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COHERENT DECADE FREQUENCY SYNTHESIZERS

A Modular Design

The term frequency synthesizer can quite properly be applied to any of a variety of devices. For instance, a type of radio transmitter widely used for aircraft communications synthesizes a large number of channels by combining frequencies selected from groups of independent crystals. Such synthesizers are not "frequency coherent," since the output frequency reflects the individual errors of several crystal oscillators. But, if each of the crystals in the groups has adequate accuracy, the synthesized output frequency is accurate enough and stable enough for the intended application.

An example of coherent frequency synthesis is found in the circuitry often used with atomic frequency standards to translate the atomic resonance frequency to a convenient round number, such as 5 Mc/s. Synthesizers of this kind derive all intermediate frequencies and the final frequency from a single source and are thus frequency coherent. However, since only one synthesized output frequency is produced, such a device is limited to its special-purpose use.

Members of a rapidly growing class of general-purpose frequency synthesizer, in which the new GR designs

Figure 1a. View of the Type 1162-A Coherent Decade Frequency Synthesizer.

belong, produce many output frequencies coherently from a single primary source. Output may be at any one of a very large number of discrete frequencies, usually selectable on a decimal-digit basis. This article will describe the outstanding characteristics and novel features, both electrical and mechanical, included in the first two of a family of synthesizers now in production by General Radio Company. Of particular note in these designs are, first, the use of repetitive plug-in subassemblies, which permit many variations to suit particular requirements; second, provision for continuous, smooth coverage of any chosen part of the frequency band, from very wide to very narrow at will; and, third, circuitry for the generation of precision frequency markers. Frequencies are selected by means of a series of stepped digit units, plus a continuously adjustable decade. Remote programming capability is standard for the continuously adjustable unit; it is an extra-cost option for the stepped decades.

TYPES 1161-A AND 1162-A COHERENT DECADE FREQUENCY SYNTHESIZERS

Frequency Ranges

Figure 1a and Figure 1b show the two GR synthesizers. The physical resemblance is no accident; the units are designed to be nearly identical. In fact, one can be transformed into the other by the change of one plug-in module.

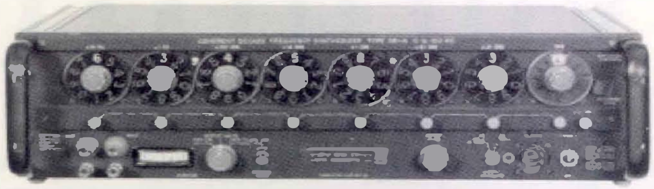

Figure 1b. The Type 1161-A Synthesizer is similar in appearance to the Type 1162-A.

The Type 1161-A Coherent Decade Frequency Synthesizer provides any desired output frequency from dc to 100 kc/s, with decimal-digit readout of the selected frequency on a series of up to seven illuminated digit dials and a continuous-coverage dial. The smallest digital step in the fully equipped unit is 0.01 c/s. The fine divisions on the continuous dial, when used at the end of the digit series, are at 0.0001-cycle intervals. For those who do not require such fine digital steps, the design permits digit-insertion units to be omitted at a reduction in price. Figure 2 shows one such stripped-down model with four digit dials plus the continuous coverage dial. The three missing digit-insertion modules can be plugged in, whenever the need arises, to upgrade the unit to a complete instrument.

The Type 1162-A Coherent Decade Frequency Synthesizer has output frequencies up to 1 Mc/s, with a smallest digital increment of 0.1 c/s and finest calibration lines on the continuous dial at 0.001-cycle intervals.

In either synthesizer, the Continuously Adjustable Decade (CAD) can be added on at the end of the series of digital dials or, at the push of a button, can functionally replace all digit dials

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below any chosen rank and thereby provide wide, single-dial frequency coverage, remotely controlled, if desired.

By virtue of the self-calibrating feature for the CAD, explained in detail later, the partially equipped models, such as the Type 1162-A4C illustrated in Figure 2, can set frequencies to more significant figures than the number of dials would suggest. Thus the Type 1162-A4C can be set to four figures on the digit dials and four more on the CAD, calibrated against the digit dials, for a total of eight significant figures.

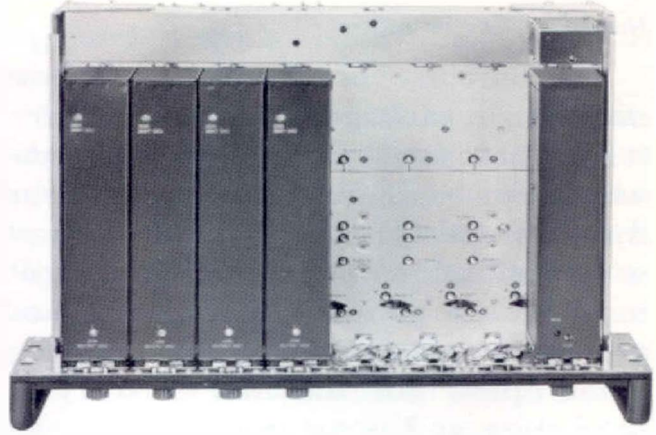
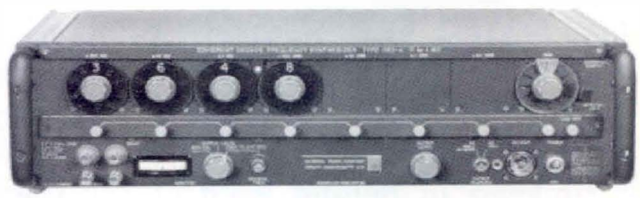
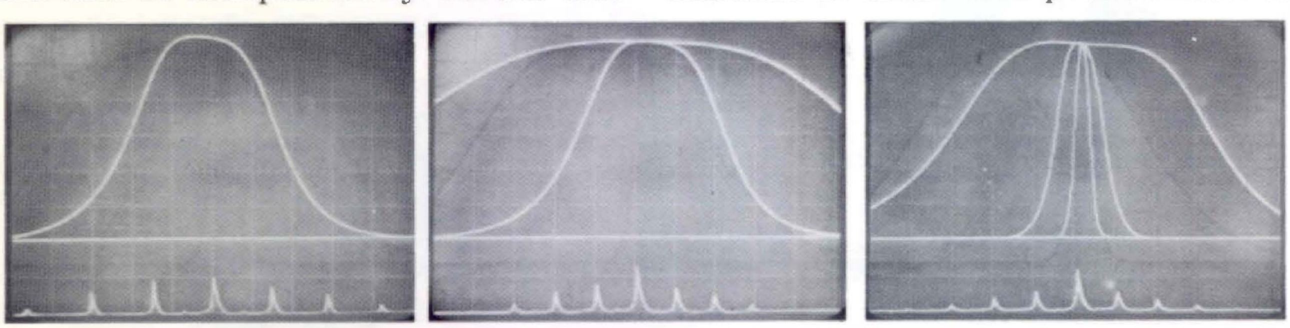


Figure 2. A partially equipped instrument, Type 1162-A4C, top and panel views.



Swept-Frequency Generation with Frequency Markers

The CAD dial is direct-reading; the numbered major divisions correspond to the digits on the step-adjustable dials. As an additional unique and very useful feature, built-in monitor circuits make it possible to set the CAD dial precisely to three or more significant figures, in terms of the digit dials. Provisions are also included for varying the frequency of the continuous unit in accordance with an electrical control input. These monitoring and calibrating circuits assist in the generation of accurate frequency markers, at the center frequency defined by the digit dials and at independently chosen side frequencies. The synthesizers thus become sweep-frequency generators, capable of being swept with precision over frequency bands ranging from a fraction of a cycle to many kilocycles. Figure 3, which will be discussed in more detail later, is an example of this sort of application. The 3-, 10-, and 50-cycle passbands of the GR Type 1900-A Wave Analyzer are shown displayed on a storage oscilloscope, with accompanying center frequency and side markers at small and precise intervals



a 1.5 ∼ MARKERS 3 ∼ Pass Band

b 1.0 ∼ MARKERS 3 ∼ and 10 ∼ Pass Bands

c 10 ∼ MARKERS 3 ∼, 10 ∼, and 50 ∼ Pass Bands

Figure 3. Pass bands of the Type 1900-A Wave Analyzer, with simultaneously generated frequency markers. The signal source for this measurement was a Type 1161-A Synthesizer.

Modular Construction

The circuits of these synthesizers have been packaged in modules carefully chosen as functional elements, which can be combined in a variety of ways to satisfy either general-purpose or specialized requirements. The plug-in modules are pictured in Figure 4 and are briefly described in the following paragraphs. All module circuitry is solid-state and is mounted on one side only of the etched boards. For more detailed descriptions, see page 7.

Digit-Insertion Unit—Type 1160-DI-1. This module, basic to all GR frequency-synthesizer assemblies in this series, is used repetitively to provide selection of each available digit. A DI-1 unit is plugged in behind each of the digit dials visible in Figures 1 and 2.

Continuously Adjustable Decade—Type 1160-CAD. One of these units is used in each instrument to provide continuous frequency coverage on a single dial over wide or narrow frequency regions as selected by push-buttons. It may be omitted from the assembly where continuous coverage is not required.

Ancillary Frequency Source—AFS. In this assembly is the 5-Mc master crystal oscillator from which all frequencies used in the synthesis are derived. It provides an additional output at 42 Mc/s, which is fed to all the DI-1 units and the CAD, and a "picket fence" of frequencies spaced 100 kc/s apart between 3 and 3.9 Mc/s. This picket fence is used in each DI-1 unit for digit-selection purposes.

Calibrating Mixer—CM-1. This simple module compares the output frequency of the CAD unit with the dialed output frequency of any chosen group of DI-1 units for self-calibration or marker generation. If the CAD unit is not installed in a particular assembly, this mixer is omitted also.

Output Mixer OM-1 and Output Multiplier-Mixer OMM-1. These modules, mechanically interchangeable, provide frequency translation between the synthesizing modules and the output circuits of the Types 1161-A and 1162-A Synthesizers, respectively. Replacement of one by the other in the main frame changes the instrument from a Type 1161-A to a Type 1162-A or vice versa.

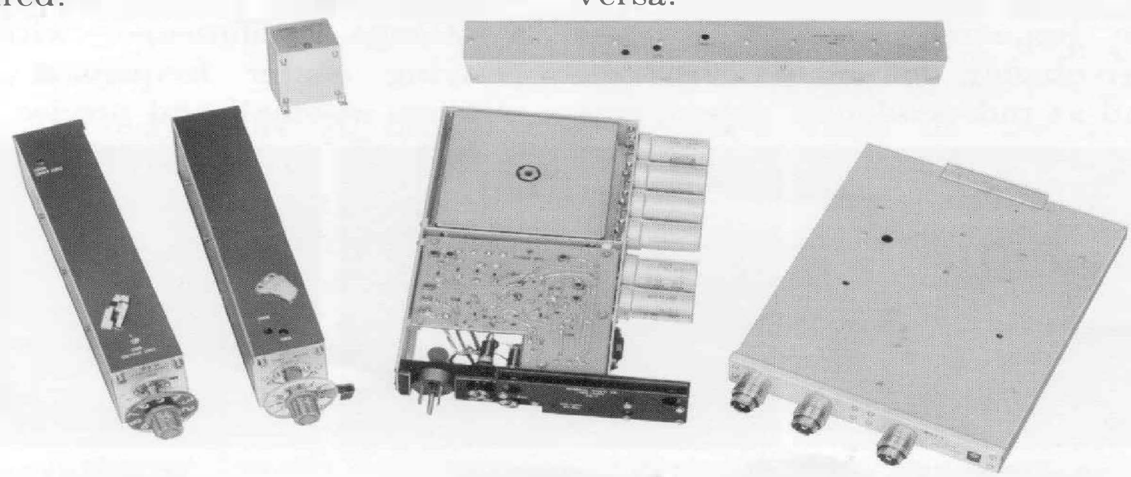


Figure 4. The basic modules of a Type 1161-A or a Type 1162-A Synthesizer. Left to right *(front)*, Digit-Insertion Unit, Continuously Adjustable Decade, Power Supply, Ancillary Frequency Source; *(rear)* Calibrating Mixer and Output Multiplier-Mixer. Dial light panels for a DI-1 unit and the CAD are resting on the respective boxes.

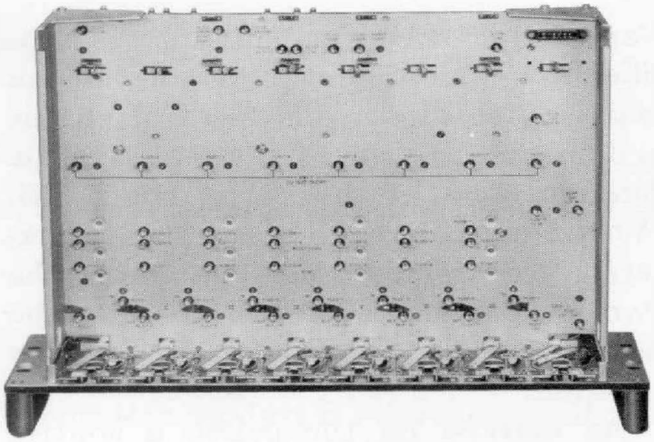


Figure 5. Top view of the Synthesizer chassis.

Power Supply—PS-1. This unit accepts ac power from the line or dc from a 20- to 28-volt battery and supplies 18 volts, regulated, to operate the synthesizer.

Figure 5 shows the main frame into which the modules listed above are plugged to make up either a Type 1161-A or a Type 1162-A Synthesizer. Its deck is of "sandwich" construction, with banana plugs protruding downward to engage the power supply and the AFS and upwards to connect with all other modules. The frame contains the push-button switches that control the functional position of the CAD, the monitoring circuits, and the final output amplifier.

PANEL CONTROLS

Frequency Selection

As may be seen in Figure 1, eight frequency-setting dials, with illuminated numbers on seven of them and a continuously calibrated scale on the eighth, provide an in-line readout of the synthesized frequency to nine or more significant figures. Behind each dial is a digit unit. The signal flows through this synthesizing portion of the instrument from right to left, entering and leaving each digit unit in sequence.

Below each digit dial is a pushbutton. When one of these buttons is pushed (and automatically latched), an rf switch behind it in the sandwich deck performs the following two functions:

1) The output from the digit unit above the actuated button and from all units to the right of it is connected to the Calibrating Mixer. (An output of the CAD unit is permanently connected to the other input of this mixer.)

2) The main output of the continuous unit (CAD) is connected to the input of the group of digit units to the left of the actuated button. The CAD thus functionally replaces the disconnected digit units, as regards their contributions to the output frequency.

Operation of the pushbutton also controls lamp switches behind the panel to extinguish the illumination behind the replaced dial numbers, so that the output frequency is read from the illuminated numbers at the left, followed by the continuous dial reading, with little chance for error.

Monitor Switch and Mixer

The MONITOR switch, in its counterclockwise position (CAD CAL), applies the calibrating-mixer output to the monitor meter. The meter behaves like an analog frequency meter when the CAD output frequency differs substantially from the output frequency of the replaced group of digit units, indicating upscale from center. As the CAD is tuned to within a few cycles of zero beat, the meter follows the beats directly. The CAD unit can thus be adjusted to the frequency of any group of replaced digits on the main dials.

The beat frequency from the calibrating mixer also appears at all times on the binding posts marked BEAT. Whenever this beat frequency is below 50 c/s, the CAD frequency is equal to that indicated by at least three figures of the digit dials used for calibration; if the beat is below 5 c/s, the CAD dial may be relied on to four figures.

When the MONITOR switch is in its central position (OUTPUT VOLTS), the meter measures the voltage at the main output connector, with a scale range from 0 to 2 volts, rms. With a 50-ohm load or higher, the output can always be adjusted to 2 volts or more, by means of the OUTPUT LEVEL control, at any frequency above 30 c/s.

As will be discussed more fully later, the master crystal oscillator may be phase-locked to an external frequency standard.

When a locking signal is introduced (through a jack at the rear of the instrument) and the MONITOR switch is in its clockwise position (LOCK TO EXT STD), the meter verifies proper phase lock of the crystal oscillator to the standard.

External CAD Control and Deviation Indication

The Continuously Adjustable Decade (CAD) can operate in either of two modes, as selected by the coaxial lever switch at the right of its dial. When this switch selects the INTERNAL LOCK mode, the CAD is highly stable, since its output frequency is a synthesis of a relatively large crystal-locked frequency and a small contribution from an LC oscillator.

In the EXTERNAL CONTROL mode, the CAD output is derived completely from a continuously tunable LC oscillator. Part of the tuning capacitance is supplied by a voltage-controllable silicon capacitance diode. The control circuit is dc-coupled to the EXTERNAL CONTROL binding posts at the left of the panel. When the CAD is switched to the EXTERNAL CONTROL mode, the dial light of the CAD is dimmed as an indication to the operator that the switch is in this position.

As marked on the panel, a control signal of −0.3-volt dc will shift the CAD frequency upward, by an amount equal to one major dial division, from a neutral position set by the CAD dial itself. The unit can be swept ±10 major divisions from any starting point within the dial range. When such electronic control is used, the beat frequency appearing at the BEAT binding posts is strictly proportional to the deviation of the CAD frequency from the digits on the replaced dials and increases at the rate of 10 kc/s per major CAD dial division. Since the major (numbered) divisions on the CAD dial correspond directly to the numbers on the digit dial immediately above the actuated pushbutton, a 10-kc beat note indicates, in the Type 1161-A, an *output* frequency deviation ranging from 0.001 c/s to 10 kc/s in decade steps, depending only on which pushbutton has been pressed. In the Type 1162-A, the corresponding range is from 0.01 c/s to 100 kc/s. (The minimum figures occur when the button directly under the CAD itself is actuated; the replaced digit in this case is 0.)

Two other controls on the front panel are screw-driver operated. The CRYSTAL FREQ control is a vernier on the free-running frequency of the master crystal oscillator. It may be used either to set the free-running frequency

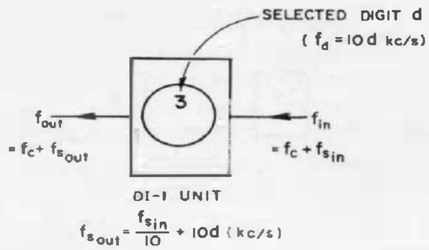


Figure 6. Signal traversing a typical Digit-Insertion Unit.

accurately against a reference or, if the synthesizer is phase-locked to an external standard, to adjust for optimum locking conditions. The other screwdriver control operates a switch that changes the normal ac-coupled output circuit to dc coupling. With dc coupling, the output frequency can be adjusted as low as desired, down to dc, but the output voltage available is only about 1 volt, rms. The output voltage monitor meter is disconnected in this switch position.

With these points in mind, let us now proceed to a consideration of the synthesizing principle used to attain stepped frequency increments as small as may be desired.

THE SYNTHESIZING PRINCIPLE USED IN GR SYNTHESIZERS

Each DI-1 module in the synthesizer receives an input signal at about 5 Mc/s, modifies the frequency of this signal very slightly in two steps, and delivers the modified frequency (again near 5 Mc/s) as an input to the next DI-1 unit in the train. Figure 6 is an elementary diagram showing the essential processes performed in a DI-1 unit.

In Figure 6 each signal (input and output) is shown as having a frequency that, for convenience, may be regarded as the sum of two components. The first component is a "carrier" frequency, which remains unchanged through all the DI-1 units at 5000 kc/s.

The second component is the "signal" component. The signal component always lies between 0 and 100 kc/s.

The signal component is modified by passage through each digit-insertion unit in the following very simple ways, as indicated in the figure. If we denote the total input frequency by

$$f_{in} = f_c + f_{s_{in}} \quad \text{kc/s} \qquad (1)$$

and the output frequency by

$$f_{out} = f_c + f_{s_{out}} \quad \text{kc/s} \qquad (2)$$

then the DI-1 unit performs operations so that:

$$f_{out} = f_c + \frac{f_{s_{in}}}{10} + 10\,d \quad \text{kc/s} \qquad (3)$$

or

$$f_{s_{out}} = \frac{f_{s_{in}}}{10} + 10\,d \quad \text{kc/s} \qquad (4)$$

where

f_{in}, f_{out} = total input and output frequencies.

f_c = carrier component, invariant.

$f_{s_{in}}$ = signal component of input.

$f_{s_{out}}$ = signal component of output.

d = selected digit, from 0 to 9 in integral steps.

For convenience in following frequency changes through the train of digit units, we can disregard the carrier component, since this passes through unchanged, and concentrate on only the signal component, as in equation (4).

Figure 7 shows four DI-1 units (A, B, C, D), each with digits selected as indicated, and the signal-component flow through the train, from right to left. Observe the correspondence between the signal component of output frequency from unit A (24.39 kc/s) and

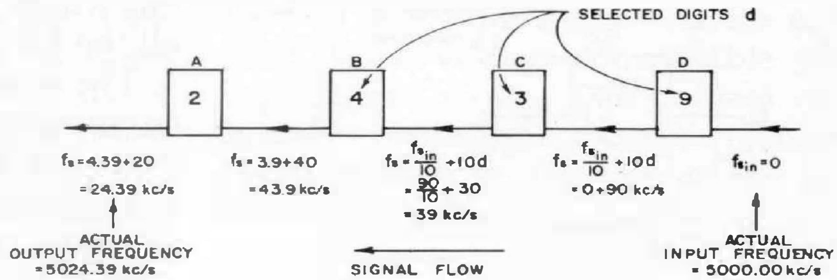


Figure 7. Signal passage through four Digit-Insertion Units, illustrating synthesis of desired signal component.

the digit dial settings (2439). It is clear that the output frequency from *any* unit in such a train of digit units will have a signal component that is, in kilocycles per second:

$$f_s = 10d_1 + d_2 + 0.1\ d_3 + 0.01\ d_4 + \ . \ . \ . \qquad (5)$$

where d_1 represents the dialed digit on the unit at which the output frequency is measured, and d_2 through d_n represent digits dialed on successive units to the right.

Equation (4) defines the two fundamental operations performed on the signal component by each digit unit, which permit frequency synthesis in steps as small as may be desired. These operations are:

1) Divide the input signal component by 10.

2) Add to this a digit component that is 10 times the dialed digit (in kc/s), and pass the result on to the input of the next DI-1 unit in the train.

This general principle is not new. It was disclosed in print at least as early as 1952[1] and has been utilized in a number of modern applications.[2, 3, 4, 5] However, the grouping of necessary circuits into a train of identical digit units, each of which performs the two listed operations, has made possible the very versatile Types 1161-A and 1162-A Synthesizers and forthcoming members of this family.

[1] Australian Patent No. 148,412, "Frequency Synthesizer," Accepted 29 September 1952, Amalgamated Wireless, Ltd.

[2] U. S. Patent No. 2,829,255, "Digital Frequency Synthesizer System," April 1, 1958, V. W. Bolie.

[3] U. S. Patent No. 2,930,988, "Apparatus for Generating Frequencies," March 29, 1960, A. F. Boff.

[4] U. S. Patent No. 2,934,716, "Variable Frequency Synthesizer," April 26, 1960, J. W. Smith.

[5] U. S. Patent No. 3,125,729, "Digit Controlled Frequency Synthesizer," March 17, 1964, Stone & Hastings.

OPERATING PRINCIPLES

The Digit-Insertion Unit (DI-1)

The principle of the Digit-Insertion Unit is the dual of that of the familiar error multiplier sometimes used to magnify small frequency differences by successive subtractions and multiplications. In the Digit-Insertion Unit, in contrast, we add and divide, to *manufacture* small differences.

As shown at the right of Figure 8, the total input signal to a digit unit lies between 5 and 5.1 Mc/s. To this is added 42 Mc/s generated coherently from the master crystal oscillator. To the resulting sum frequency, which lies between 47 and 47.1 Mc/s, is added the digit component. The digit component may be any one of 10 frequencies from 3.0 to 3.9 Mc/s in 0.1-Mc steps. The desired digit component is selected by means of a phase lock between an oscillator rough-tuned to the desired frequency and one component of a picket fence generated coherently from the crystal oscillator. The final sum frequency, after this second addition, lies between 50 and 51 Mc/s.

The output frequency from the digit unit is one-tenth of this, and therefore lies once more between 5.0 and 5.1 Mc/s. Note that the signal component of the total input frequency has thus been divided by 10, as required by equation (4), and that a digit component has been added, which, in kilocycles per second, is 10 times the dialed digit, as specified in equation (4).

In the DI-1 unit the division by 10 is achieved by the use of the phase-lock technique. The tenth harmonic of the output oscillator is compared in a phase detector with the 50- to 51-Mc signal mentioned above, and the phase-detector output locks the output oscillator at exactly one-tenth of this reference signal.

Both phase locks use automatically switched low-pass filters in the control loop — wide band for capture, narrow band as lock is achieved. Automatic-sensing circuits extinguish the dial lighting if there is no lock. The capture range for each oscillator is so far in excess of requirements, however, that such failure is rare.

Observe that the choice of frequencies used in the above synthesizing process is such that no low-order spurious products approach coincidence in any of the mixers. This means that all important spurious frequencies are relatively far removed from the desired signals and that filtering requirements are therefore not severe. In addition, the simple RC filters in the phase-lock loops are able to remove any such products not completely eliminated by the mixer output filter.

In Figure 8, a decade dial is shown as the frequency-selecting control. In the remotely programmable version of the DI-1 unit, the manual dial has an eleventh position marked "R." At this setting, control is transferred to a rear connector, which allows digit selection by closure to ground in a biquinary code.

The Continuously Adjustable Decade (CAD)

The CAD is very similar in principle to the DI-1. The digit selection uses an oscillator continuously adjustable from 2.9 to 4.1 Mc/s (3.0 to 3.9 corresponds to digits 0 to 9; 2.9 provides range to −1, and 4.1 extends the high side to 11). In the INTERNAL LOCK mode, a 5.0-Mc input signal is added to 42 Mc/s to generate 47 Mc/s, crystal-locked. The digit oscillator, combined with this, produces a signal ranging from 49.9 to 51.1 Mc/s (of which 47 Mc/s is tied to the master crystal ocillator). After divisions by 10 by techniques similar to those in the DI-1, the final output frequency lies between 4.99 and 5.11 Mc/s.

In the EXTERNAL CONTROL mode the output oscillator is allowed to run free, under control of a second section on the two-gang tuning capacitor. Part of the oscillating-circuit capacitance is supplied by a voltage-variable-capacitance diode, for external-control purposes as described earlier.

The Ancillary Frequency Source (AFS)

As discussed above, the DI-1 and CAD units all require an input at 42 Mc/s, and the DI-1 units additionally need a coherent picket fence from 3 to 3.9 Mc/s. The AFS unit provides these two inputs to the digit units. The AFS unit also contains the master 5-Mc crystal oscillator, from which these signals are coherently derived; also included are circuits by which this master crystal oscillator can be phase-locked to any stable 5-Mc signal, or submultiple thereof. Isolation amplifiers make available, at rear-panel connectors, standard frequencies at 100 kc/s and 5 Mc/s for use in auxiliary equipment. A 1-Mc output is connected into the sandwich deck and brought out at lower power level at the rear of the deck. The 42-Mc signal is also available at a rear-deck receptacle.

Figure 9 is a block diagram of the AFS unit. The primary source, at 5 Mc/s, is divided to 1 Mc/s, which is then multiplied to 42 Mc/s in three steps. In another chain, the 1 Mc/s is further divided to 100 kc/s, where pulse-shaping circuits and bandpass filters and amplifiers generate the picket-fence output.

Isolation amplifiers are used liberally to prevent undesired reactions among the various inputs and outputs.

Crystal Oscillator in AFS Unit

The master crystal oscillator is designed for temperature-coefficient turnover near normal room-temperature ambient conditions. It is not temperature-controlled but has adequate stability for most applications when operated

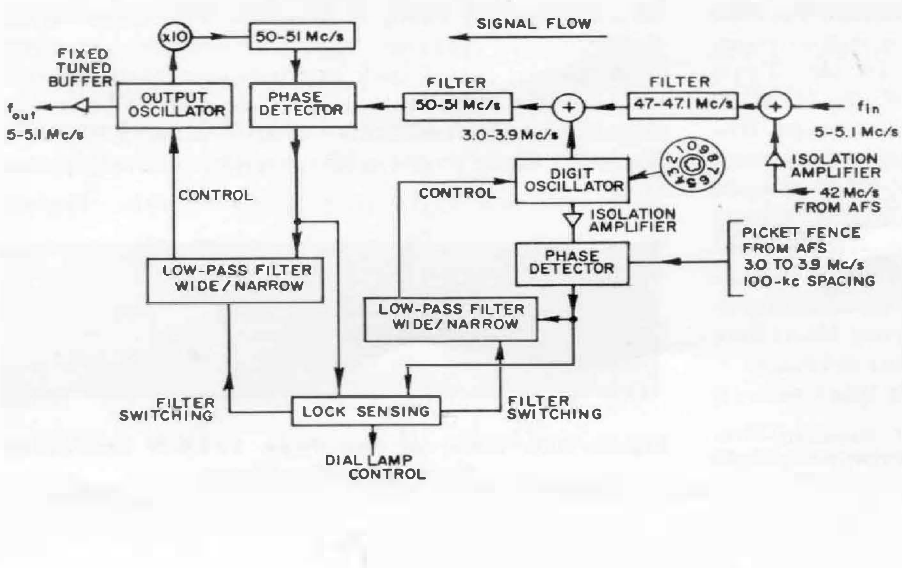


Figure 8. Functional block diagram of Digit-Insertion Unit, Type 1160-DI-1.

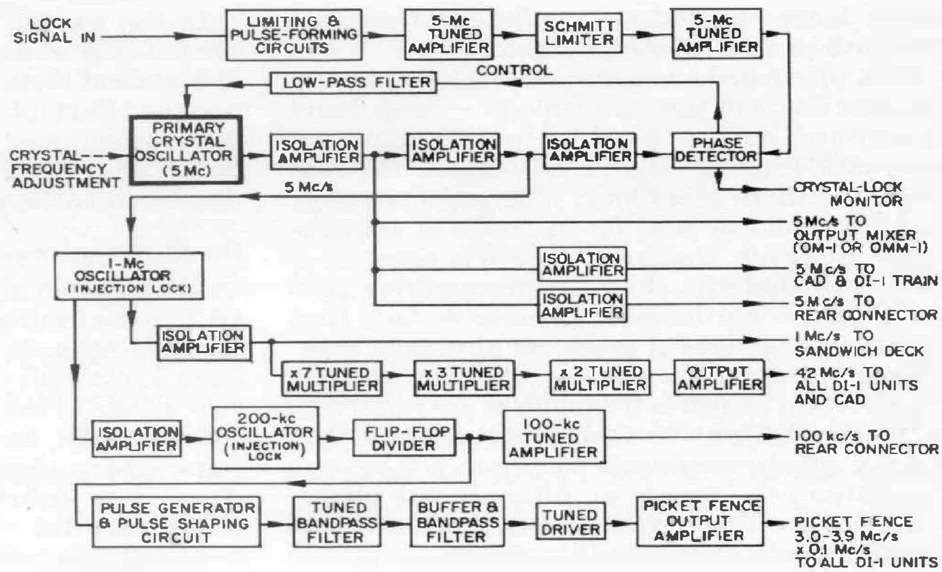


Figure 9. Functional block diagram of the Ancillary Frequency Source.

under reasonably constant ambient temperature; a 48-hour run on one unit, recorded continuously over a weekend in winter, with building heat cut back and re-established during the period, showed variations of only 2 parts in 10^8.

When more stable operation is required, the phase-locking circuitry shown in block diagram form in Figure 9 can be used to establish a tight lock to a more stable standard, such as the Type 1115-B Standard-Frequency Oscillator [6] (see Figure 10). The control signal, at a submultiple of 5 Mc/s, is first limited, and a sharp pulse is formed. The 5-Mc component of this pulse is selected in a tuned amplifier, limited by a Schmitt trigger circuit and amplified again to supply one input to the phase detector. The low-pass filter in the control loop adequately removes low-frequency components that might contribute to phase jitter.

Output Circuits

As has been seen, the output of the final unit in the train of digit units is a signal between 5 and 5.1 Mc/s, which may be considered a carrier component at 5.0 Mc/s, plus a signal component between 0 and 100 kc/s. In the Type 1161-A Synthesizer, the Output Mixer (OM-1) subtracts 5.0 Mc/s from this total output frequency, leaving the signal component as residue. In the Type 1162-A, the final DI-1 output signal is multiplied by 10 in the Output Multiplier-Mixer (OMM-1). From the multiplied frequency is subtracted 50.0 Mc/s, so that, in this case, the residue is 10 times the signal component from the last DI-1 unit, ranging therefore from 0 to 1 Mc/s, depending on dial settings.

The difference frequency in this final mix (0 to 100 kc/s or 0 to 1 Mc/s, depending on whether the OM-1 or the OMM-1 is plugged in) is fed to the final output amplifier, which is an integral part of the main frame. The output amplifier, when ac-coupled, is flat within 1 dB from 30 c/s to well beyond 1 Mc/s. The output impedance is low (approximately 5 ohms), and the available output voltage into loads of 50 ohms or higher is in excess of 2 volts, rms.

In the dc-coupled condition, the final amplifier is eliminated and the output is taken, by way of the level-control potentiometer, from the output mixer. In this case, the output impedance is high and variable (from 0 to about 3 kilohms, depending on level-control setting). The available open-circuit voltage is approximately 1 volt. The output voltmeter is disconnected in this mode of operation.

Power Supply (PS-1)

The plug-in power supply is conventional, supplying 18 volts, regulated, to the balance of the instrument. A toroidal power transformer, in an A-metal case, is used to minimize stray fields.

A special input jack permits operation of the synthesizer from batteries, if desired. The series regulator still functions, so any battery voltage from 20 to 28 volts will provide normal operation.

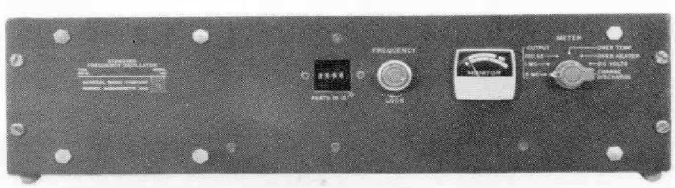


Figure 10. View of the Type 1115-B Standard-Frequency Oscillator.

[8] H. P. Stratemeyer, "The Stability of Standard-Frequency Oscillators," *General Radio Experimenter*, 38, 6, June 1964.

APPLICATIONS

When there is a requirement for precision frequencies selectable at will, the combination of a stable, free-running, adjustable oscillator and a frequency counter will often fill the bill, providing one is willing to monitor the oscillator for short- or long-term drift and correct its tuning as required. On the other hand, wherever an adjustable oscillator and a frequency counter can do a precision frequency-generating job, a decade synthesizer will do the job better and more reliably.

Frequency Measurement

In addition to its primary role of frequency *generation*, a synthesizer will often be found most useful in frequency *measurement* by heterodyne techniques. A Lissajous figure between a frequency to be measured and a standard frequency from a synthesizer will provide information on a *continuous* basis (and without any ±1 count uncertainty), instead of as averaged over the counting interval of a frequency counter. This is particularly useful in working with low frequencies, where it is necessary to use multiple-period measurements to achieve accuracy with a counter.

As an illustration, I periodically measure the tuning-fork frequency of my Accutron* wrist watch (nominal frequency 360 cycles per second) by forming a 240-to-1 Lissajous pattern with 86,400.00 c/s from a Type 1161-A Synthesizer. On this display, a frequency deviation as small as a part per million can be observed instantaneously.

The above comments and examples could, of course, apply to any synthesizer capable of sufficiently fine frequency steps. The GR synthesizers, however, offer operational possibilities not available, to my knowledge in any other device of this general character. These advantages accrue from the unique circuitry previously described, which permits the CAD unit to replace a group of digits (as selected by pushbuttons) and, simultaneously, to provide a highly magnified measure of the departure of the output frequency from that displayed on the digit dials, as the CAD frequency is adjusted either manually or electrically.

This feature can be used to advantage in measurement of the frequency characteristics of selective *passive* networks. It is also most useful in the study of frequency drift or of other changes in *active* frequency sources, such as precision crystal oscillators.

Measurement of Active Frequency Sources

Figure 11 is a block diagram, showing how very small frequency changes in a frequency source can be tracked and recorded. The unknown frequency, f_x, is compared in a phase detector (on a 1-to-1 or n-to-1 basis, or by heterodyning) with the output frequency, f_o, from the synthesizer. The dc voltage generated in the phase detector is connected to the EXTERNAL CAD CONTROL input of the synthesizer so that the synthesizer output automatically tracks the unknown frequency.

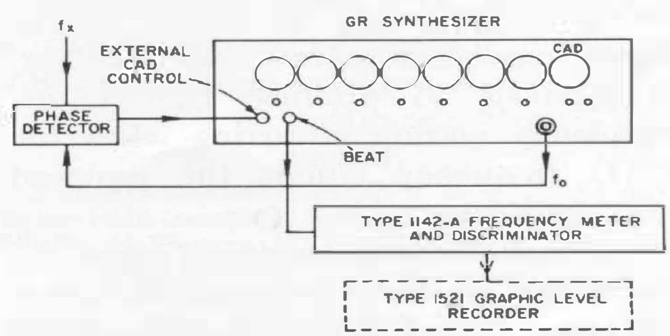


Figure 11. Method of tracking and recording the drift of an unknown frequency, f_x.

* Registered trademark of the Bulova Watch Company.

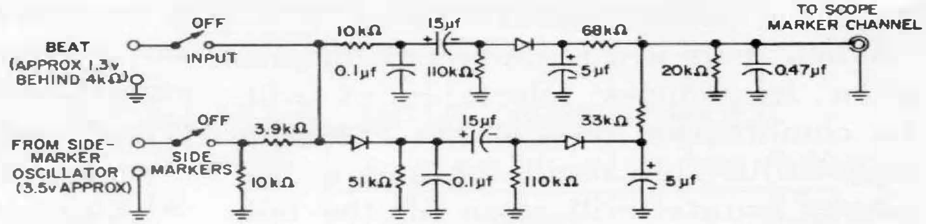


Figure 12. Suggested circuit for generating center-frequency marker and side markers, for use with slow sweeps.

The monitor frequency from the BEAT terminals is measured or recorded. As the synthesizer output frequency varies in response to changes in the unknown frequency, the beat output varies proportionately, at what may be a very highly magnified rate, depending upon which button has been pushed. For example, if the drift is small, the × 1 CPS button might be used. In this case, a change of 1 c/s in the synthesizer output would produce a 10-kc change in the recorded beat frequency — a magnification of 10^4. Smaller or greater magnifications can be used, as required, merely by operation of other pushbuttons.

Measurement of Passive Selective Networks

Figure 3 was noted briefly at the beginning of this article as an example of swept frequency analysis of sharply selective circuits, with self-generated markers. The traces of Figure 3 were obtained with the help of the circuit shown in Figure 12. This circuit was breadboarded for the purpose and is not available in packaged form, but it can be easily duplicated. In Figure 12, the signal from BEAT, after a low-pass filter, is rectified to produce the center-frequency marker occurring when the CAD frequency equals the replaced digit frequency.

Side markers are produced when the frequency at BEAT is equal to a frequency injected from the side-marker oscillator. Since we have the general rule that the frequency at BEAT changes at the rate of 10 kc/s per major CAD division (see page 6), a side-marker-oscillator frequency of 10 k/cs will produce a secondary marker whenever the CAD frequency is removed by one major division from that shown on the replaced digit dials. (A 15-kc side-marker signal thus produces markers at ±1.5 divisions, etc).

To produce the traces of Figure 3, a slowly varying dc voltage (obtained from a battery connected across a variable resistor with grounded center tap) was applied to the EXTERNAL CAD CONTROL connector and also to the horizontal input of a storage oscilloscope. The output of the synthesizer fed the Type 1900-A Wave Analyzer, and the analyzer output, rectified after passing through the internal selectivity, was connected to the vertical input of the oscilloscope on channel No. 1. The output of the marker generator was connected to channel No. 2, at the bottom of the oscilloscope face.

For the display of the 3-cycle pass band in Figure 3a, the pushbutton under × 1 CPS was operated, and the side-marker oscillator was set at 15 kc/s, so that the first pair of side markers occurred at ±1.5 c/s. (The second and third pair of markers are at ±3 c/s and ±4.5 c/s, by harmonic mixing in the marker generator.)

In Figure 3b (showing both the 3- and 10-cycle pass bands) the side-marker oscillator was set to 10 kc/s,

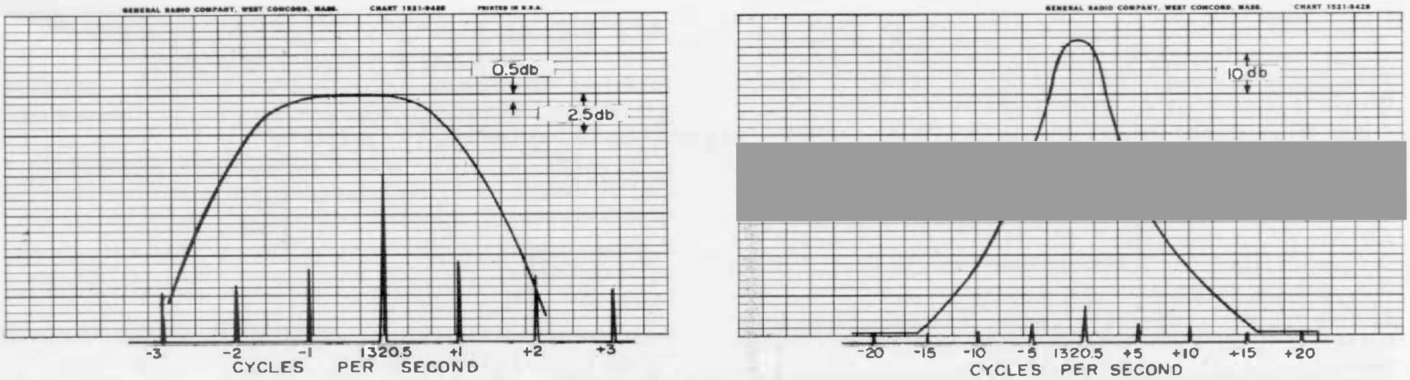


Figure 13. 3-cycle pass band of the Type 1900-A Wave Analyzer recorded by the Type 1521-B Graphic Level Recorder, equipped with an experimental plug-in for generating a sweeping voltage. Frequency markers were generated automatically by use of the circuit shown in Figure 12.

and markers thus occur at 1-cycle intervals. The sweep width is the same as in Figure 3a.

In Figure 3c, the only change is that the button under × 10 CPS has been pushed, so that the sweep width and marker spacing are 10 times as great as in Figure 3b.

Permanent records on strip charts can also be obtained by these methods. Figure 13 shows the 3-cycle pass band of the Type 1900-A Wave Analyzer recorded in this way. The source of sweeping voltage was an experimental plug-in for the Type 1521 Graphic Level Recorder, consisting of a variable resistor geared directly to the paper drive. In this arrangement, the wide-range logarithmic output of the recorder can be used to record the skirt selectivity.

Similar recordings can be made with the help of an X-Y recorder. The deflection on one axis can be made proportional to the frequency appearing at BEAT (by a frequency-to-voltage converter such as the GR Type 1142-A, for instance). The deflection on this axis is thus proportional to the *frequency difference from that shown on all the digit dials*, with scale factor as selected by pushbutton. The CAD can be swept manually or electrically; in either case the recorder deflection is strictly proportional to frequency, independent of variations or lack of linearity in the sweeping input.

Other Applications

The availability of versatile synthesizers such as those here described and their lineal descendants will undoubtedly generate a myriad of uses beyond the simple examples noted above. For instance, they can be incorporated in phase-locked loops to control the frequency of microwave oscillators. Narrow-band frequency or phase-modulation applications represent another fertile field. Transmitter-exciter or receiver-local-oscillator uses are, of course, obvious. By relatively simple circuit modifications, two-phase outputs or outputs with fixed-frequency difference can be achieved. As these synthesizers come into general use, General Radio Company will welcome suggestions for auxiliary equipment that will facilitate still more varied applications.

— ATHERTON NOYES, JR.

CREDITS

The Synthesizers described here would not have been possible without the enthusiastic efforts of George H. Lohrer and Charles C. Evans, who are responsible for a major portion of the electrical design. William F. Byers has also been an active participant in this program, particularly in connection with things yet to come.

SPECIFICATIONS

Frequency Range: Type 1162-A, 0 to 1 Mc/s; Type 1161-A, 0 to 100 kc/s.

CAD Dial Calibration: Type 1162-A, 0.001 c/s per division; Type 1161-A, 0.0001 c/s per division.

Other Outputs: Type 1162-A, 0.1, 1, 5, 42, and 50 Mc/s; 5.0-5.1 and 50-51 Mc/s; 18 volts dc. Type 1161-A, 0.1, 1, 5, and 42 Mc/s; 5.0-5.1 Mc/s; 18 volts dc.

Spurious Frequencies: Type 1162-A, at least 60 dB down. Type 1161-A, at least 80 dB down.

Harmonics: At least 40 dB down.

Output Level: Adjustable, 0 to 2 volts into 50 ohms. Output control and meter included.

Output Response: ±1 dB, 50 c/s to maximum frequency. Output also available down to dc at high impedance and lower voltage.

60- and 120-Cycle Sidebands: At least 60 dB down (Type 1162-A), at least 80 dB down (Type 1161-A).

Internal Standard: Room-temperature crystal oscillator. Temperature coefficient of frequency is approximately $1 \times 10^{-7}/°C$ at room temperature. A front-panel frequency adjustment is provided. Crystal frequency can be locked to external standard.

Power Required: 115/215/230 volts, 50 to 60 c/s or 400 c/s, 55 watts, or 20- to 28-volt battery, 1.8 amperes.

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

Dimensions: Bench model — width 19, height 5¼, depth 14½ inches (485 by 135 by 370 mm), over-all; rack model — panel 19 by 5¼ inches (485 by 135 mm), depth behind panel 13 inches (330 mm).

Net Weight: 38 pounds (17.5 kg).

Shipping Weight: 45 pounds (20.5 kg).

TYPE 1162-A COHERENT DECADE FREQUENCY SYNTHESIZER 0 to 1 Mc/s

Type	*Units Included*	*Calibrated Digits*		*Smallest Step (Digits Only)*	*Price*
		Decades Only	*Decades + CAD**		
1162-A7C	7 DI Units + CAD	7	9	0.1 c/s	$5600.00
1162-A6C	6 DI Units + CAD	6	8	1 c/s	5160.00
1162-A5C	5 DI Units + CAD	5	7	10 c/s	4720.00
1162-A4C	4 DI Units + CAD	4	6	100 c/s	4280.00
1162-A3C	3 DI Units + CAD	3	5	1 kc/s	3840.00
1162-A7	7 DI Units	7		0.1 c/s	5100.00
1162-A6	6 DI Units	6		1 c/s	4660.00
1162-A5	5 DI Units	5		10 c/s	4220.00
1162-A4	4 DI Units	4		100 c/s	3780.00
1162-A3	3 DI Units	3		1 kc/s	3340.00

TYPE 1161-A COHERENT DECADE FREQUENCY SYNTHESIZER 0 to 100 kc/s

Type	*Units Included*	*Calibrated Digits*		*Smallest Step (Digits Only)*	*Price*
		Decades Only	*Decades + CAD**		
1161-A7C	7 DI Units + CAD	7	9	0.01 c/s	$5460.00
1161-A6C	6 DI Units + CAD	6	8	0.1 c/s	5020.00
1161-A5C	5 DI Units + CAD	5	7	1.0 c/s	4580.00
1161-A4C	4 DI Units + CAD	4	6	10 c/s	4140.00
1161-A3C	3 DI Units + CAD	3	5	100 c/s	3700.00
1161-A7	7 DI Units	7		0.01 c/s	4960.00
1161-A6	6 DI Units	6		0.1 c/s	4520.00
1161-A5	5 DI Units	5		1.0 c/s	4080.00
1161-A4	4 DI Units	4		10 c/s	3640.00
1161-A3	3 DI Units	3		100 c/s	3200.00

* Direct reading. If CAD is calibrated in terms of the step decades at least one more significant figure can be added.

DECADE MODULES

Type		*Price*
1160-DI-1	Step Decade	$450.00
1160-CAD	Continuously Adjustable Decade (Including Calibrating Mixer)	510.00

U. S. Patent No. 2,548,457. Patents Pending.

NEW TALENTS FOR THE GRAPHIC LEVEL RECORDER

The Type 1521-A Graphic Level Recorder[1] has, in the five years since its introduction, seen service in many branches of physical sciences and engineering. A successor instrument, the Type 1521-B, now offers specialists in acoustics, vibration, and sonar a low-frequency response extended down to 7 cycles per second. Several new accessories are also being added to the growing line of equipment designed to ensure proper use of the recorder with various General Radio analyzers and signal sources. To simplify the job of choosing the right accessories, we are now listing, under distinct type numbers, measurement systems including analyzer or oscillator, recorder, and the appropriate link and drive units, chart paper, and other accessories.

The Type 1521-B Graphic Level Recorder is, like its predecessor, a completely transistorized, single-channel, servo-type recorder, which plots the rms magnitude of an ac voltage on a logarithmic (dB) scale. Plug-in potentiometers provide full-scale ranges of 20, 40, and 80 dB, as well as a linear range for dc recording. Recordings can be made as a function not only of time but also of frequency if the recorder is mechanically coupled to an oscillator or analyzer. This technique produces frequency-response plots automatically in a matter of seconds.

Frequency Response and Writing Speed

The low-frequency response of the new recorder is less than 0.1 dB down at

[1] M. C. Holtje and M. J. Fitzmorris, "A Graphic Level Recorder with High Sensitivity and Wide Ranges," *General Radio Experimenter*, 33, 6, June 1959.

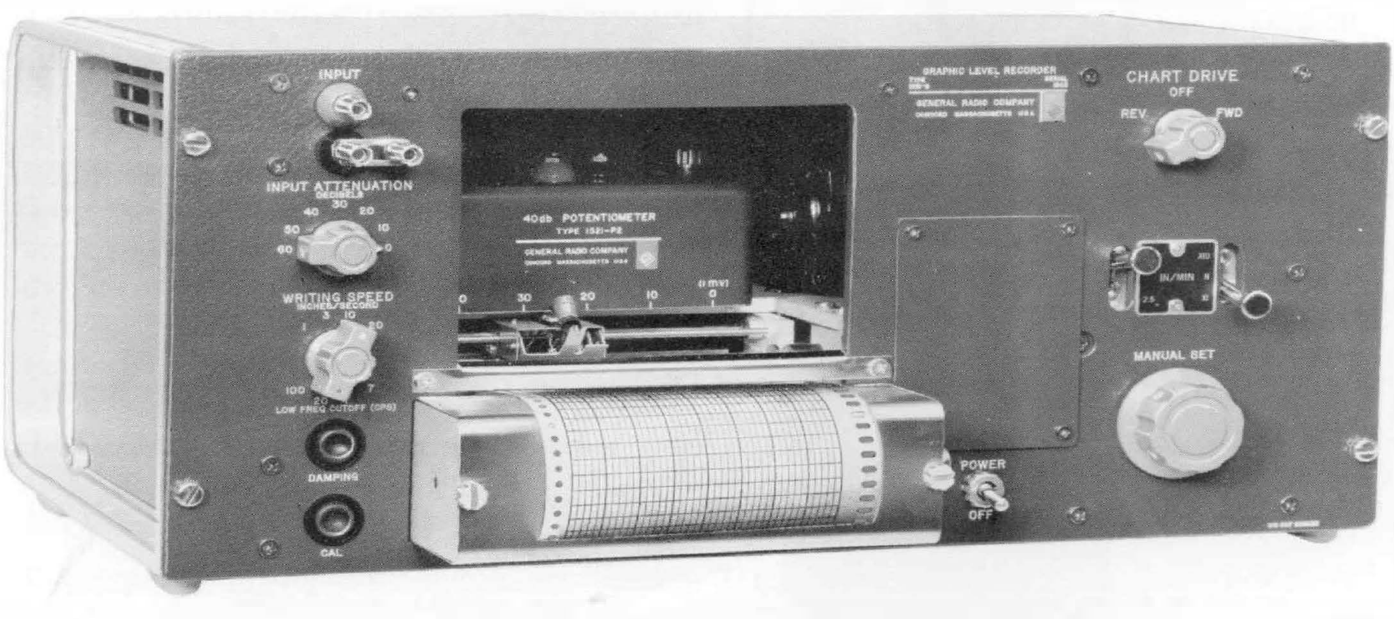


Figure 1. View of the Type 1521-B Graphic Level Recorder.

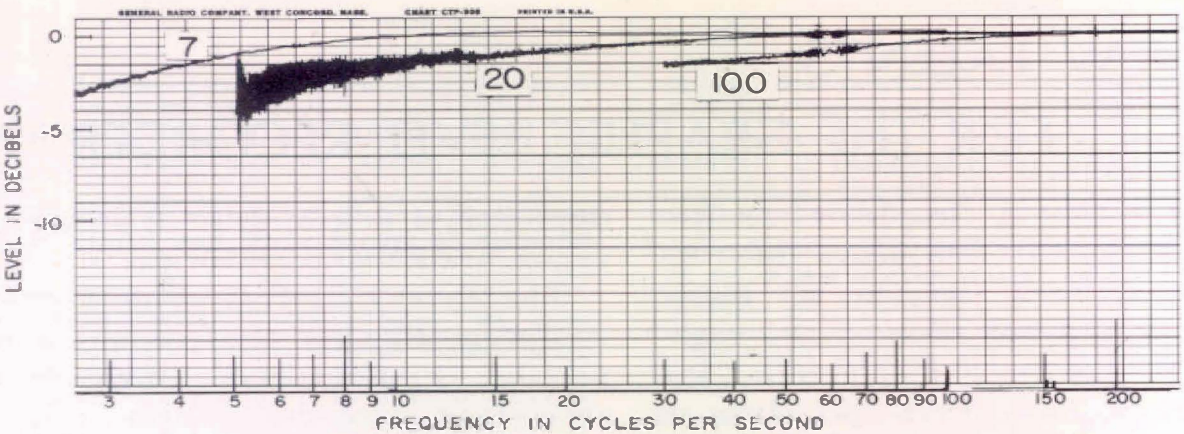


Figure 2. Low-frequency response of the Graphic Level Recorder for various positions of the low-frequency cutoff switch.

20 c/s, less than 1 dB down at 7 c/s, and 3 dB down at 4.5 c/s (see Figure 2). This extended low-frequency response requires a greater detector time constant, reducing the ability of the recorder to follow rapid changes in level. Therefore, writing speed and detector time constant are switched together, so that the user can improve low-frequency response at the expense of writing speed or vice versa. Table 1 shows the four writing-speed positions and their corresponding cutoff frequencies. This information is engraved on the front panel.

TABLE 1

WRITING SPEED AND LOW-FREQUENCY CUTOFF

Writing Speed in/sec	*Low-Frequency Cutoff c/s (Response down 1 dB)*
20	100
10	20
3	7
1	7

The sine-wave frequency response for the three low-frequency cutoffs is shown in Figure 2. For audio-band sweeping, the 20-cycle cutoff position is usually satisfactory. For greater accuracy at low frequencies, the 7-cycle cutoff must be used, but the reduced writing speed requires correspondingly low sweep speeds. Above 50 c/s, the writing speed and sweep speed can be increased during sweep to minimize over-all sweep time and error.

Figure 3 shows the response of the recorder to a ⅓-octave band of noise.

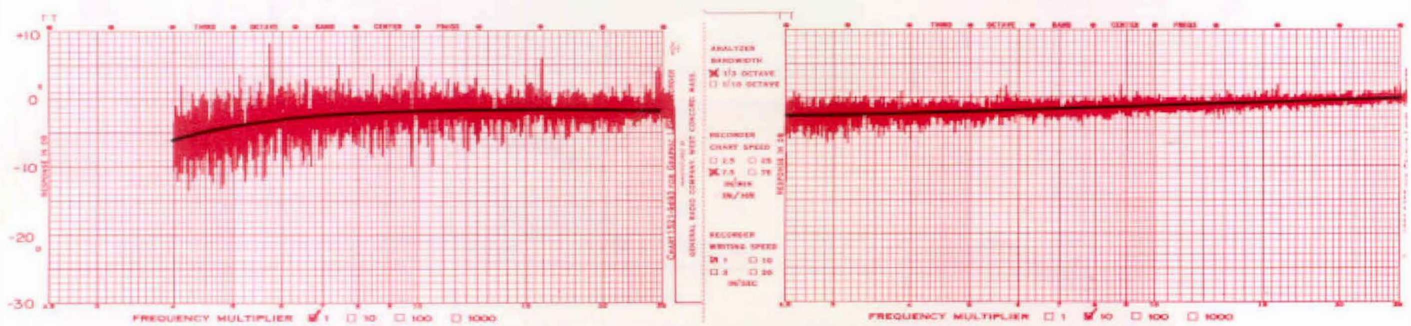


Figure 3. Low-frequency response of the Graphic Level Recorder to ⅓-octave band of pink noise, with a writing speed of 1 in/sec.

ACCESSORIES

Potentiometers

A 40-dB potentiometer is supplied; 20-dB, 80-dB, and linear potentiometers are available as accessories.

Motors

Accessory motors (50-cycle and 60-cycle) are available for slow-speed and medium-speed chart drive. The slow-speed motors produce chart speeds of 2.5 to 75 in/hr, a reduction by a factor of 60 from the speeds available with the standard high-speed motor. The new medium-speed motors, Type 1521-P23 (60 c/s) and Type 1521-P24 (50 c/s), are especially recommended for use with analyzers. The speed at which an analyzer can be swept is inversely proportional to its bandwidth. The Type 1900-A Wave Analyzer has a constant bandwidth of 3, 10, or 50 c/s and therefore requires a constant sweep speed over the full 0- to 50-kc bandwidth of the instrument. These new motors provide chart speeds of 0.5 to 15 in/min, speeds ideally suited to the 10- and 50-cycle bandwidths.

With the constant-percentage-bandwidth Type 1564-A Sound and Vibration Analyzer, the slowest speed of the medium-speed motor (0.5 in/min) is recommended for sweeping near 4.5 c/s. The sweep speed can then be increased to 5 in/min or more on the 25- to 250-cycle range.

The mounting of the new motor has been designed to reduce the coupling of the motor noise to the gear box. The resulting acoustic noise is practically inaudible, an important consideration for acoustical measurements.

Drive and Link Units for Automatic Plotting

The new Type 1521-P10B Drive Unit (Figure 4) is designed to couple the recorder to all General Radio oscillators and analyzers. When attached to the front of the recorder, it is used, in conjunction with a link unit, to couple the chart drive of the recorder to the dial of the frequency source or analyzer (see Figure 5). A continuous-adjustment clutch permits the recorder to be synchronized with the oscillator (or analyzer) dial in the idle position and then engaged in the DRIVE or NON-SLIP position. The DRIVE position includes a slip feature that will protect an instrument containing a dial stop (e.g., the older Type 1554-A Sound and Vibration Analyzer and older models of the Type 1304-B Beat-Frequency Audio Generator). The NON-SLIP position is recommended for use with the Type 1900-A Wave Analyzer and other instruments requiring greater driving torque.

Cam-operated switches in the new drive unit turn the recorder motor off at the beginning and end of a sweep. A switch in the recorder can engage or disengage the Microswitches. These cams are easily set and do not have to

Figure 4. View of the Type 1521-P10B Drive Unit.

be disengaged mechanically when they are not being used.

The new Type 1521-P15 Link Unit is used to connect the recorder and drive unit to the Type 1304-B Beat-Frequency Audio Generator or the Type 1554-A or 1564-A Sound and Vibration Analyzer. (The Type 1900-A Wave Analyzer is coupled by the Type 1900-P1 Link Unit.) The new link unit includes a 24-tooth sprocket to provide a scale factor of 30 dB/decade. (Scale factor, for a logarithmic chart, is the product of dB/in on the vertical scale and in/decade of frequency on the horizontal scale, expressed in dB/decade.) This scale factor is endorsed in the current EIA standard and is used on the GR Type 1521-9427 chart paper used with the Type 1304-B Beat-Frequency Audio Generator. Because many users have expressed preferences for other scale factors, we have designed the new unit for easy interchangeability of sprockets, and we are making available a kit (Type 1521-P16) that includes sprockets with 16, 20, 32, 36, and 40 teeth. The 16-tooth sprocket, used with the Type 1564-A Sound and Vibration Analyzer and with our Type 1521-9469 chart paper, results in a scale factor of 50 dB/decade.

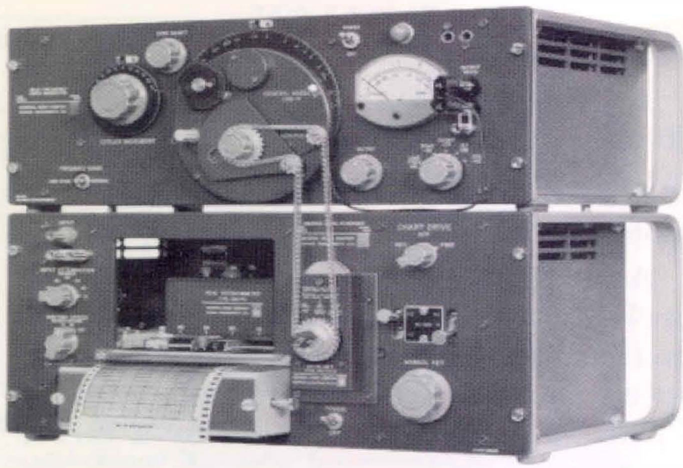


Figure 5.
View of the Type 1350-A Generator-Recorder Assembly.

Table II lists the scale factors corresponding to the various sprockets in the sprocket kit, along with the industries

TABLE II INDUSTRY SCALE FACTORS

Industry Standard	*Scale Factor (dB/decade)*	*Decade Length (inches) for Type 1304 Generator*	*Sprocket (teeth)*	*Pot (dB)*
Institute of High Fidelity Manufacturers	20	2.0	16	40
Proposed International Standard	25	2.5	20	40
Electronic Industries Association	30	3.0*	24	40
Institute of High Fidelity Manufacturers	20	4.0	32	20
Hearing Aid Industry	45	4.5	36	40
Proposed International Standard	50	5.0	40	40
Proposed International Standard	50	5.0**	16	40

* Chart paper available for Type 1304-B Beat-Frequency Audio Generator.
** Decade length applies to Type 1564-A Sound and Vibration Analyzer; chart paper available.

supporting these scale factors. Although we currently catalog chart paper for only the 30- and 50-dB/decade scale factors, we shall be glad to recommend other suppliers to users sending us a description of the chart desired, including decade length, vertical scale, etc.

MEASURING AND RECORDING ASSEMBLIES

The recorder can be used in conjunction with an oscillator or analyzer to plot directly frequency-response data of networks or systems. The setup for these measurements requires the recorder, an oscillator or analyzer, a drive unit, and a link unit. This equipment is assembled and supplied as a complete system under a separate type number. The user will find it advantageous to purchase the system in this manner, since our recommended combination of instruments, parts, and chart paper will automatically be supplied.

Type 1350-A Generator-Recorder Assembly

This is a most useful automatic system for measuring the audio-frequency characteristics of filters, attenuators, networks, loudspeakers, microphones, transducers, and complete acoustic systems (see Figure 5). The Type 1304-B Beat-Frequency Audio Generator is an ideal oscillator for such measurements, since it has a truly logarithmic frequency dial and an output-voltage variation of less than 0.25 dB as the oscillator is swept. Examples of measurements made with this system are shown in Figure 8. Notice the impracticability of a point-by-point frequency-response plot of the sound level in a room.

In addition to the generator and recorder, the Type 1350-A Generator-Recorder includes drive and link units, a kit of sprockets, and a muting switch. The switch short-circuits the output of the oscillator during the blank part of the dial or at low frequencies, so that loudspeakers or systems can be protected while the recorder is continuously swept. Because the blank parts on the chart paper correspond to the length of the blank portion on the dial, successive charts can be recorded with synchronization of the chart and the dial frequency.

Type 1910-A Recording Wave Analyzer [2]

The linear frequency scale, the three bandwidths (3, 10, and 50 c/s), and the high-level 80-dB dynamic-range output of the Type 1900-A Wave Analyzer make it an ideal companion instrument for the Type 1521-B Graphic Level Recorder (see Figure 6). An example of a measurement made with the Recording Wave Analyzer is shown in Figure 9.

[2] Arnold Peterson, "New Wave Analyzer Has 3 Bandwidths, 80-dB Dynamic Range," *General Radio Experimenter*, 38, 4, April 1964.

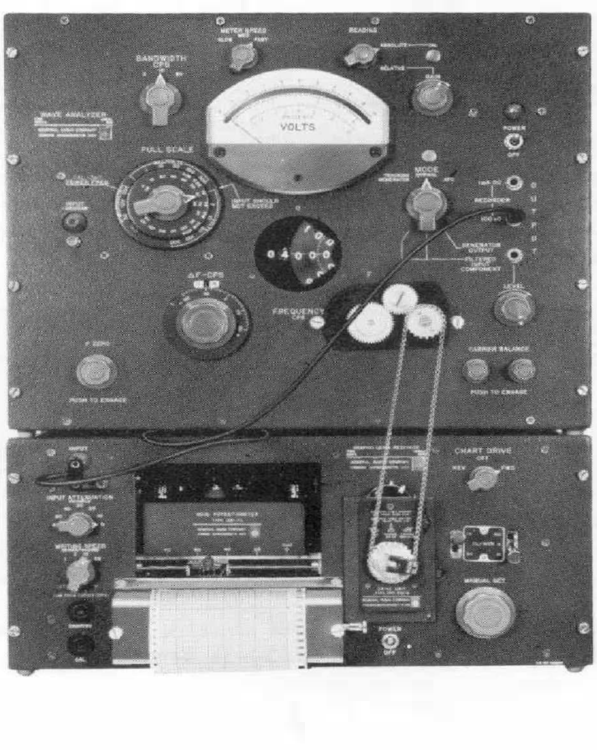


Figure 6. View of the Type 1910-A Recording Wave Analyzer.

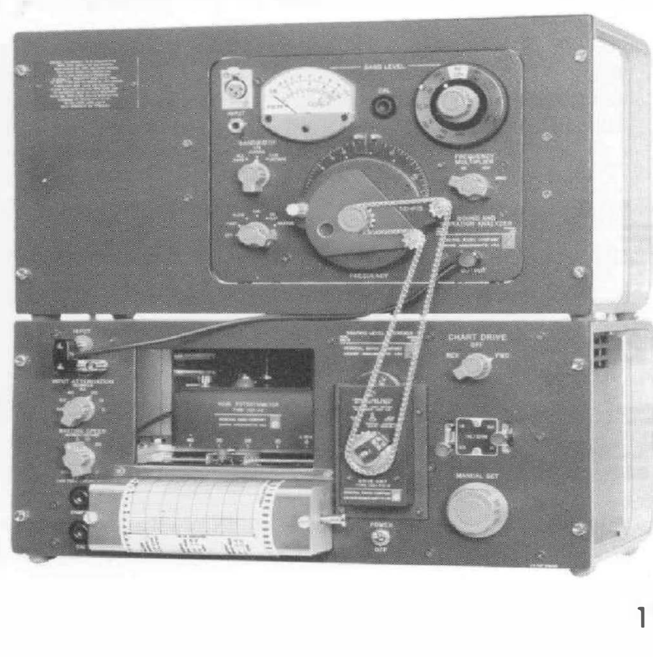


Figure 7. View of the Type 1911-A Recording Sound and Vibration Analyzer.

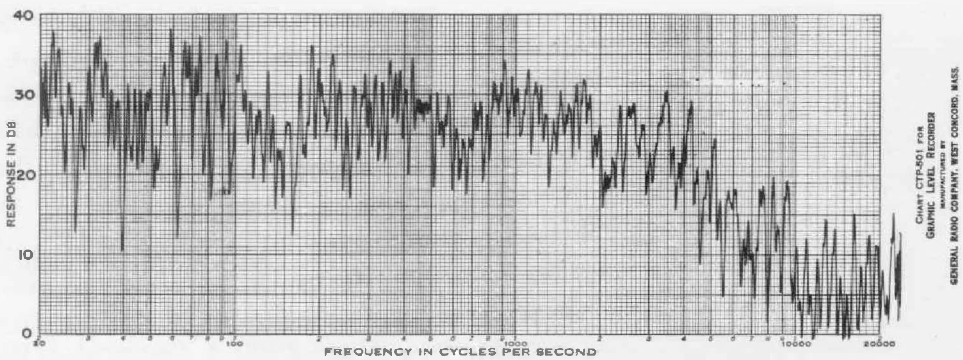
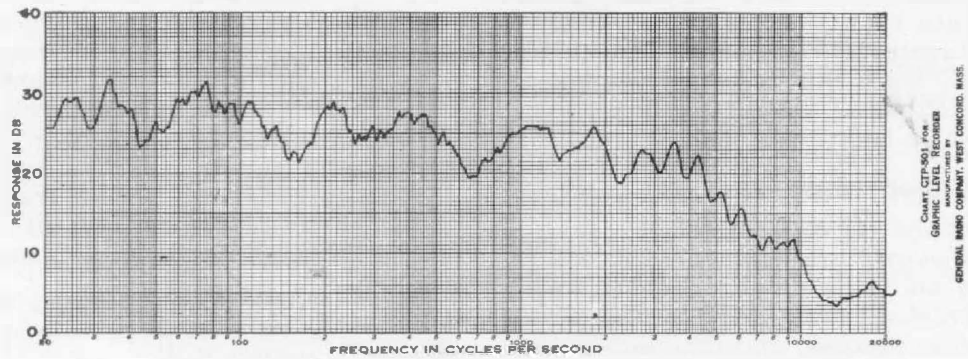


Figure 8. Records of the frequency response of a public address system, taken with (*top*) maximum writing speed and (*below*) minimum writing speed.



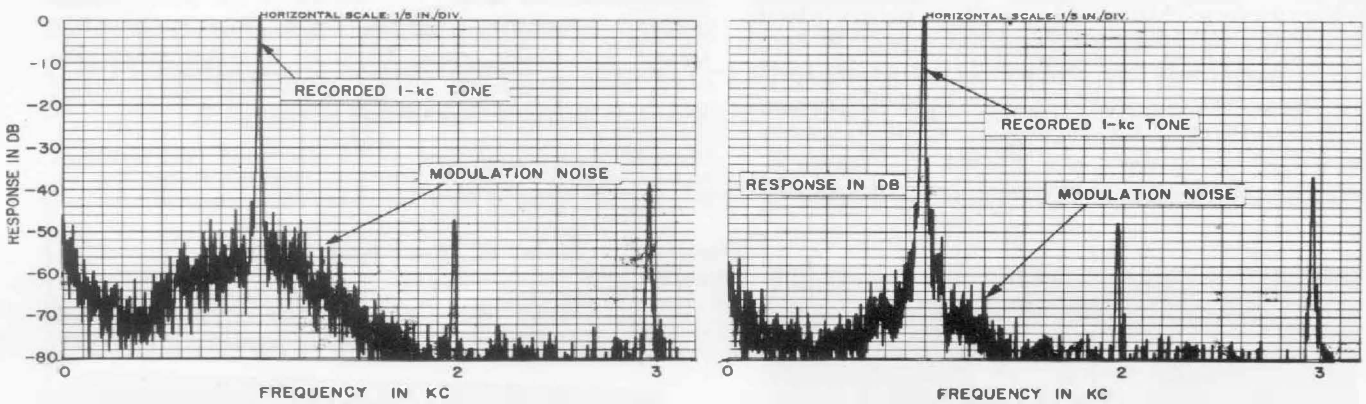


Figure 9. Charts of modulation noise on a 1-kc tone for two different types of magnetic tape. Note that one is about 10 dB better than the other. Such measurement can be made easily with the recording analyzer, owing to the 80-dB dynamic range. For these records, chart speed was 2.5 inches per minute; writing speed, 10 inches per second; bandwidth, 10 c/s.

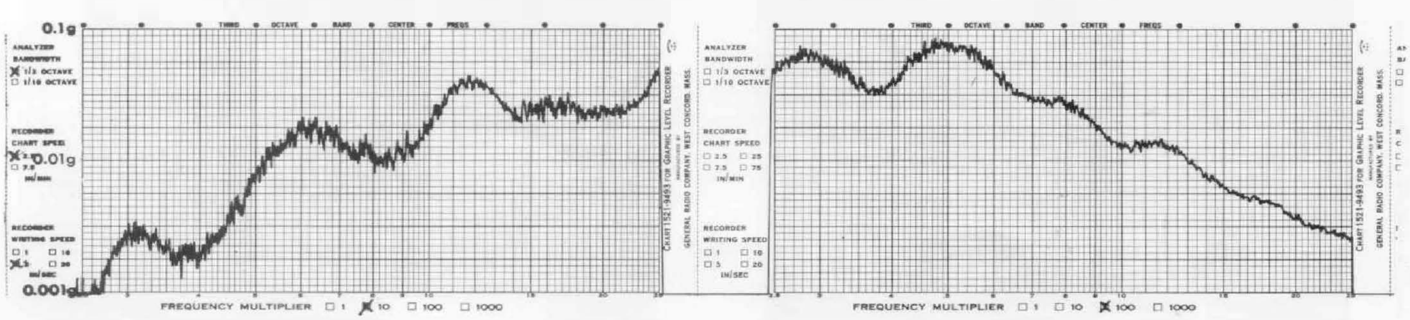


Figure 10. Chart record of a vibration acceleration spectrum measured on the chassis of a calculating machine. For this measurement a high-frequency vibration pickup is used.

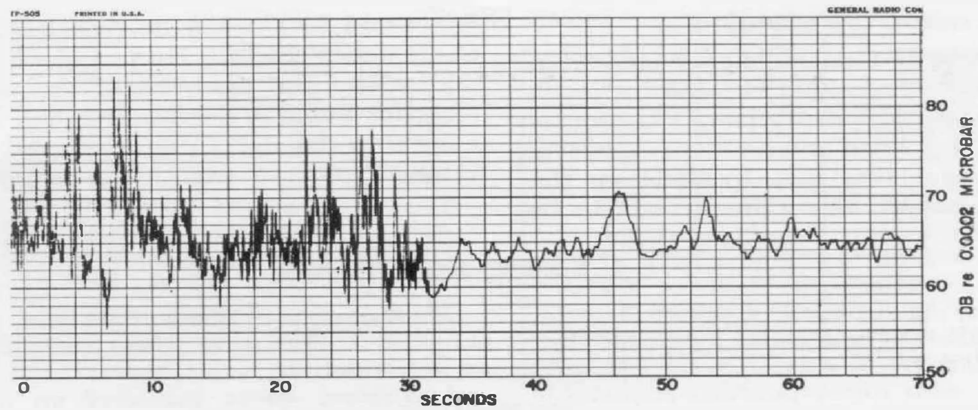


Figure 11. Recording of noise level in a cafeteria with both fast and slow writing speeds and 40-dB potentiometer.

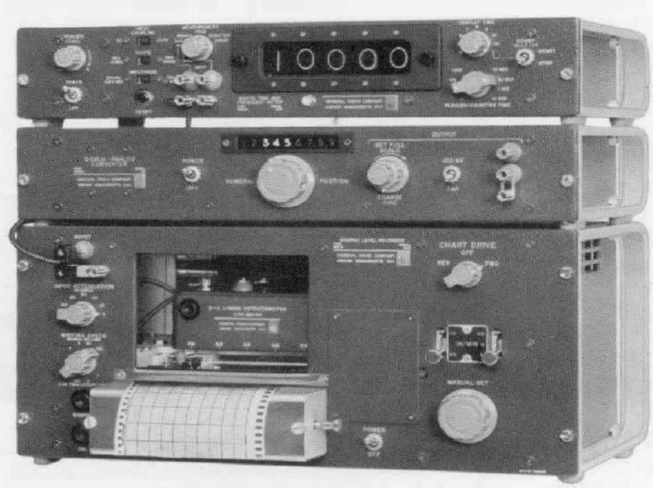
Type 1911-A Recording Sound and Vibration Analyzer

This assembly is based on the Type 1564-A Sound and Vibration Analyzer[3], which has constant-percentage bandwidths of 1/3 and 1/10 octave and a frequency range of 2.5 to 25,000 c/s (Figure 7). This analyzer includes two features especially important in recording: an automatic frequency-range-changing device and a built-in muting switch that short-circuits the output during the blank part of the dial. The extended low-frequency response of the new recorder greatly enhances its use with the Type 1564-A Sound and Vibration Analyzer for vibration measurements. The recorder can be used down to 4.5 c/s (3 dB down) if a response plot of the recorder itself is first made and then compared with the recording made with the analyzer. Figure 10 is an example of a recorded vibration measurement. Another example is our reduction of the acoustic noise in the chart-drive system of the recorder itself. The recorder analyzed its own acoustic noise with the Type 1564-A Sound and Vibration Analyzer and a sound-level meter. The resulting data were observed for peaks in sound level. These were found to be the fourth and fifth harmonics of the motor pinion gear mesh, amplified by the gear-box mounting plate. Isolating the motor from the gear box solved the problem, reducing the noise until it was practically inaudible in a quiet room.

[3] W. R. Kundert, "New Performance, New Convenience with the New Sound and Vibration Analyzer," *General Radio Experimenter*, 37, 9 and 10, September-October 1963.

Figure 12. View of the Type 1521-B Graphic Level Recorder with the Type 1551-C Sound-Level Meter.

Figure 13. View of the Graphic Level Recorder bench-mounted with the Type 1151-AP Digital Time and Frequency Meter and the Type 1136-A Digital-to-Analog Converter.



Level-vs-Time and DC Recording

The Type 1521-B Graphic Level Recorder, like its predecessor, can also be used for level-vs-time recordings, as, for instance, in the measurement of sound level over long periods of time (see Figures 11 and 12). In addition, the Type 1521-B Graphic Level Recorder can be converted to a 1-mA dc recorder by means of the Type 1521-P4 Linear Potentiometer. The high speed and accuracy of this servo-type dc recorder make it useful with the Type 1136-A Digital-to-Analog Converter and the Types 1150-AP and 1151-AP Counters (see Figure 13).

— MARTIN W. BASCH

SPECIFICATIONS

Recording Range: As supplied, 40 dB full-scale; 20-dB and 80-dB ranges are also available. For dc recording, 0.8 to 1 volt (0.8 to 1.0 mA) full-scale, with zero input position adjustable over full scale.

Frequency Response and Writing Speed

Level Recording: High-frequency response ±2 dB to 200 kc/s. Low-frequency sine-wave response depends on writing speed, as shown in following table:

Writing Speed (approx) in/sec with 0.1-inch overshoot	*Low-Frequency Cutoff c/s (less than 1 dB down)*
20	100
10	20
3	7 (3 dB down at 4.5 c/s)
1	7 (3 dB down at 4.5 c/s)

DC Recording: 3 dB down at 8 c/s (peak-to-peak amplitude less than 25% of full scale).

Potentiometer Linearity

20-, 40-, 80-dB Potentiometers: ±1% of full-scale dB value plus a frequency error of 0.5 dB at 100 kc/s and 1.5 dB at 200 kc/s.

Linear Potentiometer: ±1% of full scale.

Resolution: ±0.25% of full scale.

Maximum Input Voltage: 100 volts ac.

Input Attenuator: 60 dB in 10-dB steps.

Input Impedance: 10,000 ohms for ac level recording; 1000 ohms for dc recording.

Maximum Sensitivity: 1 mV at 0 dB for level recording; 0.8 V full-scale for dc recording.

Paper Speeds

High-speed motor (normally supplied): 2.5, 7.5, 25, 75 in/min. Used for high-speed-transient measurements and production testing with Type 1304 Audio Generator.

Medium-speed motor (supplied on request): 0.5, 1.5, 5, 15 in/min. Used with analyzers and in level-vs-time recordings.

Low-speed motor (supplied on request): 2.5, 7.5, 25, 75 in/hr. Used for level-vs-time measurements of long duration (1 to 24 hours).

External DC Reference: An external dc reference voltage of from 0.5 to 1.5 V can be applied internally to correct for variations of up to 3 to 1 in the signal source of the system under test.

Detector Response: Rms within 0.25 dB for multiple sine waves, square waves, or noise. Detector operating level is 1 volt.

Chart Paper: 4-inch recording width on 5-inch paper. All rolls are 100 feet long. See full list of charts at end.

Accessories Supplied: 40-dB potentiometer, 2 pens, 2-ounce bottle of red ink, 2-ounce bottle of green ink, bottle of potentiometer cleaner, 1 roll of Type 1521-9428 paper, droppers for filling pens, Type CAP-22 Power Cord, spare fuses, adaptor cable for connection to sound-measuring equipment and to other devices having telephone jacks.

Accessories Available: Potentiometers, charts, ink, high-, medium- and slow-speed motors, drive and link units, as listed in price table.

Power Requirements: 105 to 125 (or 210 to 250) volts, 60 c/s, 35 watts. 50-cycle models are available.

Cabinet: Rack-bench.

Dimensions: Bench model — width 19, height 9, depth 13½ inches (485 by 230 by 350 mm), over-all; rack model — panel 19 by 8¾ inches (485 by 225 mm), depth behind panel 11¼ inches (290 mm).

Net Weight: 50 pounds (23 kg).

Shipping Weight: 62 pounds (29 kg).

Type	*Mounting*	*Supply Frequency*	*Paper Speed*	*Price*
1521-BR	Rack	60 c/s	2.5-75 in/min	$995.00
1521-BM	Bench	60 c/s	2.5-75 in/min	995.00
1521-BRQ1	Rack	50 c/s	2.5-75 in/min	995.00
1521-BMQ1	Bench	50 c/s	2.5-75 in/min	995.00

DRIVE AND LINK UNITS FOR COUPLING TO GENERATORS AND ANALYZERS

1521-P10B	**Drive Unit** to operate any link unit	$72.00
1521-P15	**Link Unit** for coupling to Type 1304-B Beat-Frequency Audio Generator or to Type 1554-A or Type 1564-A Sound and Vibration Analyzer	26.00
1521-P16	**Sprocket Kit** for above link unit. These sprockets offer a choice of the following scale factors (ratio of dB/inch vertical scale to decades/inch on horizontal scale): 20, 25, 45, and 50 dB/decade.	15.00
1900-P1	**Link Unit** for coupling to Type 1900-A Wave Analyzer	35.00

CHART PAPER

Type	Calibration Horizontal	Calibration Vertical (Div)	Chart Length (in) Calibrated	Chart Length (in) Blank	Associated Instrument	Price
1521–9427	20 c/s-20 kc/s, log	80	9	4½	1304-B Generator	**$2.75**
1521–9464	0-10 kc/s, linear	40	20	0	1900-A Analyzer	**2.75**
1521–9465	0-50 kc/s, linear	40	16	0	1900-A Analyzer	**2.75**
1521–9493	2.5-25 normalized, log	40	7½	1½	1564-A Analyzer	**2.75**
1521–9469	2.5-25 normalized, log	40	5	1	1564-A Analyzer	**2,75**
1521–9463	2.5 c/s-25 kc/s, log	40	18	3	1554-A Analyzer	**2.75**
1521–9429	25-7500 c/s, log	40	12½	1	760-B Analyzer	**2.75**
1521–9428	Continuous ¼-in div	40	continuous			**2.75**
1521–9466	Continuous ⅝-in div	50	continuous		1134-A, 1136-A D/A Converters	**2.75**

MOTORS

Type		Price
1521-P19	(high-speed, 60 c/s) for paper speeds of 2.5 to 75 in/min	**$59.00**
1521-P21B	(high-speed, 50 c/s) for paper speeds of 2.5 to 75 in/min	**65.00**
1521-P23	(medium-speed, 60 c/s) for paper speeds of 0.5 to 15 in/min	**59.00**
1521-P24	(medium-speed, 50 c/s) for paper speeds of 0.5 to 15 in/min	**65.00**
1521-P20B	(low-speed, 60 c/s) for paper speeds of 2.5 to 75 in/hr	**59.00**
1521-P22	(low-speed, 50 c/s) for paper speeds of 2.5 to 75 in/hr	**65.00**

RECORDING ASSEMBLIES

Factory assembled and ready to use. End frames and rack supports supplied for bench or relay-rack mounting.

Type 1910-A Recording Wave Analyzer

Component Units
- Type 1900-A Wave Analyzer
- Type 1521-B Graphic Level Recorder with medium-speed motor and recorder accessories
- Type 1521-P10B Drive Unit
- Type 1900-P1 Link Unit
- Type 1521-9464 Chart Paper, 10 rolls
- Type 1521-9465 Chart Paper, 10 rolls
- Type 1521-P3 80-dB Potentiometer (inaddition) to 40-dB Potentiometer included with recorder)
- Type 1560-P95 Adapter Cable (phone to double plug)

Type		Price
1910-A	Recording Wave Analyzer (60-cycle supply)	**$3500.00**
1910-AQI	Recording Wave Analyzer (50-cycle supply)	**$3500.00**

Type 1911-A Recording Sound and Vibration Analyzer

Component Units
- Type 1564-9820 Sound and Vibration Analyzer, Rack Model
- Type 1521-B Graphic Level Recorder with medium-speed motor and recorder accessories
- Type 1521-P10B Drive Unit
- Type 1521-P15 Link Unit (with interchangeable 16- and 24-tooth sprockets)
- Type 1521-9469 Chart Paper, 10 rolls
- Type 1560-2141 Adaptor Cable, double plug to offset phone plug

Type		Price
1911-A	Recording Sound and Vibration Analyzer (60-cycle supply)	**$2315.00**
1911-AQI	Recording Sound and Vibration Analyzer (50-cycle supply)	**$2315.00**

Type 1350-A Generator-Recorder Assembly

Component Units
- Type 1304-B Beat-Frequency Audio Generator
- Type 1521-B Graphic Level Recorder and recorder accessories
- Type 1521-P10B Drive Unit
- Type 1521-P15 Link Unit
- Type 1521-P16 Sprocket Kit
- Type 1304-P1 Muting Switch
- Type 1521-9427 Chart Paper, 10 rolls
- Type 1560-P95 Adaptor Cable, phone to double plug
- Type 274-NP Patch Cord, double plug to double plug

Type		Price
1350-A	Generator-Recorder Assembly (60-cycle supply)	**$2000.00**
1350-AQI	Generator-Recorder Assembly (50-cycle supply)	**2000.00**

The Type 1304-P1 Muting Switch supplied with the Type 1350-A assembly is available separately for $37.50.

Coming in September

ELECTRONIC INSTRUMENT MANUFACTURERS' EXHIBIT

Boston to Washington, D.C.

Nine leading manufacturers of electronic instruments have joined together to present the Fifth Annual Electronic Instrument Manufacturers' Exhibit (EIME), which will open September 21 in Massachusetts, make six one-day stands in New York, New Jersey, and Pennsylvania, and close in Washington, D.C. on October 8.

As before, EIME will offer operating displays of the latest in instrumentation, plus the chance to discuss measurement problems with factory engineers. A new feature of this year's EIME is a series of technical sessions, at which engineers from the nine participating companies will give short formal talks on various instrumentation and measurement subjects. These talks will run consecutively throughout the day.

General Radio will exhibit its new Type 1162-A Coherent Decade Frequency Synthesizer, Type 900-LB Precision Slotted Line (and recording system), Type 1150-BH 1-Mc Digital Frequency Meter, Type 1396-A Tone-Burst Generator, Type 1806-A Electronic Voltmeter, Type 1900-A Wave Analyzer, Type 1025-A Standard Sweep-Frequency Generator, Type 1644-A Megohm Bridge, and Type 1115-B Standard-Frequency Oscillator.

Sponsors of EIME, in addition to GR, are: Ampex Corporation, Brush Instruments, Keithley Instruments, Inc., Lambda Electronics, Non-Linear Systems, Inc., George A. Philbrick Researches, Inc., Singer Metrics Division (Panoramic Instruments and Sensitive Research Instruments).

The complete EIME schedule:

Lynnfield, Massachusetts	Monday, Sept 21	Colonial Country Club, Route 128
Syracuse, New York	Wednesday, Sept 23	Randolph House, Exit 37, N. Y. State Thruway
Bethpage, Long Island	Monday, Sept 28	Holiday Manor, Hicksville Road, south of Grumman
Cedar Grove, New Jersey	Wednesday, Sept 30	Friar Tuck, Route 23
North Plainfield, New Jersey	Thursday, Oct 1	Washington House, Route 22
Philadelphia, Pennsylvania	Monday, Oct 5	Marriott Motor Hotel
Red Bank, New Jersey	Tuesday, Oct 6	Molly Pitcher Hotel
Washington, D. C.	Thursday, Oct 8	International Inn

General Radio Company