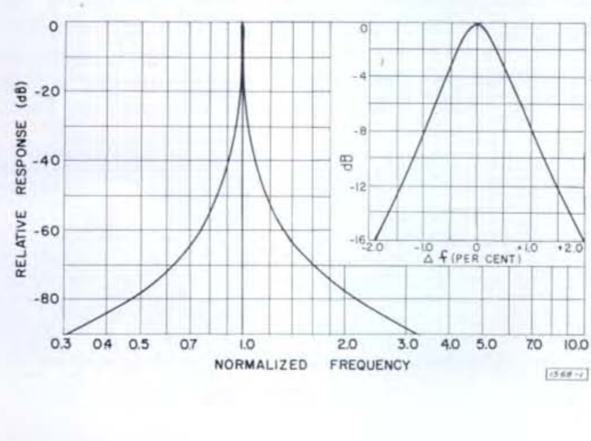


Figure 2. Attenuation characteristic of the filter.

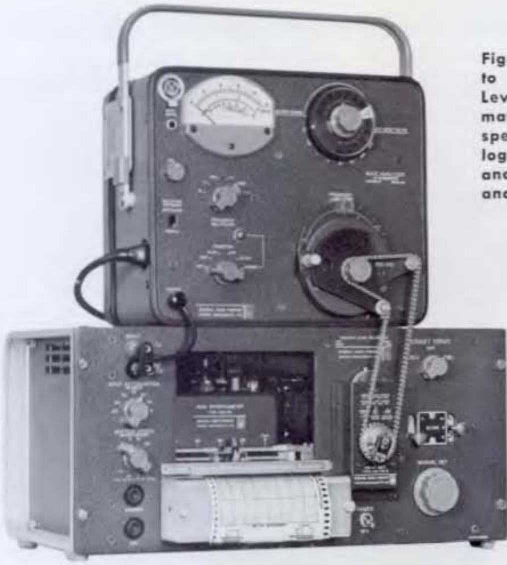


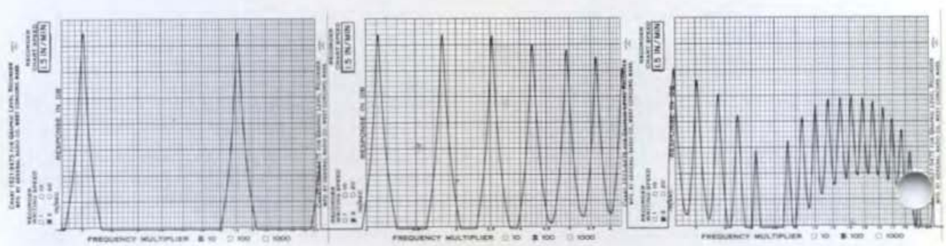
Figure 3. The analyzer coupled to the Type 1521-B Graphic Level Recorder for the automatic plotting of frequency spectra. The chart paper has a logarithmic frequency scale, and frequency ranges on the analyzer are changed automatically.

The dynamic range of the Type 1568-A varies somewhat with frequency, but it is sufficient to yield a recording range that approaches 80 dB when the overall signal applied to the analyzer is 30 millivolts or greater. The Type 1568-A has been designed for convenient automatic recording with the Type 1521-B Graphic Level Recorder[1] (combination shown in Figure 3). The frequency range changes automatically when the main frequency control is driven. The chart produced has a frequency scale of 10 inches per decade and a 4-inch vertical scale of 20, 40, or 80 dB, depending on the recorder potentiometer used.

[1] Martin W. Basch, "New Talents for the Graphic Level Recorder," *General Radio Experimenter*, September 1964.

APPLICATIONS

The following discussion of applications necessarily includes a comparison of the Type 1568-A and fixed-bandwidth wave analyzers. It should be emphasized that the Type 1568-A's advantages of low price, portability, and ease of use will, for some applications, outweigh some of the features of the complex and more expensive fixed-bandwidth analyzers.



Measurement of Harmonic Distortion

Harmonic distortion is readily measured with either type of analyzer, though some fixed-bandwidth models do not have sufficient filter attenuation at frequencies below 100 Hz. The second harmonic, being closest to the fundamental, is the most difficult to resolve. When the analyzer is tuned to the second harmonic, attenuation of the fundamental must be sufficient to reduce its level to less than that of the harmonic. Half-frequency attenuation in the TYPE 1568-A Wave Analyzer is at least 75 dB, independent of the frequency to which it is tuned. When the third harmonic is selected, the fundamental is attenuated by more than 85 dB.

Harmonic Analysis

The TYPE 1568-A will separate about 50 harmonics, a sufficient number for almost all applications. Above this number, it will display the envelope of the spectrum, which usually contains sufficient information. Figure 4 illustrates this effect.

When more than 50 components of a simple periodic signal are to be resolved, there may be some advantage in a fixed-bandwidth analyzer and a linear frequency scale for recording. The separate harmonics are spaced an equal number of hertz apart, and so, if a fixed-bandwidth analyzer has sufficient attenuation to resolve a few harmonics (it may not at low frequency), it will resolve them all within its amplitude and frequency limits.

Measurements on Modulated Signals

A periodic signal modulated with a simple periodic signal also has equally spaced components. Component spacing is equal to the fundamental frequency of the modulating signal.

Whether the TYPE 1568-A can resolve a carrier and sidebands depends on the ratio of the carrier frequency to the lowest frequency component of the modulating signal and also on the relative amplitude of these components. As a rule of thumb, the frequency ratio must be less than 50.

Measurement of Discrete Components at Low Frequencies

The bandwidth of the TYPE 1568-A is reduced to 0.2 Hz at its low-frequency limit, much narrower than that of even the narrowest fixed-bandwidth analyzers. At low frequencies it can separate components spaced only a fraction of one hertz apart. Furthermore, in this range, it does not have the annoying frequency drift associated with some heterodyne instruments, and its frequency accuracy and dial resolution are far superior. The filter curves for the TYPE 1568-A Wave Analyzer

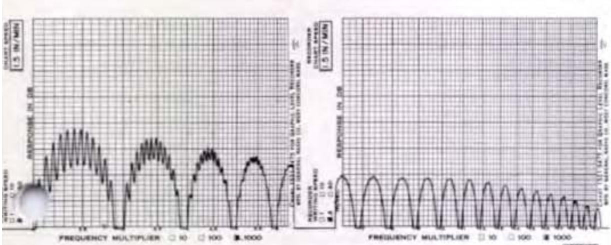


Figure 4. Frequency spectrum analysis of a 1.0-ms pulse at a 70-Hz repetition rate. The 1% bandwidth yields high resolution at low frequencies, shows the envelope at high frequencies.

and the Type 1900-A Wave Analyzer,[2] a constant-bandwidth instrument, are compared in Figure 5 at center frequencies of 20 and 60 Hz. The bandwidth of the Type 1900-A is set to 3 Hz, its narrowest.

Measurements of Discrete Components of Other Types of Signal

In a data-transmission system many carriers may be used for information transmission. It is often desirable to monitor each carrier individually for amplitude and frequency. The Type 1568 and a frequency meter make an excellent combination for this purpose.

In an Instrument Landing System, distortion products must be low to ensure an accurate, course-direction indication in the cabin of a landing aircraft. The analyzer can be used to check distortion by measuring the spectrum of the sideband energy produced by the ILS Localizer Transmitter.

Random-Noise Measurements

The detail required in the analysis of noise spectra containing no important discrete components does not often warrant the use of a bandwidth as narrow as that of the Type 1568-A. The one-third- or one-tenth-octave bandwidths of the Type 1564-A Sound and Vibration Analyzer are better suited to this application. The Type 1568-A is generally used when a recorded analysis is desired. However, the analyzer can be used manually and a slow meter speed is included to facilitate noise measurements.

Analysis of Machinery Noise and Vibration

The reduction of the sound and vibration generated by machines and appliances is becoming increasingly important,[3] because of their effect on man and because they result in mechanical failure and excessive wear of machine

[2] Arnold Peterson, "New Wave Analyzer has 3 Bandwidths, 80-dB Dynamic Range," *General Radio Experimenter*, April 1964.
[3] Arnold Peterson, "Vibration: Problems, Measurements, and Control," General Radio Preprint B-22.

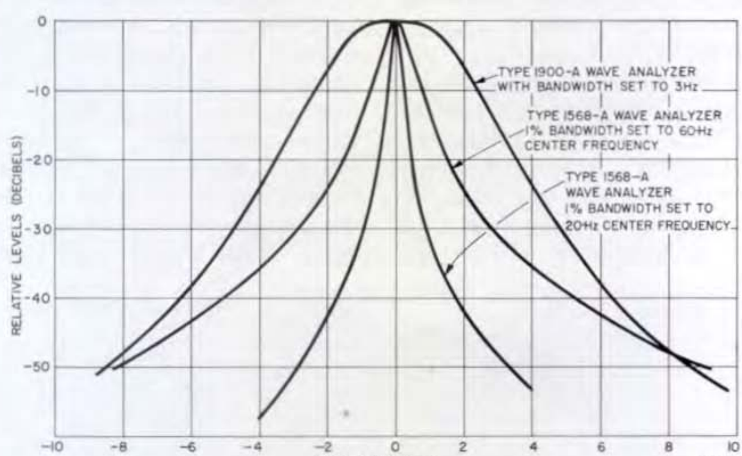
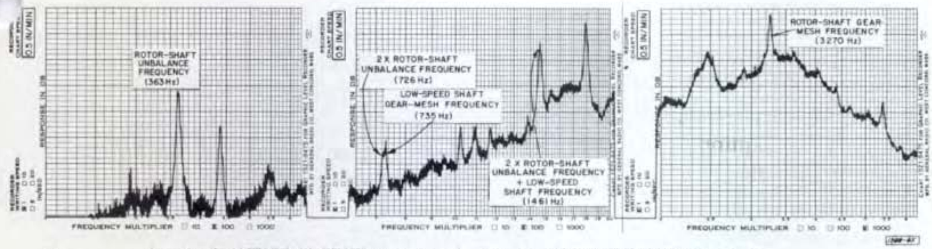
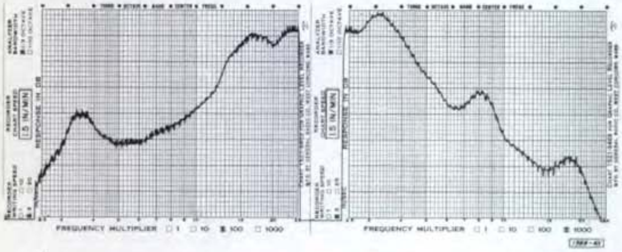


Figure 5. Comparison of the filter characteristics of the Type 1568-A Wave Analyzer at 20 Hz and 60 Hz with the 3-Hz bandwidth of the Type 1900-A Wave Analyzer.

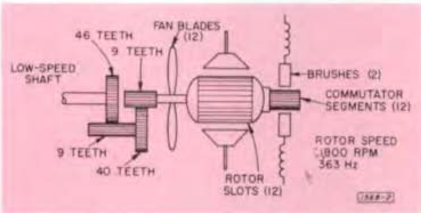


a



b

Figure 6. Chart records of the vibration acceleration spectrum of a motor and gear-train assembly (see sketch). (a) A 1%-bandwidth analysis, taken with the Type 1568-A Wave Analyzer and (b) a ⅓-octave analysis. For diagnostic measurements of this kind, the detail of the spectrum provided by the 1% bandwidth is by far the better.



elements. The source of the noise within the machine must first be identified, then eliminated or reduced. A fine-spectrum analysis of the sound or vibration (or both) with the Type 1568-A Wave Analyzer will show various discrete frequencies and resonances, which can be related to motion within the machine. Broader-band octave or one-third-octave measurements are of little use in such diagnostic applications.

Figure 6 shows the acceleration spectrum measured on the housing of a machine employing a high-speed universal motor and gear train. For comparison, a one-third-octave spectrum is also shown. The various sources of vibration that are identified include frequencies caused by motor-armature unbalance and gear-teeth meshing. The large component at 3270 Hz is critical, from the standpoint of its effect on man, since it is in the frequency range where human hearing is most acute. A reduction in the level of this component through improved gear design at this point would markedly reduce the loudness and speech-interference level of the sound. Alternatively, to reduce loudness, the frequency of this component might be shifted by a change in design. Various other components will be found critical when other aspects of the vibration problem are considered. For example, bearing wear could be reduced by improved armature balance.

Mil-Std-740B

Mil-Standard-740B (SHIPS) (Airborne and Structureborne Noise Measurements and Acceptance Criteria of Shipboard Equipment) allows a narrow-band vibration analysis in the frequency range below 500 Hz when requirements cannot be met by a one-third-octave analysis. The acceptance limits are the same in either case. A narrow band is defined as ". . . a band whose width is not less than one percent or more than eight percent of the band center frequency." This specification should make the TYPE 1568-A an important tool for acceptance testing in accordance with the standard.

DESCRIPTION

Input

The block diagram of Figure 7 shows the various sections that make up the analyzer. The INPUT drives a three-section attenuator. The first section is operated by the dial of the coaxial METER RANGE switch and is set in accordance with the over-all level of the signal being measured. The second block in the diagram represents part of the analyzing attenuator, which is adjusted by the knob of the same switch. A third attenuator, which is continuously adjustable, is used in amplitude calibration. The attenuators present a nearly constant impedance of 100 kΩ at the input connectors.

[4] W. R. Kundert, "The RC Amplifier-Type Active Filter: A Design Method for Optimum Stability," *IEEE Transactions on Audio,* Vol. AU-12, No. 4, July-August 1964, p 66–71. (General Radio Reprint A-113).

Filter

The filter used in the TYPE 1568-A is unique.[4] Active RC filters often require an unreasonable degree of stability in one or more filter components to maintain stable transmission with tuning, time, temperature, and other variables. However, it is possible by careful design to trade off component sensitivities and thus to reduce the filter sensitivity to a given disturbing effect. In the TYPE 1568-A, the filter has been designed for low sensitivity to tracking errors in the tuning potentiometer. This design also results in relatively low sensitivity of the filter to drift in all other passive components. The price paid is a high sensitivity factor for amplifier gain, but, surprisingly, an amplifier can readily be constructed with much better stability than that of readily available passive components.

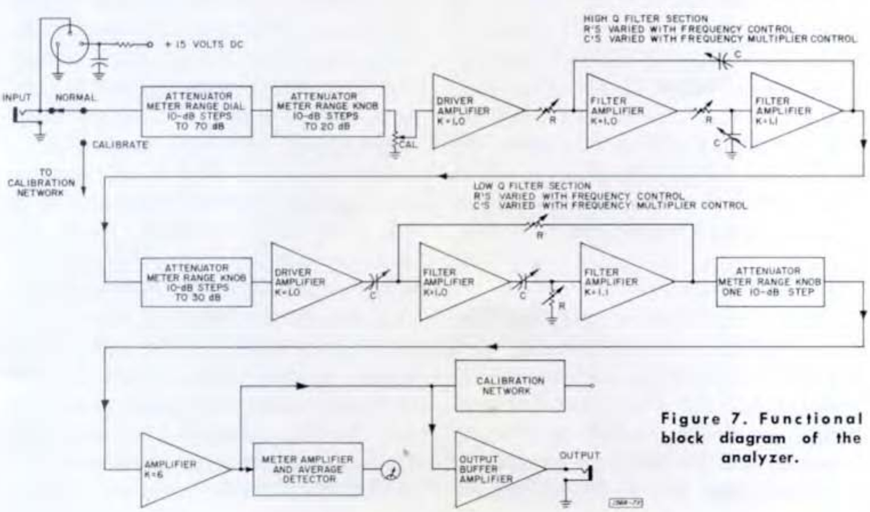


Figure 7. Functional block diagram of the analyzer.

The filter is synthesized as an isolated cascade of two active, RC resonant sections. These sections differ in Q to reduce further the effect of potentiometer tracking error. The audio range from 20 Hz to 20 kHz is covered in six bands, each spanning a half decade (range of 3.16 to 1). Within any one range the instrument is tuned by means of a four-gang potentiometer, whose resistance-versus-angle characteristic produces a logarithmic frequency scale on the FREQUENCY control. Close-tolerance polystyrene capacitors are switched to change ranges. Manual or automatic range changing is selected with a panel switch. The automatic mode is used in recording with the Graphic Level Recorder. Three-transistor filter amplifiers provide the necessary high ratio of input to output impedance and stable voltage gain. As indicated by the block diagram, sections of the analyzing attenuator are included between the first and second filter stages and after the second stage. Through this separation of the analyzing attenuator into three sections, wide dynamic range can be maintained over a wide range of input signal levels.

Output

A final amplifier supplies a signal for the meter circuit and output buffer. The output is isolated, so that performance is not affected by the load. The 6000-ohm output is intended primarily for driving a recorder or counter, although any load can be connected. The meter, driven by an average-type detector, has three full-scale ranges: 0 to 3 and 0 to 10 volts and −15 to +2 dB for reading in dB referred to one milliwatt in 600 ohms.

Calibrator

The feedback-type calibrator used to standardize the gain is similar to that used in other GR analyzers. To amplitude-calibrate the instrument, a signal from the output amplifier is fed to the input through a limiter and a calibrated attenuator. When the gain of the analyzer is adjusted, by means of the CAL control, to equal the loss in the feedback path, the system oscillates, signifying that the instrument is calibrated as a voltmeter. The frequency of oscillation is determined by the center frequency of the filter, and this calibration can be made at any selected frequency. For the measurement of levels in dB or percent, with an arbitrary reference, a special attenuator dial is supplied, and the instrument is calibrated to suit a reference level.

Power Supply

The power supply permits either line or battery operation. The battery supplied is a rechargeable nickel-cadmium unit, which also serves as a ripple filter for line operation. The built-in charger operates from the ac line. A fully charged battery provides about 20 hours of operation and requires 16 hours for recharging. Though the instrument should normally be operated using line power when it is available, because of grounding considerations it is sometimes desirable to operate the instrument isolated from the line.

Warren R. Kundert received his BSEE degree in 1958 and his MSEE in 1961 from Northeastern University. He came to General Radio as a development engineer in the audio group in 1959, where he is engaged in the design of audio-frequency circuits, filters, and other networks, and in the development of instruments for measurements at audio frequencies. He is a member of the IEEE, Acoustical Society of America, Audio Engineering Society, and Eta Kappa Nu.

Cabinet

The analyzer is packaged in the General Radio Flip-Tilt case, whose protective cover serves as a mounting base when the instrument is in use and allows its panel to be adjusted to a convenient angle for operation. Alternatively, the analyzer can be supplied adapted for rack mounting.

The TYPE 1568-A Wave Analyzer is an important new instrument for both electrical and sound-and-vibration analysis when high resolution is needed. For sound-and-vibration work, it fills a gap between the TYPE 1564-A Sound and Vibration Analyzer (1/3 octave and 1/10 octave) and the TYPE 1900-A Wave Analyzer. It combines the desirable features of a narrow, constant-percentage-bandwidth analyzer with an excellent filter shape. Its low cost, portability, and simplicity of operation, and the option of line or battery operation are features seldom encountered in other wave analyzers.

— W. R. KUNDERT

SPECIFICATIONS

FREQUENCY

Range: 20 Hz to 20 kHz in six half-decade bands.

Dial Calibration: Logarithmic.

Accuracy of Frequency Calibration: 1%.

Filter Characteristics: Bandwidth between 3-dB points on selectivity curve (see Figure 2) is one percent of selected frequency.

Attenuation at 20% above and at 20% below selected frequency is greater than 50 dB referred to the level at the selected frequency. Attenuation at twice and at one-half the selected frequency is at least 75 dB referred to the level at the selected frequency. Ultimate attenuation is greater than 85 dB.

Uniformity of filter peak response with tuning is ±1 dB from 20 Hz to 6.3 kHz and ±2 dB from 20 Hz to 20 kHz.

INPUT

Impedance: 100 kΩ.

Voltage Range: 100 μV to 300 V, full scale, in 3–10 series steps. Power is supplied at input socket for the Type 1560-P40 Preamplifier, which extends the sensitivity to 10 μV, full scale, and increases the input impedance to more than 500 MΩ.

Distortion: Input-circuit distortion is lower than −80 dB relative to input-signal level.

OUTPUT

Impedance: 6000 Ω. Any load can be connected.

Voltage: At least one volt open circuit when meter reads full scale.

Crest-Factor Capacity: Greater than 13 dB.

Output Meter: In addition to normal-speed mode, meter has slow-speed mode for manual measurements of noise.

GENERAL

Analyzing Range: 80 dB. Components of an input signal that differ in amplitude by as much as 80 dB can be measured.

Automatic Recording: Automatic range switching is provided to allow convenient, continuous spectrum plotting when the Type 1521 Graphic Level Recorder is used. Medium-speed motor is recommended. Chart paper is Catalog No. 1521-9475. Frequency scale is logarithmic, 10 inches per decade; vertical scale is 4 inches for 20, 40, or 80 dB, depending on the potentiometer used in the recorder.

Amplitude Calibrator: A built-in, feedback-type calibration system permits amplitude calibration at any frequency.

Accessories Supplied: Type CAP-22 Power Cord; Type 1568-2090 Detented Knob and Dial Assembly, used to facilitate measuring the components of an input signal as a percentage or in decibels with an arbitrary voltage reference.

Power Supply: 100 to 125 or 200 to 250 V, 50 to 60 Hz. 2 W for normal operation, 3.5 W for battery operation. A rechargeable nickel-cadmium battery is also supplied. Battery provides about 20 hours of operation when fully charged and requires 16 hours for charging. Internal charger operates from the power line.

Mounting: Flip-Tilt case.

Dimensions: Portable model, with case closed, width 13¼, height 13, depth 8¼ inches, (340, 330, 210 mm), over-all, including handle. Rack model, 19-inch (485 mm) rack panel, 12¼ inches (35 mm) high; depth behind panel 5 inches (130 mm).

Net Weight: 21½ lb (10.0 kg).

Shipping Weight: 27 lb (12.5 kg).

Catalog Number	*Description*	*Price in USA*
1568-9701	**Type 1568-A Wave Analyzer,** Portable Model	$1350.00
1568-9820	**Type 1568-A Wave Analyzer,** Rack Model	1350.00
1560-9510	**Type 1560-P40J Preamplifier and Adaptor Set** *	184.00

U. S. Patent Nos. 3,012,197; D187,740; 2,966,257.
* For complete details see *General Radio Experimenter*, June 1965.

New BIG Smith Charts

Occasional inquiries for Smith Charts larger than the standard 8½″ x 11″ size have induced us to introduce a new giant-size chart, which is 22½″ x 35″. These charts, direct enlargements of the regular normalized Smith Chart, are printed on relatively heavy paper in red ink. We assume their greatest use would be in classrooms or conferences where several people are involved. However, some presbyopic engineers may also find them useful. The new charts are Catalog No. 5301-7563 NX, and pads of about 75 sheets are $6.00.

ADDITION — The publication date of the report given in Footnote 1, page 3 of the August *Experimenter* was August 19, 1963.

VIBRATION ANALYSIS KEEPS 'COPTERS FLYING

Boeing "Chinook" helicopters in Viet Nam are providing better service at less expense to Uncle Sam, thanks in part to GR's Type 1564-A Sound and Vibration Analyzer. Field service engineers of Boeing's Vertol Division reporting from the combat zone tell of consistent success with the analyzer in spotting potential problems in the helicopters' engines, transmissions, drive shafts, and auxiliary equipment, as part of normal preventive maintenance procedures. Early diagnosis of impending trouble helps keep these modern-day pack mules in service when they are so badly needed and saves countless tax dollars in repair costs.

For use with the Sound and Vibration Analyzer, Boeing specifies the Type 1560-P52 Vibration Pickup, the Type 1560-P35 Permanent-Magnet Clamp, and a 25-foot extension cable for the pickup. The magnetic clamp is used to secure the pickup to aluminum bolts (which contain steel) on the helicopter structure. For locations where magnetic clamping is impossible, Boeing's engineers use a vice-grip clamp, to which has been brazed a bracket with a ¼-28 threaded stud that accepts the pickup.

Trouble-shooting usually consists of measuring the frequency of a vibration and then tracking down its source by relating the vibration frequency to the characteristic speeds of various components.

This vibration-measuring system has been praised for sensitivity (better than 0.001 G), frequency accuracy (±2%), and frequency discrimination (7% bandwidth). Vibration components at frequencies from 3.8 to 250 Hz

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Photo courtesy of The Boeing Company, Vertol Division

Engineer measures the frequencies of the vibration components in a helicopter transmission. He can then track down the vibration sources by relating the measured frequencies to the characteristic speeds of the various transmission parts.

are measured with separations as small as 1.5 Hz at low frequencies.

The portability of the 1564 is all-important in this application. In-flight measurements can be made with ease. The rechargeable batteries can be charged overnight from any field generator to be ready at a moment's notice.

— C. W. Alsen

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