SAW-TOOTH TESTING OF AUDIO AMPLIFIERS

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In many ways, a saw-tooth waveform is superior to either sine- or square-wave testing of audio amplifiers. A discussion of these advantages and the circuit for a saw-tooth generator are covered.

THE saw-tooth waveform, one of the most widely used analog waveshapes, can be effectively employed as a test signal for video or audio amplifiers. Using the saw-tooth waveshape for these test purposes provides many features which, if used in the proper manner, offer several advantages in contrast with the square-wave or sine-wave methods of testing amplifier response.

There are certain basic criteria that determine an amplifier's response and these have to be checked out in order to assure proper amplifier performance. They include frequency response, saturation points, treble or bass response, over-all distortion, transient response, and power gain without distortion.

These parameters can be readily determined by sine-wave testing. However, this technique presents certain disadvantages in that the frequency of the test oscillator has to be continuously adjusted to cover the frequencies of interest. Another disadvantage is that the test oscillator must be capable of furnishing a constant-level output voltage over this frequency band to assure that the proper 1-dB or 3-dB points are noted.

To eliminate some of the difficulty associated with sine-wave tests, square-wave testing techniques are often used. A square wave makes use of the fact that a complex wave, such as a square wave or a saw-tooth, can be represented as a combination of different frequency sine waves, which when added together produce the square or saw-tooth waveform. This concept is called the Fourier analysis of a waveshape. However, suffice it to say that such complex waves can be represented by a plurality of harmonically related sine waves of various amplitudes. Hence, to properly amplify the complex wave, the amplifier must be capable of passing a sufficient number of these harmonic components without distortion.

The saw-tooth is preferable to the square wave in that the saw-tooth contains *all* harmonics rather than just the odd ones and the amplitudes of these frequencies are related according to $1/n$ where n is the nth harmonic of the fundamental frequency. Therefore, to properly recreate a 1-kHz saw-tooth, the amplifier must have a bandwidth of at least 10 kHz because the saw-tooth requires the harmonics at 2, 3, 4, 5, 6, 7, 8, 9, and 10 kHz. The amplitude of the 10th harmonic is approximately 10% of the fundamental's amplitude. Therefore, if the amplifier properly amplifies 90% of the over-all energy, an undistorted saw-tooth will be present at the amplifier output. In contrast, if a square wave is used, the amplitudes of the harmonics also varies as $1/n$, but there is only energy at the odd harmonics, such as the ninth, eleventh, etc. Hence the amplifier response does not have to be as wide to amplify an undistorted square wave.

Assume that a relatively undistorted saw-tooth (Fig. 1A) is to be used in conjunction with the proper amplifier load and an oscilloscope (preferably one that responds down to d.c.) to test the response of an amplifier. If the amplifier has a poor high-frequency response, it will not pass all the high-

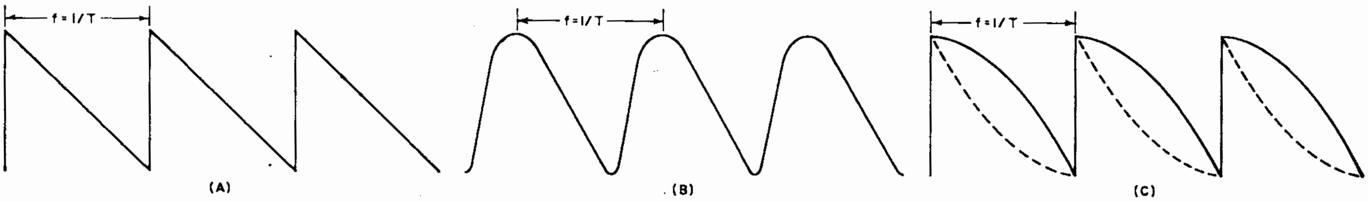


Fig. 1. (A) Ideal linear saw-tooth where the frequency is the reciprocal of time. (B) Lo
low-frequency response can result in a bowing out of the saw-tooth, while a loss in

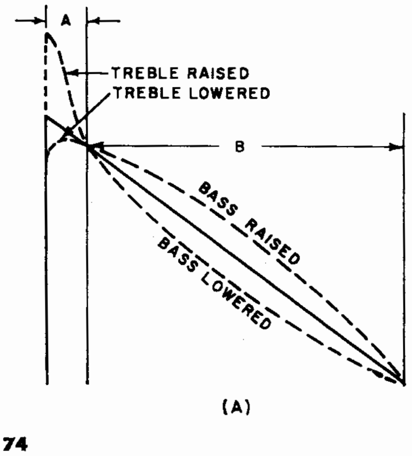
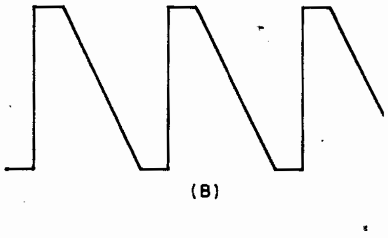


Fig. 2. (A) Effects of va
controls. Crossover point
saw-tooth due to amplifi
a saw-tooth. (C) Ringin



Total battery current drain: 2.5 mA at all frequencies				
Transistor voltage readings to ground using a v.t.v.m.:	*Q1*	*Q2*	*Q3*	*Q4*
emitter	+3.9	+6.8	+0.64	+6.6
base	+4.2	+5.2	+0.78	+6.8
collector	+6.8	+9	+5.2	+9
Nominal output impedance: 2000 ohms				
	1 kHz	*10 kHz*	*20 kHz*	
Freq. vernier (R2) control range:	.2 to 1.56	1.82 to 12.5	4 to 25	
Maximum output level:	5 mV to 3 V	8 mV to 3.8 V	8 mV to 4.4 V	

Table 1. Test specifications for the saw-tooth oscillator.

frequency energy-contributing harmonics and the saw-tooth will appear at the amplifier output as shown in Fig. 1B. This waveshape is beginning to take on a sinusoidal appearance, and the straight, clean lines of the saw-tooth fast rise time are gone, indicating that the high-frequency response of the amplifier is limited. Of course, the amplifier might be one designed for a 100-kHz bandwidth and hence the 1-kHz saw-tooth would pass through undisturbed. If this is the case, then a 10-kHz saw-tooth may be used, or even a higher frequency saw-tooth, depending on the bandwidth dictated by the manufacturer.

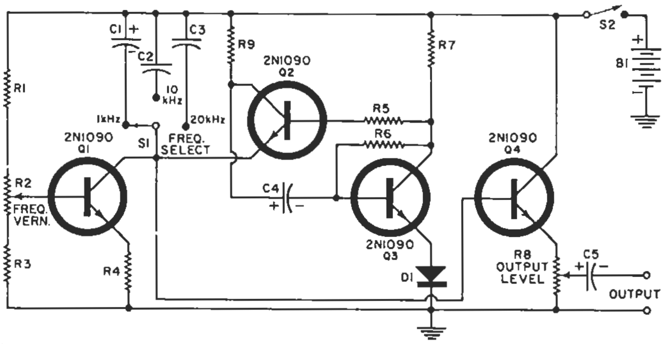
If the low-frequency response of the amplifier is poor, the saw-tooth may take on the appearance of the waveform shown in Fig. 1C. Proper setting of the amplifier bass and treble controls should cause reproduction of the saw-tooth depicted in Fig. 1A.

The bass-control setting of an amplifier usually affects the gain in the region from 500 to 1000 Hz, while the treble control usually affects the gain from 1000 Hz and above. These are merely representative ranges and in any given amplifier they may overlap. Fig. 2A shows a saw-tooth and the composite effects of varying the bass and treble controls. The solid line represents the ideal saw-tooth. The portion of the saw-tooth denoted as the "A" region is that affected by the treble control. The portion of the saw-tooth in the "B" region is that affected by the bass control.

If the treble control is raised, the amplified saw-tooth overshoots during the saw-tooth's fast transition. This overshoot is shown in Fig. 2A as the dashed line labeled "treble raised." If the treble is lowered, the clean, sharp top of the saw-tooth will not be properly amplified and will appear rounded as shown. If the bass control is raised, the saw-tooth "bows" out as shown in section "B" and becomes concave for a lowering of the bass response. Hence, to obtain a properly amplified saw-tooth, both the bass and treble controls must be adjusted until the amplifier reproduces the clean saw-tooth shown in Fig. 1A. When such a saw-tooth waveform is obtained, the control settings at this point are called the "flat settings" of bass and treble.

The utility of the saw-tooth for testing is obvious, as a 1-kHz saw-tooth will check bass down to 100 Hz and treble to 10 kHz. It is a simple matter to check overload of an amplifier with a saw-tooth as the extremities flatten when the amplifier is driven from cut-off to saturation as shown in Fig. 2B. To drive an amplifier to saturation with a square wave accomplishes very little, however, as the top and bottom of the square wave are already flattened. A saw-tooth of a certain peak-to-peak rating has an equivalent sine-wave rating. For example, a saw-tooth of 20 volts peak-to-peak would represent a sine wave of 7.07 volts r.m.s. If a peak-to-peak saw-tooth of 20 volts is the largest amplitude the amplifier passes without clipping as shown in Fig. 2B, the equivalent sine wave is then 7.07 volts r.m.s. and the power output capability of the amplifier would be $(7.07^2/R)$ where R is the terminating or load resistor.

Maximum power rating can be approximated by noting the peak-to-peak value of the undistorted output of the amplifier, using a calibrated scope or peak-to-peak voltmeter; dividing this value by 2.83 to obtain the equivalent r.m.s. sine-wave value; and calling it E. The power capability of the amplifier is then given by E^2/R where R is the terminating or load resistor.



R1—56,000 ohm, ¼ W res. ±5%
R2—100,000 ohm pot
R3,R4,R5—10,000 ohm, ¼ W res. ±5%
R6—200,000 ohm, ¼ W res. ±5%
R7—2700 ohm, ¼ W res. ±5%
R8—10,000 ohm pot
R9—150 ohm, ¼ W res. ±5%
C1—0.1 μF, 35 V tantalum capacitor
C2—0.01 μF, 150 V mica capacitor
C3—4700 pF, 150 V mica capacitor
C4—1 μF, 35 V tantalum capacitor
C5—100 μF, 35 V tantalum capacitor
D1—1N91
S1—S.p. 3-pos. switch
S2—S.p.s.t. switch
B1—9 V battery
Q1,Q2,Q3,Q4—2N1090

Fig. 3. Schematic and parts list for the saw-tooth generator.

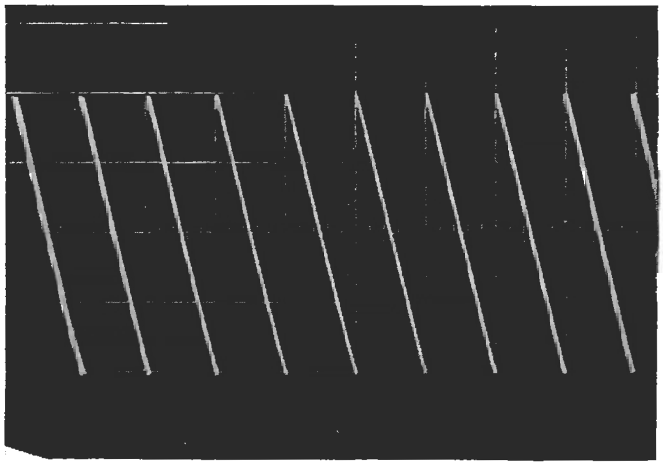
The saw-tooth also possesses a steep leading edge which may cause unstable amplifiers to "ring" when they are trying to amplify this rapid wavefront. This phenomenon is due to poor transient response of the amplifier caused by instabilities in design. Fig. 2C shows a typical response due to ringing. Usually the manufacturer has taken care of ringing by appropriate bypass networks in the feedback path. Such instabilities are cured by connecting relatively small capacitances to ground at various signal points within the amplifier.

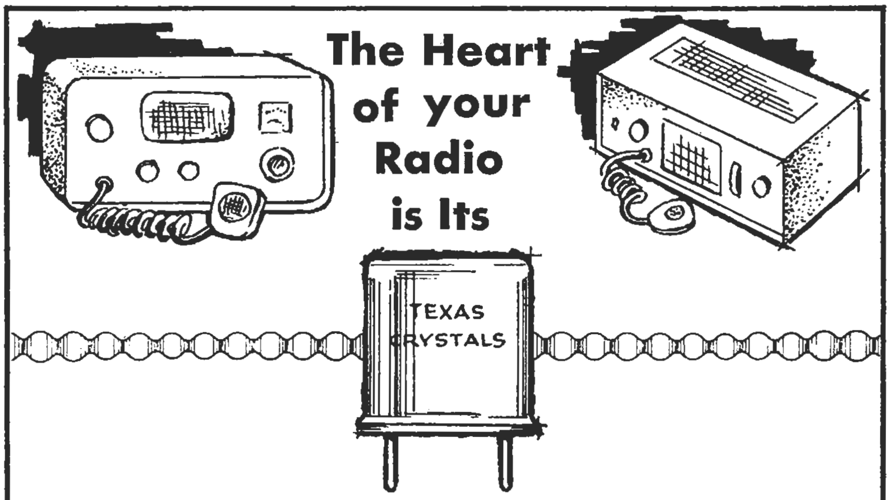
An amplifier might have more gain at some harmonic other than the fundamental; therefore, its frequency *vs* amplitude response curve would have peaks and valleys and would not be the typical flat response of a good amplifier. If the response is poor, the bass and treble controls may be used to compensate to a clean saw-tooth. The amplifier may generate harmonics due to non-linearity of the transistor or tube characteristics, and such distortion may not be easily remedied.

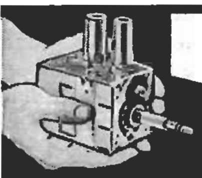
Saw-Tooth Generator

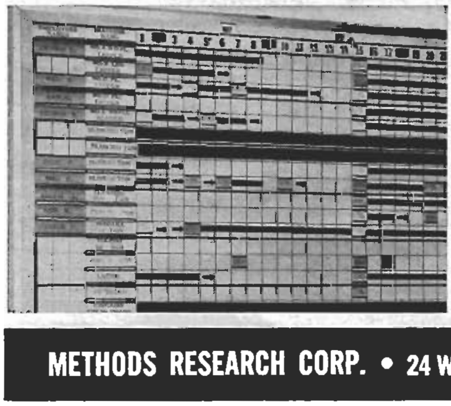
A saw-tooth oscillator is not an ordinary piece of test equipment which is readily found among the audiophile's inventory. The practical test oscillator to be described produces a saw-tooth which covers the frequency range from 200 Hz to 25 kHz with a linear output over this range and which is amply stable for amplifier testing. Circuit is shown in Fig. 3.

Typical saw-tooth waveform signal produced by this generator.









Operation of the circuit is as follows. Assume that switch $S1$ is in the 1-kHz position and that the voltage at the collector of $Q1$ and the emitter of $Q2$ is essentially the battery voltage. $Q3$ is biased in its active region and the voltage at its collector is the battery voltage minus the voltage drop across $R7$ (due to collector current); hence, $Q2$ draws no current, as its base, coupled to $Q3$ collector through $R5$, is at a lower potential than its emitter.

As timing capacitor $C1$ starts to charge through $Q1$ and emitter resistor $R4$, the voltage at the collector of $Q1$ starts to reduce due to collector current through $Q1$ and $R4$. As this voltage decreases, the emitter of $Q2$ also goes less positive, and as this potential approaches the base potential, $Q2$ starts to conduct and places a low-Z discharge path across $C1$ through $Q2$ and $R9$.

As the collector voltage of $Q2$ drops, the negative-going transition is coupled *via* $C4$ to the base of $Q3$. This causes $Q3$ to cut off, making its collector voltage rise rapidly. This rapid rise in voltage, in turn, is coupled to the base of $Q2$, causing it to conduct even more and lowering the discharge path resistance for $C1$. This rapid feedback technique allows $C1$ to discharge very rapidly to obtain the fast flyback for the saw-tooth.

Variable resistor $R2$ controls the collector-to-emitter resistance of $Q1$ and hence the charging time of $C1$, or frequency of operation. $Q1$ also functions as a constant-current source for charging the timing capacitor. A typical waveform is shown in the photograph.

The changes in frequency obtainable by varying $R2$ are shown in Table 1. The circuit shown will operate with *p-n-p* transistors if the battery polarity, diode $D1$, and the polarized capacitors are reversed. The circuit shown should be capable of higher or lower frequency operation by the addition of suitable capacitors in place of, or in addition to, $C1$, $C2$, or $C3$. Actually, a saw-tooth having a duration of seconds can be obtained by making $C1$ a 25-μF capacitor.

To test the performance of the oscillator, check the wiring of each stage before inserting the transistors. With this done, connect a v.t.v.m. to the base of $Q1$ and vary $R2$ until $+4.2$ volts are measured at this point. Then measure the voltage drop at the emitter, base, and collector of each stage to see if they comply closely with the Table 1 values.

The 2N1090's shown in Fig. 3 are switching transistors and have a minimum *beta* of 30, but the maximum value might be much higher. If this is the case, the collector of $Q3$ might be at a lower voltage value than indicated, which will cause a concave saw-tooth. To remedy this, either interchange $Q3$ with a lower *beta* transistor or parallel $R7$ until the proper level is obtained. ▲