# Subaudio Sawtooth Generator

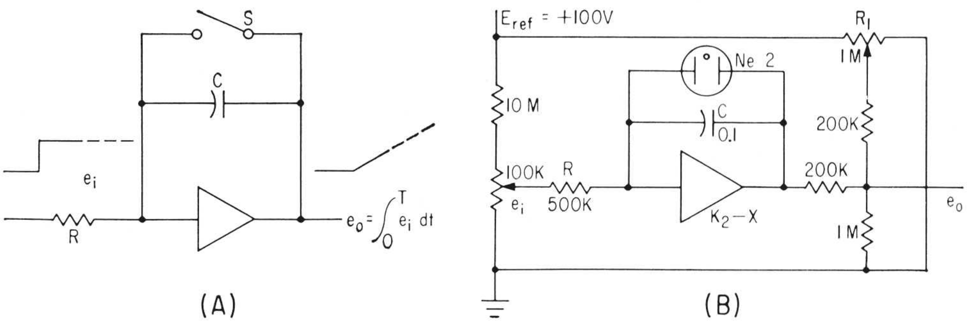


*FIG. 1—Integrator uses mechanical switch to reset circuit to zero (A). In more elaborate versions a neon tube does the resetting (B), while a resistance network enables the output to vary around the level set by $R_1$*

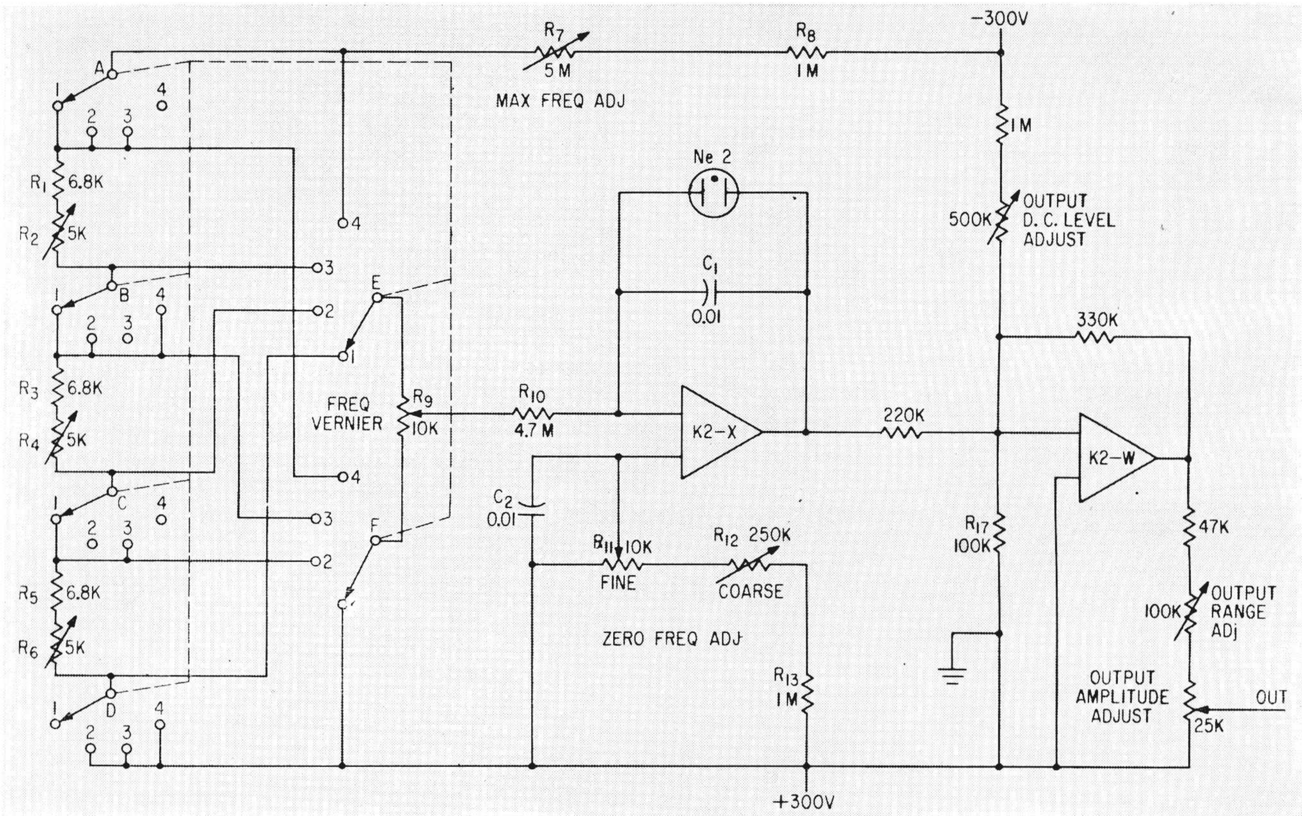


*FIG. 2—Ganged switch covers the operating range from about 0.2 cps to 18 cps; output sweep is about 5 volts amplitude*

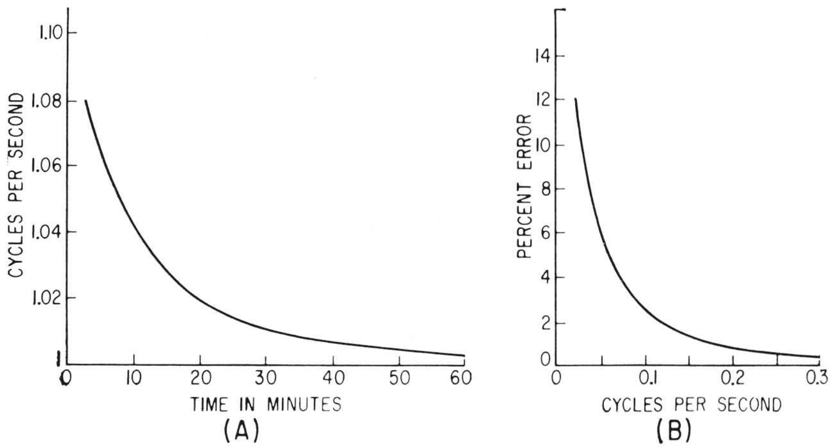


*FIG. 3—Frequency drift is equivalent to ± 20 ms an hour after one hour's warmup (A), while frequency variation at low frequency levels is probably due to jitter in the neon firing*

# Gives One-Percent Linearity

*Instrument was designed to provide low-frequency sweeps of high linearity to complement conventional generators having maximum accuracy at faster sweeps. Maximum frequency is about 18 cps and the output sweep has about 5 volts amplitude*

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THE INTERNALLY GENERATED sawtooth waveform of an ordinary oscilloscope generally deteriorates at low frequencies. Sometimes it is desirable to generate an external sawtooth of known linearity; this article describes such a sawtooth generator having a deviation from linearity of less than 1 percent at frequencies as low as 0.2 cps. It has been used for driving an accurate display of heart pulses, for driving a photoformer function generator, and as a sweep voltage source for feeding an arbitrary-function generator during adjustment of its function.

A high-gain operational amplifier can be arranged to yield a mathematical integral, Fig. 1A. If a constant voltage, $e_i$, is applied to this integrating circuit, then at $t = 0$, $e_o = 0$; and at $t = T$

$$e_o = \frac{1}{RC}\int_0^T e_i\,dt.$$

As $t$ varies from $t = 0$ to $t = T$, $e_o$ describes a ramp function whose slope is a constant determined by the choice of $C$, $R$ and $e_i$. If $C$ and $R$ are fixed, then the slope is controlled by $e_i$.

Now if the switch, $S$, is closed some time after $t = 0$ and before the amplifier saturates, $C$ is discharged, $e_o$ is returned to zero, and the result is a single finite ramp function possessing a high degree of linearity. Further, if $S$ is selected to be an automatic, repetitive action switch operated by $e_o$, then the desired free-running sawtooth oscillator is obtained.

The circuit of Fig. 1B uses an operational amplifier in the integrating circuit and a neon bulb as the automatic switch. When $e_o$ reaches approximately 70 volts, the neon conducts and discharges $C$ until $e_o$ drops to about 60 volts, at which time the neon again becomes a high impedance. Since the firing of the neon depends on $e_o$, and since the slope of $e_o$ is a function of $e_i$, then the frequency is controlled by $e_i$ (for fixed $R$ and $C$). The amplitude of the sawtooth is relatively constant, being the difference between the conducting voltage and the extinction voltage of the neon.

Since a low-frequency sawtooth oscillator operating between the voltage levels of approximately 60 volts and 70 volts is inconvenient, the output is biased by the one-megohm variable resistor $R_1$ so that either end of the sawtooth may be chosen to start from zero. If a function of opposite slope is required, $E_{ref}$ should be reversed in polarity.

Figure 2 circuit is more flexible than Fig. 1B and, with the given circuit values, its maximum frequency and maximum output voltage are about 18 cps and 5 volts respectively.

The alignment of this circuit is accomplished in three steps:

(1) Set the ranges to continuity of frequency selection by adjusting $R_1 + R_2 = R_3 + R_4 = R_5 + R_6 = R_9$.

(2) With the switch in position 1 and $R_9$ set to zero resistance, set zero cps by adjusting $R_{11}$ and $R_{12}$ until the output voltage is approximately halfway between the extreme voltages of the sawtooth ramp and does not drift.

(3) With the switch in position 4 and $R_9$ set at maximum resistance, adjust $R_7$ for maximum frequency desired. If this frequency is 4 cps, then the frequency vernier will cover exactly one cycle per second in each of the switch positions. For example, in position 2 the vernier will yield frequencies ranging from one cps to 2 cps; in position 3, frequencies from 2 to 3 cps.

Figure 3A shows the initial frequency drift as a function of warmup time. After one hour the drift is equivalent to ± 20 ms per hr, and after 24 hours the drift is equivalent to ± 5 ms per hr.

For frequencies above one cps the linearity error is negligible. As zero frequency is approached, however, the error increases as shown by Fig. 3B. Note that the error is still only one percent at 0.2 cps. This linearity error appears primarily at the tail end of the ramp function and seems to be caused by leakage currents delaying the achievement of the neon firing voltage. Linearity can be increased considerably by using high quality $C_1$ and $R_{10}$, and also by cleaning the base of the neon lamp and by shielding it from light.

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