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A MODERN, WIDE-RANGE, RC OSCILLATOR

Figure 1. Panel view of the Type 1310-A Oscillator showing synchronization jack

A MODERN, WIDE-RANGE, RC OSCILLATOR

> The introduction of the new Type 1310-A Oscillator continues the development of the modern two-feedback-path RC oscillator, invented by General Radio back in 1937. Another modern instrument that uses this circuit is the solid-state Type 1311-A Audio Oscillator[1].

The TYPE 1310-A Oscillator brings the small size, mechanical ruggedness, and reliability of transistorized circuitry to a wide-range, general-purpose instrument. It offers substantial improvement in many oscillator characteristics, includes an entirely new frequency-synchronization feature, and yet maintains the high accuracy, infinite resolution of variable-capacitance tuning, high-output voltage, and other desirable features of older vacuum-tube designs — all at a reasonable cost.

FREQUENCY

The unusually wide frequency range alone makes the TYPE 1310-A Oscillator a signal source of exceptional utility. The lower limit of 2 c/s covers the roll-off region of most ac-coupled circuits, and the upper limit of 2 Mc/s includes the important area around 1 Mc/s where many high-frequency measurements are made on components. A finely graduated, vernier-driven dial with ±2% accuracy makes for rapid yet precise setting of frequency. High-stability frequency-determining components in the oscillator and the low internal power dissipation result in a very stable output frequency. Drift during warm-up is typically below 0.1% at frequencies above 20 c/s.

OUTPUT

The output waveform has a high degree of purity. Harmonic distortion

[1] R. G. Fulks, "High-Performance, Low-Cost Audio Oscillator, with Solid-State Circuitry," *General Radio Experimenter*, August-September 1962.

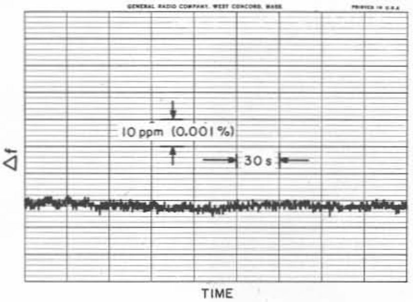
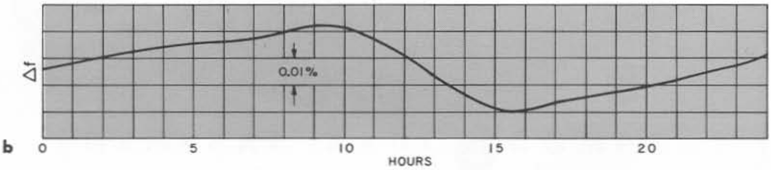


Figure 2. Typical frequency stability after warmup at 1 kc/s; (a) short term, (b) long term. Sampling time is 0.1 second (100 periods).



is low, less than 0.25% over most of the audio range. This low distortion is always obtainable, even at full output, because it remains constant regardless of the size of the linear load applied, including short circuit. This feature is particularly useful at higher frequencies where low impedances are required, as, for example, in 50-ohm systems. Hum is below 0.02% of the output regardless of the attenuator setting and is typically 0.005%. Noise at frequencies distant from a 1-kc fundamental, measured in a bandwidth of 5 c/s to 500 kc/s, is typically less than 0.02%. Noise close to the fundamental is low, as the spectrum analysis of a 1-kc output in Figure 4 shows. This low noise level permits amplitude modulation in magnetic recordings and inter-modulation products in any device to be measured to −90 dB with ease.

The 20-volt, open-circuit output behind 600 ohms is adjustable over approximately a 50-dB range by means of a constant-percentage-resolution attenuator. The output is essentially constant with frequency (Figure 5), a convenience for frequency-response

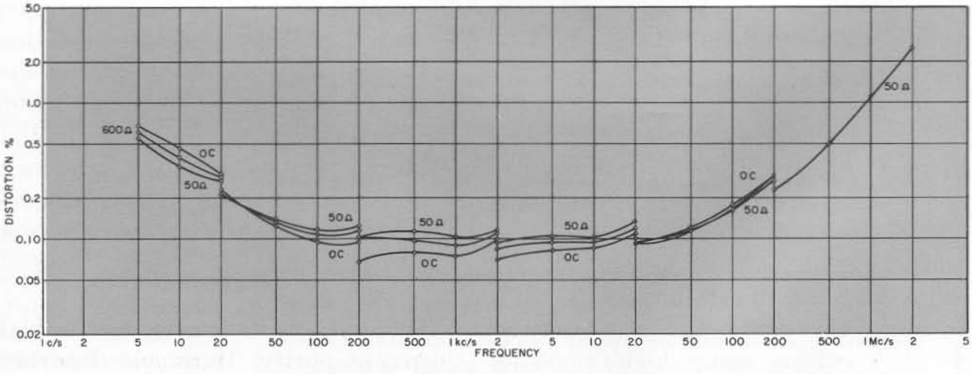
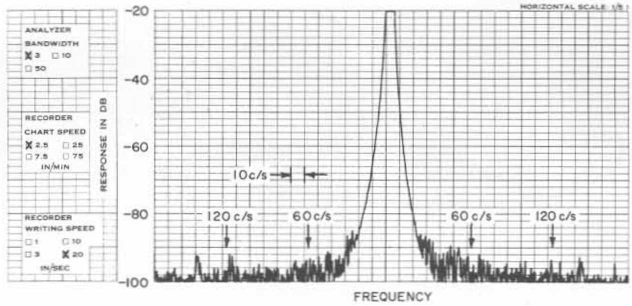


Figure 3. Measured harmonic distortion of a typical Type 1310-A Oscillator for 50-ohm and 600-ohm loads and open circuit. When the attenuator is used for open-circuit output voltages of five volts or less, the load seen by the oscillator is 600 ohms.

Figure 4. Spectrum analysis of 1-kc output. Type 1910-A Analyzer bandwidth is 3 c/s. Note absence of components at the line frequency and multiples.



measurements. Changes in the output within the audio range are imperceptible on the usual analog type of voltmeter.

SYNCHRONIZATION—INPUT

Provision is made for external synchronization, which is believed to be unique with General Radio oscillators. At a single-conductor, shielded telephone jack on the side of the instrument, an external signal can be introduced. Whenever the oscillator frequency is near to the introduced frequency, the oscillator locks in with the signal, and their frequencies will be identical. An input of one volt will keep the oscillator locked for changes of approximately $\pm 3\%$ in frequency of either the signal or the oscillator dial setting. The lock range and capture range are identical and are approximately proportional to the amplitude of the component of the signal to which the oscillator is locked. Sinusoidal inputs of up to ten volts may be used for locking ranges of up to 30 or 40 percent.

For small synchronizing signals, the output characteristics of the oscillator are essentially the same as when the oscillator is operating normally, and the output waveform is independent of the waveform fed in. Larger signals may increase the hum, noise, jitter, or distortion of the output above the specifications, if these components are present in the signal, but, in general, there will be a considerable improvement over the synchronizing signal.

By means of the frequency dial the oscillator output can be adjusted to differ in phase from the synchronizing signal by approximately $\pm 75°$.

One obvious application for the synchronizing capability is for locking one or more oscillators to a frequency standard. Because the oscillator is in essence phase locked to the standard, the long-term stability and accuracy will be identical with the standard. The short-term stability or jitter will be limited to that of the oscillator, which, as shown in Figure 2(a), is typically below 10 parts per million at 1 kc/s for a 0.1 second (100 period)

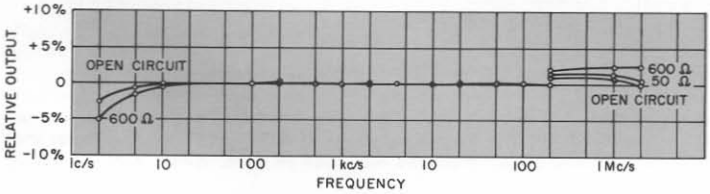


Figure 5. Typical output voltage-vs-frequency characteristics for various load impedances.

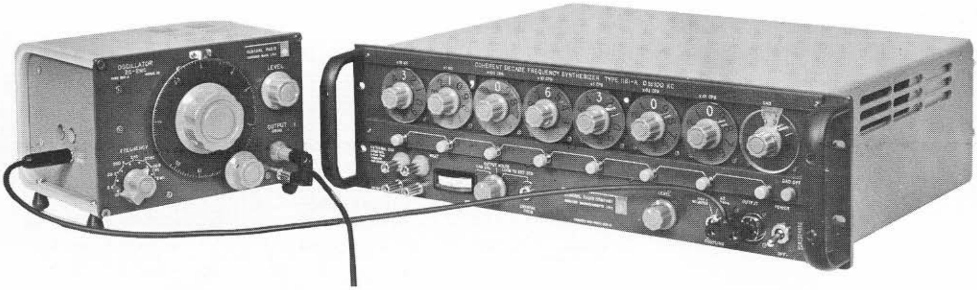


Figure 6. The Type 1310-A Oscillator with a Type 1161-A7C Synthesizer used as an adjustable high-accuracy, high-voltage, low-distortion source for a precision fm-deviation measurement. The output frequency, 31.063 kc/s, when used to modulate an fm generator produces a null in the carrier for a ±75.00-kc frequency deviation.

sampling time. The oscillator has all the characteristics of a narrow-band distribution amplifier: increasing voltage and power output, reducing hum and distortion, and isolating the standard from load changes with the additional advantage of automatic level control.

The oscillator can also be locked to the harmonics of a signal. This allows precise frequency multiplication of most sources since harmonics are usually present or can be easily generated. The accuracy and long-term stability of the submultiple source are maintained in the output, and the waveform is, of course, sinusoidal.

Even if the oscillator is not locked to a high precision standard, the ability to lock onto any signal can be very

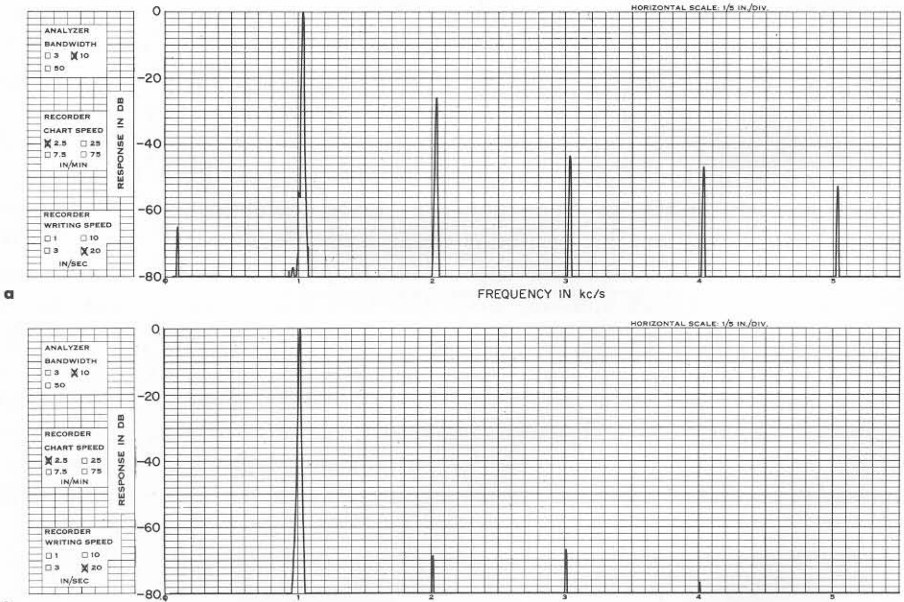
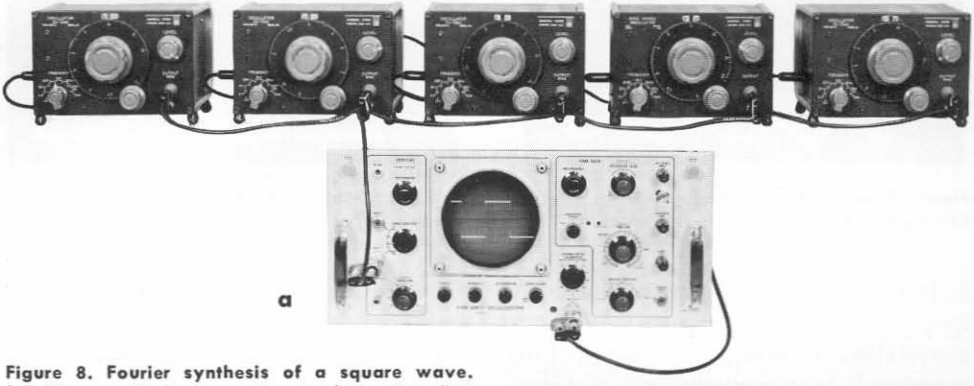


Figure 7. (a) The spectrum of the output of a typical sinusoidal 1-kc standard frequency, derived by division from a crystal frequency standard. (b) The output spectrum of a Type 1310-A Oscillator that has been synchronized to the 1-kc standard of (a). Note the reduction in hum, noise, and distortion.



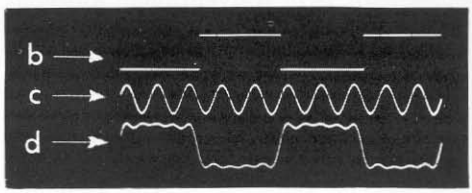


Figure 8. Fourier synthesis of a square wave. (a) Five oscillators synchronized to the first five odd-order harmonics of a square wave. The sinusoidal outputs of the oscillators are adjusted for phase coherence and summed in the ratio of their respective Fourier coefficients to make a Fourier approximation to the original square wave. (b) The original synchronizing square wave. (c) The coherent fifth harmonic. (d) The synthesized square wave.

useful. When measurements are to be made at the fundamental or harmonics of the power-line frequency, it is often desirable to lock the source to the line frequency in order to avoid beats. With the oscillator locked to the line or its harmonics, there will be no beat, and the phase can be adjusted to minimize other effects of pickup.

Although the short-term frequency stability, or jitter, of the synchronized oscillator output will not be less than that of the free-running oscillator, it can be better than that of the synchronizing source. In this respect, also, it behaves like a phase-locked oscillator[2] Or, to express it differently, the synchronized oscillator acts as a tracking narrow-band filter to reduce short-term instability. For example, Figure 9(a) is a plot of the cycle-to-cycle frequency of a jittery 10-cycle source versus time. Figure 9(b) shows the same measurement made on the output of a Type 1310-A Oscillator that has been synchronized to the source. Notice that the cycle-to-cycle change in frequency has been greatly reduced, yet the relatively long-term change of about 1% has been faithfully tracked. The ef-

[2] Harold T. McAleer, "A New Look at the Phase-Locked Oscillator," *Proceedings of the IRE*, Vol 47, pp 1137–1143; June, 1959. (GR Reprint No. A-79).

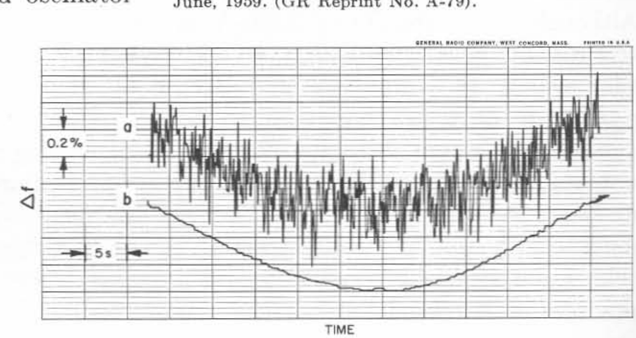


Figure 9. (a) Frequency of output of a drifting 10-cycle jittery source. (b) Output frequency of oscillator synchronized to source of (a). Note reduction in jitter and yet tracking of drift.

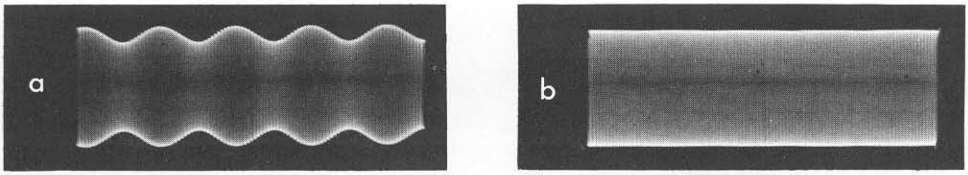


Figure 10. (a) 10-kc output of oscillator, amplitude modulated at 500 c/s by 9.5-kc signal fed into the synchronizing jack. (b) The reduction of the amplitude modulation in the output of an oscillator that has been locked to the a-m signal of (a).

fective bandwidth of the oscillator to frequency perturbation or frequency modulation is related to the locking range as it is in conventional, automatic-phase-controlled oscillators. Since the locking range is proportional to the synchronizing-signal amplitude, the effective bandwidth is also proportional to the amplitude. For example, if a one-volt signal is used to synchronize the oscillator at 100 kc/s giving a $\pm 3\%$ locking range, then the oscillator will have a 3-dB bandwidth of 3 kc/s to perturbations in frequency. Thus, frequency deviations in the 100-kc source at a 3-kc rate will be reduced by 3 dB in the output of the oscillator.

If the oscillator is operated outside the locking range, the signal fed into the synchronizing jack will beat with the oscillator frequency and produce an amplitude-modulated output as shown in Figure 10(a). The modulation will be approximately sinusoidal for modulation levels up to about 10%. Although using the Type 1310-A in this manner does not make it a versatile source of amplitude-modulated signals, it does provide a-m in the audio range where it is not normally obtainable, but nevertheless useful. For example, the modulated output can be used to measure the effects of incidental a-m on other measurements, and it provides a "wobbulated" source for reducing meter friction errors in ac measurements.

The synchronized oscillator can also be used to reduce amplitude modulation (Figure 10(b)). This again is a natural consequence of the oscillator's similarity to a high-Q filter. Any amplitude modulation on the synchronizing signal is reduced to the extent that the modulation sidebands fall outside the pass band of the oscillator.

SYNCHRONIZATION—OUTPUT

The synchronization jack serves as an output as well as an input. Approximately 0.8 volt behind 25 kilohms is available regardless of the setting of the output attenuator or the size of the output load. This output can be used to trigger an oscilloscope when the oscillator amplitude is often varied; frequent readjustment of the triggering level is thus eliminated. Also, a counter can be driven from the jack when a more precise measure of the frequency is desired. One side of this output is grounded, and the signal is 180° out-of-phase with the front-panel output, which makes possible a high-impedance output balanced to ground for driving push-pull circuits. The synchronization output will drive any size load without increasing the oscillator distortion. However, only high-impedance loads are recommended where the full frequency accuracy is required. A short circuit will decrease the frequency by 1 to 2 percent.

Because the synchronizing jack is simultaneously an input and an output, two or more oscillators can be synchronized by interconnection. Oscillators connected in this way will operate at the same frequency or multiples of it and can be adjusted to differ in phase by 180 ±75°.

TECHNICAL DESCRIPTION

The circuit is a capacitance-tuned Wien-bridge oscillator followed by a low-distortion, shortable amplifier and a constant-impedance, bridged-T attenuator. Figure 11 is a simplified diagram of the seven-transistor, one-Nuvistor circuit. A high-gain, wide-band amplifier is used for low distortion and noise and to achieve high input and low output impedances for use with the Wien bridge. This assures that the frequency of oscillation is dependent only upon the passive values of R and C of the bridge. Stable, low-temperature-coefficient, metal-film resistors are used on all but the lowest-frequency range, which uses glass-sealed, carbon resistors.

A negative-temperature-coefficient thermistor is used in the upper half of the negative-feedback divider of the bridge to keep the oscillator amplitude constant, rather than the more conventional positive-TC incandescent lamp in the lower half. This is in large part responsible for the flat frequency characteristic.

Changes in oscillator amplitude with frequency in any Wien-bridge oscillator may be caused by three major factors: (1) unbalance in the values of R for the different frequency ranges; (2) unbalance in C values as the oscillator frequency is varied across one range; and (3) change in the gain, phase and terminal impedances of the amplifier with frequency. These changes all affect the loop gain of the bridge-amplifier combination, and, to maintain stable oscillation, the amplitude-regulating mechanism must change the negative-feedback divider gain so that the over-all loop gain remains at unity. It is inherent in incandescent lamp-regulating circuits that the output level must change if the divider gain changes. This can be seen by reference to the E-I characteristics of Figure 12(a) where the subscripted components, voltages, and current correspond to those of Figure 11. The output voltage is E_3 or $E_1 + E_2$, and the gain of the negative feedback divider (R_1 and R_2) is $\frac{E_2}{E_3}$. It is apparent from Figure 12(a) that, regardless of the

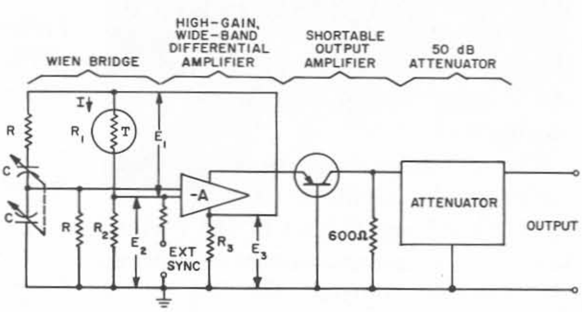


Figure 11. Simplified circuit diagram of Type 1310-A Oscillator.

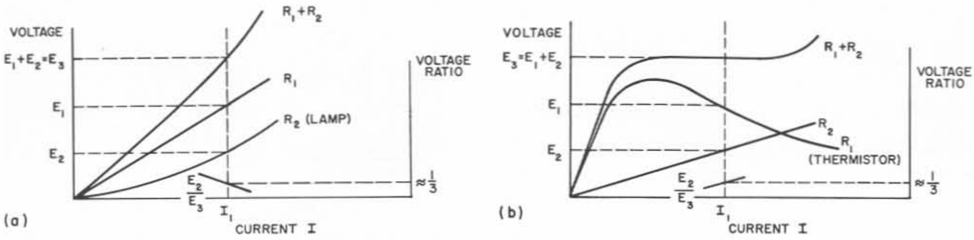


Figure 12. Voltage-current characteristic curves for amplitude-regulating divider of Wien bridge using (a) an incandescent lamp, (b) a thermistor.

actual slopes of the lines involved, for the ratio $\frac{E_2}{E_3}$ to change, the current through the divider must change, and, therefore, the output voltage, E_3, must also change.

Figure 12(b) shows equivalent E-I characteristics where a negative-temperature-coefficient thermistor is used, as in the TYPE 1310-A. In this case, the slope of the thermistor curve in the area of operation near I_1 has been made equal in magnitude to the slope of the R_2 line but opposite in sign. When the two characteristics are added to obtain the E_3 vs I characteristic, the result is approximately a horizontal line. Hence, the output voltage in the normal range of operation is independent of the current and, therefore, independent of the ratio $\frac{E_2}{E_3}$. The ratio $\frac{E_2}{E_3}$ is free to change to keep the loop gain constant at unity, and yet the output voltage, E_3, remains unchanged.

The grounded-base transistor stage following the oscillator translates the constant-voltage output of the oscillator into a constant-current source at the amplifier output, shunted by a 600-ohm internal load. It is the fact that the current is constant and, therefore, limited, which permits low-impedance loads, even a short circuit, to be driven without clipping. The circuit functions as follows: Voltage E_3 is maintained constant by the thermistor regulator, and, since R_3 is much smaller than the resistance of the bridge circuit, the current through R_3 is also maintained constant. This same constant current flows through the emitter and collector of the output transistor since the forward current gain of the transistor is almost unity. The high degree of isolation between emitter and collector of the grounded-base stage prevents changes of the load from being reflected back across R_3. The equivalent circuit of the output with the internal 600-ohm load shunting it is shown in Figure 13(a). Since the h_{ob} of the transistor is small compared with the load conductance, the more familiar equivalent circuit of Figure 13(b) is also correct.

The method used to synchronize the oscillator is commonly called injection

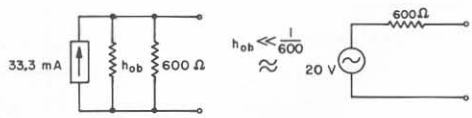


Figure 13. (a) Equivalent circuit of output systems (b) Thévenin equivalent approximation of (a) is conventional voltage source behind 600 ohms.

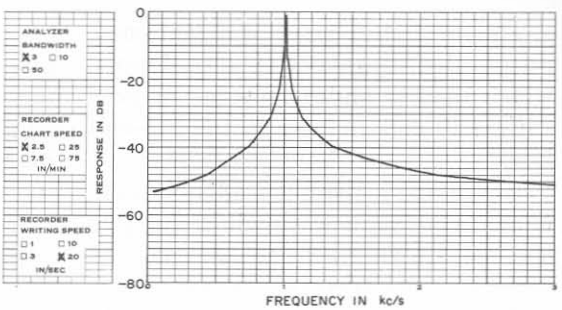


Figure 14. Plot of frequency response between synchronizing jack and oscillator output with dial set to 1 kc/s and with an input of 0.1 volt. Output level is constant at 1 kc/s regardless of the input voltage.

locking. This same mechanism causes some oscillators to beat with the power-line frequency or to lock to it. It is an old phenomenon, perhaps first observed between two pendulum clocks hanging on the same wall, and has been frequently discussed.[3, 4, 5, 6]

The synchronizing signal is injected into the negative-feedback loop. For small signals, the transfer function between this point and the oscillator output is the closed-loop response of the oscillator. This results in a gain near the frequency of oscillation and rejection elsewhere. This rejection reduces the hum, noise, distortion, and both amplitude and frequency modulation in the synchronized output.

Figure 14 is a plot of the forward transfer response between the synchronizing jack and the output for a 0.1-volt input with the oscillator set at 1 kc/s. In the audio-frequency range this curve can be used to estimate the reduction in the output of components in the synchronizing signal. For example, if a one-volt signal that has 10% (0.1 volt) second-harmonic distortion is used to synchronize the oscillator, the second harmonic (2 kc) will be approximately 50 dB below the fundamental in the oscillator output, reducing distortion to 0.3%.

If the oscillator is locked to the same 1-kc signal with an amplitude of only 0.5 volt (0.05-volt second harmonic), then the second harmonic in the output will be 50 dB + 6 dB or 56 dB below the fundamental or only 0.15%. This illustrates the effective decrease in bandwidth as the synchronizing signal decreases. Thus, the smallest signal that will provide stable locking should be used to achieve the greatest rejection of unwanted frequencies.

Figure 15. Rack-mounted Type 1310-A Oscillator and Type 1396-A Tone-Burst Generator used to test amplifier overload characteristics. A behind-the-panel connection to the synchronization jack allows precise readout of frequency on the Type 1150-B Digital Frequency Meter.

[3] W. A. Edson, *Vacuum-Tube Oscillators*, John Wiley & Sons, Inc., New York, Chapter 13; 1953.
[4] P. R. Aigrain and E. M. Williams, "Pseudo-synchronization in Amplitude-Stabilized Oscillators," *Proceedings of the IRE*, Vol 36, pp 800–801; June, 1948.
[5] Robert Adler, "A Study of Locking Phenomena in Oscillators," *Proceedings of the IRE*, Vol 34, pp 351–357; June, 1946.
[6] Marcel J. E. Golay, "Normalized Equations of the Regenerative Oscillator — Noise, Phase Locking and Pulling," *Proceedings of the IEEE*, Vol 52, pp 1311–1330; November, 1964.

The oscillator has a self-contained, ac-operated, regulated power supply, which assures uniform operation even with ±10-volt changes in the 115-volt line.

In summary, the TYPE 1310-A Oscillator, by using new circuit techniques and modern transistorized design, provides a wide-range, high-output, general-purpose instrument useful in the many applications that require oscillators in electronics today. Its small size, light weight, and rugged construction make it a convenient source of ac signals, and its low distortion, noise, and hum, its flat-frequency characteristic, and its good frequency stability give outstanding performance.

In addition, owing to its unique synchronizing feature, this oscillator can often perform many of the functions of other laboratory instruments. It can serve as:

A tracking, narrow-band filter to reduce hum, noise, and distortion in a signal.

A source of amplitude-modulated signals.

An automatic-phase-controlled oscillator to reduce frequency modulation or jitter.

A single-frequency, leveling amplifier.

A phase-locked, sinusoidal-frequency multiplier.

A phase shifter.

A narrow-band, isolation amplifier.

— R. E. OWEN

Credits

The author gratefully acknowledges the contribution of R. G. Fulks who initiated the development.

SPECIFICATIONS

FREQUENCY

Range: 2 c/s to 2 Mc/s in 6 decade ranges; continuously adjustable, one-turn, high-resolution dial with 4¼:1 drive.
Accuracy: ±2% of reading.
Stability: Typical warmup drift, under 0.1%; typical drift after warmup, 0.001% short term (1 min), 0.03% long term (12 h); all at 1 kc/s.
Synchronization: Telephone jack provided for external phase-locking signal. Locking range is about ±3% for 1-V, rms, input reference signal. Frequency dial can be used for phase adjustment.

OUTPUT

Power: 160 mW into 600 Ω.
Voltage: Over 20 V, open circuit; continuously adjustable attenuator (approximately 50 dB).
Amplitude Stability: Typical drift after warmup, 0.02% short term (1 min), 1.0% long term (12 h); both at 1 kc/s.
Frequency Characteristic: ±2%, 20 c/s to 200 kc/s, open circuit or 600-Ω resistive load. (See Figure 5).
Impedance: Approximately 600 Ω.
Distortion: <0.25%, 50 c/s to 50 kc/s, with linear loads. **Hum:** <0.02% independent of attenuator setting.
Synchronization: High-impedance, constant-amplitude, 0.8-V, rms, output for use with oscilloscope, counter, or other oscillators.

GENERAL

Power Required: 105 to 125, 195 to 235, or 210 to 250 V, 50 to 400 c/s, 12 W.
Terminals: Two Type 938 Binding Posts, one grounded to panel.
Accessories Supplied: Type CAP-22 Power Cord, spare fuses.
Accessories Available: Type 1560-P95 Adaptor Cable (telephone plug to Type 274-M Double Plug) for connection to synchronizing jack.
Mounting: Convertible-bench cabinet.
Dimensions: Width 8¼, height 6, depth 8⅛ inches (210 by 155 by 210 mm), over-all.
Net Weight: 7¾ lb (3.6 kg).
Shipping Weight: 10 lb (4.6 kg).

Catalog Number	*Description*	*Price in USA*
1310-9701	**Type 1310-A Oscillator**	**$295.00**
1560-9695	**Type 1560-P95 Adaptor Cable**	**3.00**

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