



## A New Generator of Frequencies Down to 0.01 CPS

**I**N contrast to ever-widening uses of higher and higher frequencies, much work goes on in that portion of the spectrum lying below the audio range. Medical, geological, servo, and vibration studies are all concerned with sub-audio frequencies. Servo applications in particular involve unusually low frequencies—often lying well below 1 cps.

The new -hp- Model 202A Low Frequency Function Generator has been designed to provide test voltages for such low-frequency work. The instrument generates frequencies from 1000 cps down to 0.01 cps. This range is covered in five decade bands, each of which has an effective range of approximately 13:1 to provide suitable overlap between bands.

The instrument generates three types of waveforms that are useful in low-frequency work: sinusoidal, square, and triangular. The particular waveform desired is selected

by a panel switch. Also provided is a synchronizing pulse for triggering external equipment.

Output voltage from the instrument has been made ample for general-purpose work. For all three waveforms, a maximum of at least 30 volts peak-to-peak is provided. The synchronizing pulse is of 5 volts peak amplitude and occurs at a time corresponding to the crest of the sinusoidal output.

The output waveforms are provided from a system that can be operated either balanced or single-ended. The internal impedance of the output system has been made low—less than 100 ohms—although rated load for the system is 5000 ohms. The output amplifier is a stable d-c system having negligible drift; tests have shown the d-c component in the output to remain less than 0.1 volt over long intervals. However, an adjustment is available from the front panel to balance out this component if desired.

A number of interesting new ideas are represented in the circuitry of the Model 202A. To achieve a circuit capable of generating such low frequencies as 1 cycle per 100 seconds, a considerable departure has been made from established oscillator designs. However, the performance of the Model 202A is in all respects comparable to that of established laboratory-type audio oscillators. For example, transients of the type that frequently arise when chang-

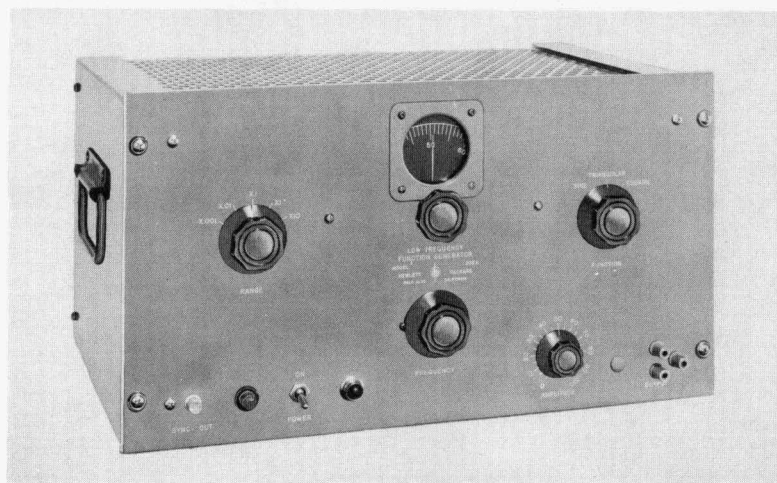


Figure 1. New -hp- Model 202A Low Frequency Function Generator produces frequencies as low as 1 cycle per 100 seconds. Sine, square, and triangular wave outputs are provided.

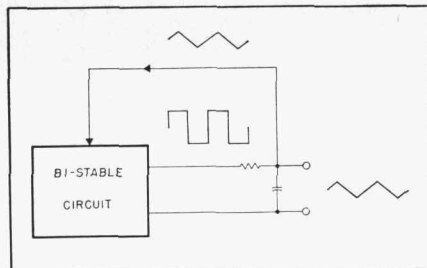


Figure 2. Bi-stable circuit and integrator arranged to generate triangular waveform.

ing frequency in 1-f circuits are virtually non-existent. RMS distortion in the sinusoidal output is less than 1%, variation of output frequency with line voltage changes and warm-up is less than 1%, and dial calibration is accurate within 2%.

#### UNDERLYING CONSIDERATIONS

Formerly, low frequency generators have often made use of conventional multivibrator or phase shift techniques. While such techniques were useful to a point, they were not satisfactory for extremely low frequency applications. In some cases instability and drift were too large for many applications and very high values of circuit components were required. In other cases the need for amplitude control led to the use of avc circuits having long time-constants with resultant undesirable transients in the generated voltage. A real need existed for a circuit capable of stable operation in the range lying below about one cycle per second.

Before describing the circuitry of the Model 202A, it may be of interest to describe some of the fundamental considerations underlying the development of the generator circuit:

Among the possible methods of producing a sine wave is the method of synthesis. One possible synthesis<sup>1</sup> of a sine wave assumes the availability of a square wave. If a square wave is applied to an integrator, a triangular waveform is obtained. Now, a

<sup>1</sup>This basic generator circuitry is due to Dr. O. J. M. Smith of the University of California, Berkeley.

triangular waveform can be distorted into an approximation of a sine wave by use of non-linear elements. For example, if a generator of triangular waveforms is suitably loaded with a non-linear resistance whose value decreases as the instantaneous triangular voltage increases, an approximation of a sine wave can be obtained.

Such a synthesis is made practical in part by the use of the circuit of Figure 2. The generating system consists of a controlled bi-stable circuit and an integrating circuit. The bi-stable circuit drives the integrator with a square wave, while the triangular output of the integrator is coupled back to and triggers the bi-stable circuit. This arrangement gives a self-sustaining circuit that can be considered to be a very stable relaxation oscillator.

It is important that the triangular waveform generated at the integrator output have uniform characteristics at all fundamental frequencies generated by the instrument. This is accomplished by choosing the constants of the integrator so that an essentially pure triangular waveform is obtained. Specifically, the RC product of the integrator circuit is made more than 50 times the half-

period of the lowest-frequency square wave generated. Under this condition, the sides of the triangular voltage are always linear within 1%, assuring an essentially pure triangular waveform at all times.

The bi-stable circuit that generates the square wave is a combination of a flip-flop and two amplitude-comparators, designed so that the flip-flop will be triggered accurately even for signal voltages that have low slope. This basic circuit is shown in Figure 3. The flip-flop configuration is apparent, while the grid of each tube is also coupled to its cathode through a diode and transformer. Normally, neither of these diodes is conducting; the voltage at which each diode does conduct is determined by pre-set bias or reference voltages.

To describe the operation of the circuit, assume that V2 is conducting because of suitable grid bias obtained from the voltage divider. When V2 is conducting, its plate current flows through the upper part of the voltage divider at the right, causing V3 to be cut off. Now, as a positive-going voltage of the triangular waveform from the integrator becomes equal to the bias (upper reference voltage) on diode

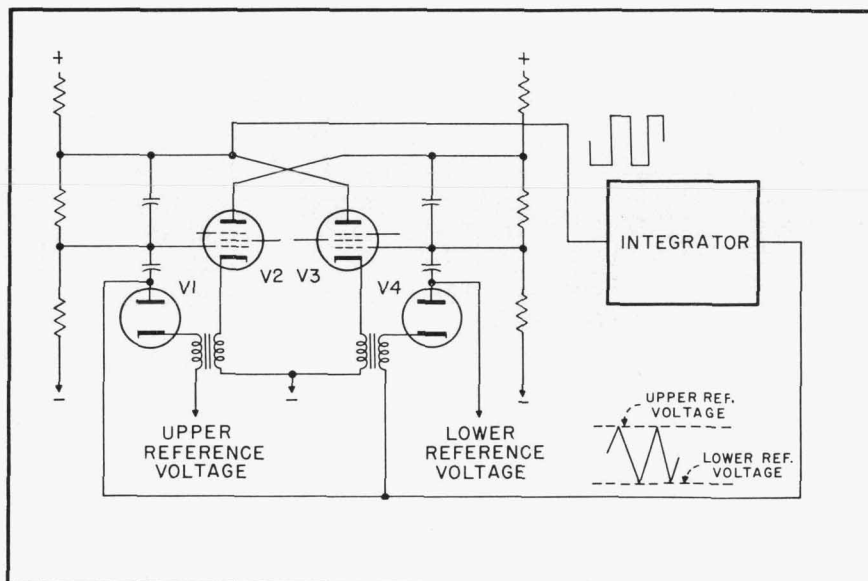


Figure 3. Basic bi-stable circuit used in generator.

V1, V1 will conduct, thus coupling the grid of V2 to its cathode. When this occurs, oscillations quickly build up in V2, resulting in a large pulse voltage at the plate of V2. This pulse raises the grid of V3 above cut-off. V3 then conducts, producing a steep negative voltage front at the plate of V3. This negative voltage front is applied to the grid of V2, driving it below cut-off. The circuit is now stable until a negative-going voltage of the triangular waveform causes diode V4 to conduct. The reverse of the above action then occurs and the circuit reverts to its other stable condition.

The upper and lower reference voltages serve as amplitude controls that limit the excursions or peaks of the triangular waveform out of the integrator. Hence, the constants of the integrator can remain fixed for any one frequency band and the amplitude of the triangular waveform will always be constant. The amplitude control action is further aided by the use of the amplitude-comparators. In contrast to triggering methods that use a low slope trigger voltage directly, the amplitude-comparators generate a "whiplash" voltage that triggers the flip-flop.

#### INTEGRATOR

The integrator must give a linear voltage rise at its output over a period equal to one-half cycle of the square wave. Thus, the integrator time constant  $RC$  must be much larger than 50 seconds if a frequency of 1 cycle per 100 seconds is to be obtained. To obtain such a large time constant with highest practical values of  $R$ ,  $C$  would normally be in the order of 100 microfarads—an impractical value for a precision capacitor.

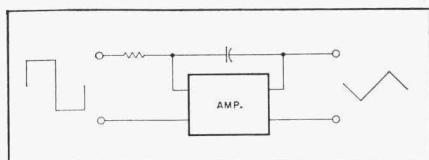


Figure 4. Simple integrator converted into amplified time constant integrator.

The electrical values of the components required in the integrator have been greatly reduced by converting the simple  $RC$  integrator into a Miller integrator where a high-gain amplifier is connected across the integrating capacitor (Figure 4). This amplifier reduces the value of the required time constant by a factor equal to the gain of the amplifier. In addition, the amplifier increases the voltage out of the integrator by the same factor. Thus, the slope of the voltage out of the integrator is still  $E/RC$  as with a simple integrator, but the linear range of the integrator is greatly increased.

#### FREQUENCY CONTROL

The slope  $E/RC$  of the voltage out of the integrator is obviously dependent upon the amplitude of the input square wave. This characteristic offers a means of controlling the frequency of the generator, because the time required for the triangular voltage-front to build up to a value that can trigger the bi-stable circuit is thus dependent upon the amplitude of the square wave applied to the integrator. Consequently, the frequency control for the instrument consists of a means of varying the amplitude of the integrator input. In production equipment, this control is a wire-wound potentiometer of high quality and high resolution. Band changes are accomplished by means of a switch that changes the capacity in the  $RC$  integrating network.

From the standpoint of accuracy, the frequency control system is good. Warm-up drift is less than 1%, while the dial calibration is accurate within 2%.

Since the output frequency is dependent upon the amplitude of the square wave applied to the integrator, the circuit would normally be susceptible to frequency drifts caused by tube aging and supply voltage changes. These drifts are avoided by clamping the square wave at its positive and negative extremes

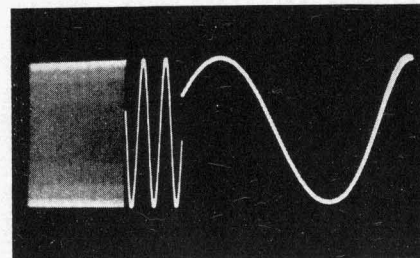


Figure 5. Oscillogram of output waveform as output frequency changed twice. Freedom from transients is apparent.

and by relating the reference voltages for the amplitude comparators to the same voltages used in the clamping. Thus, a change in clamping voltage will modify the amplitude of the square wave, but the reference voltages for the amplitude-comparators will also be modified by the same percentage. This arrangement reduces supply voltage and tube aging effects to the point where no discernable change in frequency occurs over reasonable limits.

An interesting side light on the operation of the generator circuit as a whole is that it has practically no transient responses of the type that are common when changing frequency in 1-f circuits. Usually, these transients arise from the use of a long time-constant avc system where a generator must operate for a number of cycles to provide the avc system with the proper correction voltages. These transients can be especially annoying at the low frequencies of the Model 202A. For example, if a generator must operate for 3 cycles to provide an avc system with a correction voltage, transients can exist for 3 cycles or up to 5 minutes each time frequency is changed. In the Model 202A, a change in frequency merely changes the amplitude of the square wave that drives the integrator. This change is at once reflected in a change in slope at the output of the integrator without introduction of transients. An oscillogram in Figure 5 shows the output sine wave as two changes in frequency were made, and the freedom from transients is apparent.



## SHAPING THE WAVE

As stated earlier, a generator of triangular waveforms, when loaded with a non-linear resistance, can be made to produce a wave that is a close approximation of a sine wave. Such an arrangement is used in the Model 202A to shape the triangular waveform out of the integrator.

The basic shaping circuit is shown in Figure 6. If a triangular voltage is applied to the circuit of Figure 6 and if the bias voltages on the voltage divider at the left are suitably adjusted, the various diodes will conduct during different portions of a cycle. For example, as the triangular voltage-front rises above the axis, none of the diodes will conduct until the voltage at the output terminal overcomes the bias on V3, at which time V3 will conduct. The additional current flowing through R1 as a result of V3's conducting will alter the slope of the voltage appearing at the output terminals. As the input voltage increases more, it will cause diode V4 to conduct, again altering the slope of the output voltage.

On the negative-slope portion of the input voltage, diodes V4 and V3 will successively cease conducting. As the voltage passes below the axis, diodes V2 and V1 will conduct. All of these operations will alter the slope of the output voltage as indicated in the figure.

The practical shaping circuit used in the instrument has six duo-diodes that modify the triangular waveform. The resulting waveform, con-

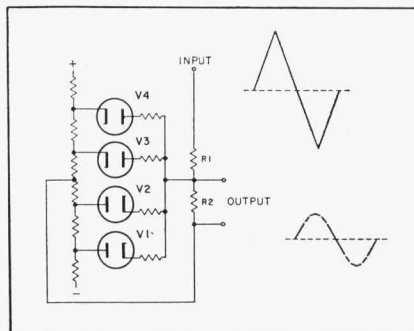


Figure 6. Basic circuit for shaping triangular waveform into sine wave.

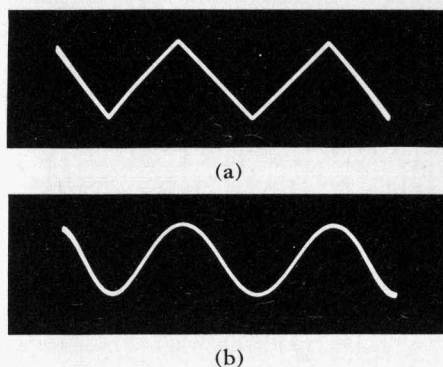


Figure 7. Oscillograms of (a) triangular waveform applied to shaping circuit, and (b) resulting sine wave.

sisting of 26 linear segments, is a surprisingly close approximation of a sinusoid and has less than 1% distortion. In laboratory set-ups, the distortion has been adjusted to be less than 0.2%. Oscillograms of the triangular waveform and resulting sine wave are shown in Figure 7.

## OUTPUT AMPLIFIER

The output amplifier is a balanced type d-c amplifier stabilized with feedback. The output stage is a push-pull arrangement that can be operated either single-ended or balanced-to-ground. In order to accomplish this feature, the complete circuitry behind the output system is operated in a floating condition. The output system itself can be operated either floating or grounded, as desired.

The output amplifier is also provided with a suitable switching arrangement so that square and triangular waveforms, as well as the sinusoidal waveform, can be obtained at the output terminals. The sinusoidal waveform is obtained from the shaping circuits as described, while the square and triangular waveforms are obtained from the bi-stable and integrator circuits respectively.

## GENERAL

The frequency calibration for the instrument is on a large 6-inch diameter dial, calibrated from approximately "0.8" to "10.4". Approximately 95 calibrated points are pro-

vided, all five ranges using the same calibrations with a suitable multiplier selected by the range switch. The dial drive system includes two knobs, one of which is a direct drive and the other a 6:1 vernier.

The main output terminals are conventional  $\frac{3}{4}$ -inch spaced binding posts. The Sync Out pulse, useful for triggering l-f sweeps, is provided at similar terminals.

The Model 202A is supplied in a rack-mounting style case. However, end frames are available to modify the rack-mounting style for bench use, although these frames are not essential for bench work. The end frames are provided with rubber mounting feet and with large trunk handles to facilitate carrying.

—R. H. Brunner

## SPECIFICATIONS MODEL 202A

### Low Frequency Function Generator

**FREQUENCY RANGE:** 0.01 to 1,000 cps in five decade ranges with suitable overlap at each dial extreme.

**DIAL ACCURACY:** Within 2%.

**FREQUENCY STABILITY:** Within 1% including warm-up drift.

**OUTPUT WAVEFORMS:** Sinusoidal, square, and triangular. Selected by panel switch.

**MAXIMUM OUTPUT VOLTAGE:** At least 30 volts peak-to-peak across rated load for all three waveforms.

**DISTORTION:** Less than 1% rms distortion in sine wave output.

**OUTPUT SYSTEM:** Can be operated either balanced or single-ended. Output system is direct-coupled; d-c level of output voltage remains less than 0.1 volt over long periods of time. Adjustment available from front panel balances out any d-c.

**FREQUENCY RESPONSE:** Constant within 1 db.

**HUM LEVEL:** Less than 0.1% of maximum output.

**SYNC PULSE:** 5 volts peak, less than 10 microseconds duration. Sync pulse occurs at crest of sine wave output and at corresponding position with other waveshapes.

**POWER:** Operates from nominal 115-volt, 50/60 cycle source. Requires 175 watts.

**CABLES SUPPLIED:** 7 1/2 foot power cable permanently attached.

**DIMENSIONS:** 10 1/2" high, 19" wide, 13" deep.

**MOUNTING:** Relay rack style; end frames are available to convert to table mounting but are not essential.

**WEIGHT:** 35 lbs.; shipping weight, approx. 75 lbs.

**PRICE:** \$450.00 f.o.b. Palo Alto, California. End frames \$5.00 per pair f.o.b. Palo Alto, California (Specify No. 17).

Data subject to change without notice.