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Obtaining Precise Audio Frequencies

By the Engineering Department, Aerovox Corporation

IT is not so very long ago that simple tuning forks were the only reliable pitch standards. Scientists, musicians, and other investigators of tones had nothing better to depend upon. The fork has a long record of dependable service, although in the light of current standard frequency demands and present instrumentation the crudity of early versions is manifest.

The tuning fork has not been entirely supplanted by modern, elaborate audio-frequency standards. There are some services that do not require all of the extreme accuracy and stability of the latter equipment and are fully expedited by the highly refined forks now available. Examples are facsimile synchronization, timepiece and power alternator rating, and certain a.c. bridge measurements.

Modern fork-type standard oscillators meet the demands of any application not requiring closer original frequency adjustment than about 0.005 percent or smaller frequency drift than approximately 0.01 percent.

PRECISION TUNING FORKS

The precision tuning fork, with its associated circuit, is a highly refined electro-mechanical oscillator which is generally operated between 25 and 1000 cycles per second.

Metal used in the manufacture of the modern precision fork is a special alloy having a low temperature coefficient of frequency and permitting a large mass for a given frequency. It is graded with considerable meticulosity.

Vibrations of the fork are sustained either by one or two carbon microphone buttons mounted on its tines, or by a regenerative vacuum-tube circuit. If microphone buttons are employed, they are placed in contact with such portions of the tines that the frequency error due to damping and loading is at a minimum.

In the best laboratory setups, where the maximum amount of precision is desired, the fork itself is held at constant temperature in an oven similar to those employed in quartz crystal stabilization. The maximum variation encountered within such a chamber does not exceed 0.2 degree Centigrade above or below an optimum operating temperature.

Small, readily portable precision forks are available for desk and bench operations where maintenance of temperature is not essential. These instruments are operated by a small dry-cell battery and are carbon-button sustained. They are available in the frequency range 40 to 200 cycles per second as stock items and generally at other specified frequencies on special order. Higher frequencies may be obtained from a given fork by common frequency multiplication methods. The frequency stability of this type of oscillator at room temperature is markedly superior to that obtained with the older type forks.

The amplifiers associated with precision, temperature-controlled forks are adjusted for best operation at the fork frequency and have adequate provision for output impedance matching.

The precision tuning fork oscillator is to be encountered in numerous laboratories where the order of precision afforded by this type of audio-frequency standard is sufficient.

CRYSTAL STANDARDS

Quartz crystals, so well known for their part in stabilizing radio-frequency oscillators, are, of course, not available with audio-frequency fundamentals. However, it was explained in the Research Worker (November, 1940), that a multivibrator may be used to *divide* the frequency of a standard radio-frequency oscillator. The frequency emitted by the multivibrator may then be divided by a second multivibrator, and the frequency of the latter divided by a third, etc.

Thus, a series of successively controlled multivibrators will provide integral submultiples of the standard radio frequency, extending down through the audio-frequency spectrum. The accuracy and stability of these low frequencies thus obtained may be known to the same degree possible with the standard oscillator.

This, briefly, is the method whereby highly precise audio frequencies are obtained from a standard radio-frequency oscillator. The principle may be applied in an instrument designed purposely as an audio-frequency standard, or made use of by adding the necessary multivibrators and filtered amplifiers to any existing primary or secondary radio-frequency standard.

In the practical arrangement of a crystal type audio-frequency standard,

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isolating amplifiers are positioned after the standard oscillator and each multivibrator stage, as explained in last month's article. In addition, an *output* amplifier follows each multivibrator, and these in turn feed into appropriate filters which correct the wave form of the output voltages by passing fundamentals and removing harmonics.

A simple crystal audio-frequency standard, based on the foregoing description, is shown in block diagram in Figure 1. A precision 100-kc. crystal oscillator and four multivibrators are indicated with isolating amplifiers, output amplifiers, and filters.

The standard-frequency crystal oscillator and amplifier supply control voltage to a 10-kc. multivibrator. The multivibrator operates into two amplifiers whose input circuits are connected in parallel. The first of these amplifiers supplies 10-kc. control voltage to the following 1-kc. multivibrator, and the second delivers a 10,000-cycle per second standard audio-frequency signal through an output filter.

The 1-kc. multivibrator works into two amplifiers in the same manner. The first supplies 1-kc. control voltage to the 0.1-kc. multivibrator, and the second delivers a 1000-cycle per second standard audio-frequency signal through an output filter.

The first of the two amplifiers following the 0.1-kc. multivibrator supplies 0.1-kc. control voltage to the 0.2-kc. multivibrator; the second delivers standard 100-cycle per second audio output voltage through a filter.

The single amplifier following the 0.02-kc. multivibrators delivers standard 20-cycle per second audio output voltage through a filter.

The multivibrators employed in this equipment are conventional. Their circuit values may be determined by any of the methods outlined in last month's article.

HARMONIC GENERATING STAGES

It is observed that only four frequencies are supplied by the apparatus illustrated in Figure 1. The number of audio frequencies furnished by the system might be increased by adding multivibrator-amplifier-filter sections to operate (1) at other ratios than 10 to 1, or (2) on harmonics of the present frequency dividers. The latter method is most often employed in audio-frequency standards because it provides a larger number of frequencies in the simplest manner.

The principle utilized is that of synchronizing one multibrator with a suitable harmonic voltage from another. Operation is based on the fact that before filtration the output voltage of each multivibrator contains a multitude of harmonics, any one of which (up to a reasonable limit) may be selected by an appropriate filter, amplified, and used to synchronize a second multivibrator designed for the harmonic frequency.

An example is the control of a 2-kc. multivibrator by second-harmonic voltage from a 1-kc. multivibrator. One 2-kc. filter system would be used to select the second harmonic from the output voltage of the first multivibrator, and another to correct the waveform of the second multivibrator output voltage.

The input filter is connected to the first multivibrator circuit, as shown in Figure 2A, *ahead* of the stage filter in order to encounter the output voltage before its waveform is corrected.

Figure 2B illustrates the general arrangement of apparatus within a harmonic generator stage. The proper harmonic voltage is selected from the complex output voltage of the control multivibrator by the input filter system. This harmonic voltage is then amplified and applied to multivibrator No. 2 which it synchronizes at the same frequency. Standard audio-frequency voltage at the desired harmonic of the control multivibrator is then delivered through an output filter which corrects its waveform.

Sufficient harmonic generating stages may be added, to augment the few frequencies supplied by the simple arrangement of Figure 1, as may be required by individual demands for spot frequencies and spectrum coverage. Such stages may be operated on harmonics of the 1-kc. multivibrator (Figure 1) that occur every 1000 cycles between 2000 and 19,000 cycles. The frequency 20,000 cycles may be obtained from a second-harmonic stage controlled by the 10-kc. multivibrator.

Harmonics of the 0.1-kc. multivibrator are available at 100-cycle intervals from 200 to 1900 cycles, and those of the 0.02-kc. multivibrator at 20-cycle intervals from 40 to 180 cycles.

Obviously, an elaborate standard of frequency might so be set up to supply audio frequencies in a large quantity. In actual practice, however, the supply is generally determined by the demand. The filter systems required in this type of equipment are particularly costly and, in some cases, bulky as well. Therefore most actual crystal-type audio-frequency standards are designed to furnish only those frequencies which are particularly required.

PRIMARY AND SECONDARY STANDARDS

In standards of the type just described, the crystal oscillator is temperature controlled, and plate power

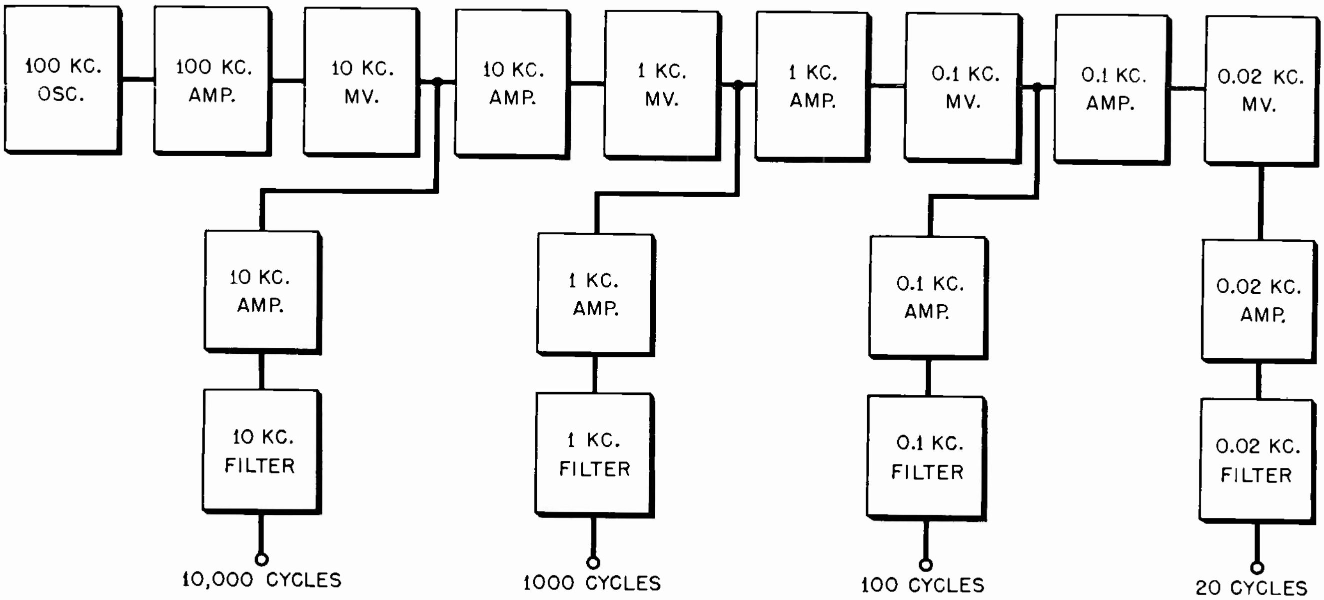

Fig. 1

supplies voltage-regulated for maximum stability.

For periodic checking of accuracy, the frequency of the crystal oscillator, or one of its harmonics, may be compared with a standard radio-frequency signal, such as one of the WWV transmissions. Or a synchronous motor-driven clock may be operated by the 1000-, 50-, or 60-cycle voltage delivered by the harmonic generator stages, and its indicated time checked against NAA time signals to compare the oscillator frequency directly with standard time.

The instrument is a *primary standard* if the frequency of its master oscillator may be compared directly with standard time in the manner last described, and is a *secondary standard* if the first method of checking against a primary standard (or signal rated therefrom) must be used.

For best performance in a primary standard, the operating temperature of the quartz plate controlling the master oscillator must be maintained within 0.01 degree Centigrade. The high-potential power supplies are voltage-regulated to offset frequency shifts or loss of multivibrator control due to excursions of the plate voltage.

The manner in which the frequency is checked against time in a primary standard is a matter of interest. The clock which is propelled by the frequency standard actually becomes a counter of the vibrations undergone by the quartz plate in the master oscillator. If the number of oscillations per second agree with the stated frequency of the plate, the clock will keep correct time.

Let us assume a 100-kc. master oscillator and a 1000-cycle clock. The latter will be driven by the voltage delivered by the 1-kc. multivibrator-amplifier-filter circuit.

Each second indicated by the clock represents 1000 cycles supplied by the 1-kc. stages. The frequency reduction factor here is 100 (ratio of the 100-kc. oscillator frequency to the 1-kc. clock motor frequency) so that the quartz plate must vibrate 100,000 times for each second indicated by the clock.

Now, if the clock time is compared with standard time signals once in a 24-hour interval, the actual number of crystal vibrations during that interval can be determined (and the frequency accuracy discovered) by multiplying the total number of seconds the *clock* travelled in 24 hours of *standard* time by 1000, which is the number of cycles required to drive the clock over each indicated second; by 100, which is the frequency reduction factor. If this product is then divided by 86,400 (the number of seconds in a 24-hour day), the result will be the quartz plate frequency in *cycles per second*. This may be expressed by the formula:

$$f = \frac{T \times 1000 \times 100}{86400} = \frac{100{,}000\ T}{86400}$$

which may be simplified further.

The frequency of commercial primary frequency standards may be known with the accuracy of 1 part in 10 million (0.00001 percent).

NOTEWORTHY APPLICATION

The standard-frequency radio transmissions from the National Bureau of Standards station, WWV are modulated at 1000 cycles and 440 cycles with audio-frequency voltages obtained in the manner outlined in this article. A block diagram of the apparatus employed is given in Figure 3.

In the audio-frequency generator, the master oscillator is operated at 200 kc. and its output voltage controls a 50-kc. multivibrator. The latter stage in turn controls a 10-kc. multivibrator, and this in turn a 1-kc. multivibrator. 1000-cycle audio-frequency voltage is then made available through a 1-kc. output filter.

An 11-kc. filter selects the 11th harmonic of the 1-kc. multivibrator output voltage and applies this to an 11-kc. multivibrator which is controlled thereby. The 11-kc. multivibrator in turn controls another multivibrator operated at 2.2 kc., and the latter controls the last multivibrator which is operated at 0.44 kc. (440 cycles). The 440-cycle output voltage is then delivered through an appropriate output filter which corrects its waveform.

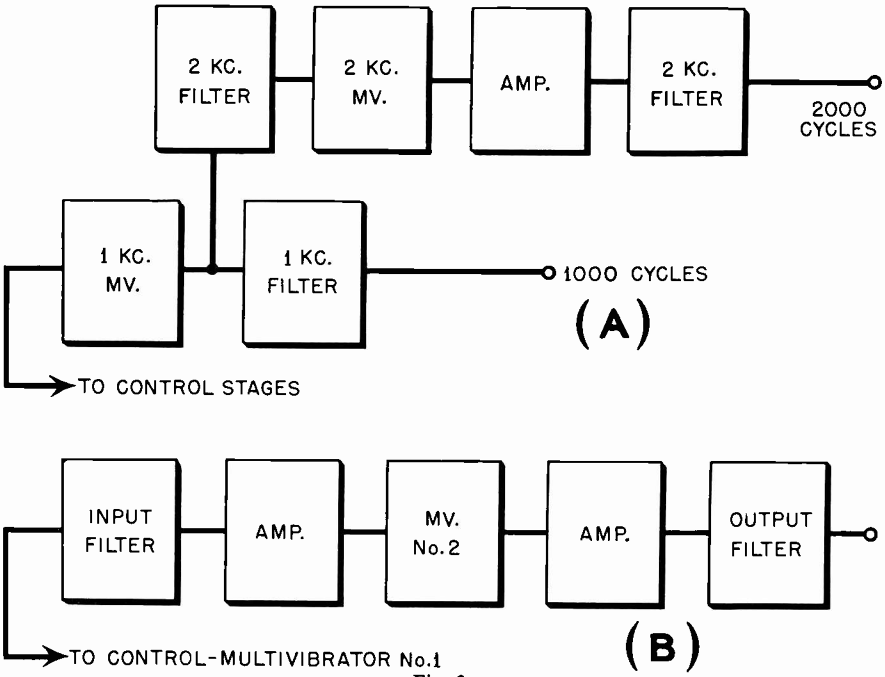

Fig. 2

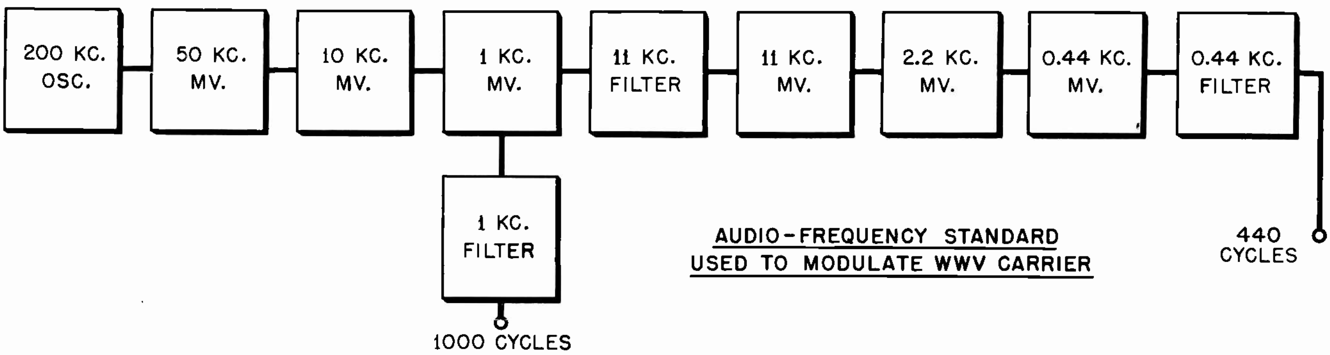

Fig. 3

SINGLE-SECTION PBS ELECTROLYTICS

Type & D.C.W.V.	Cap. Mfds.	Size-Ins. D.—W.—L.	List Price	Net Price
PBS 600	4	1-7/16x1-⅛x2-7/16	$1.75	$1.05
PBS 600	8	1-7/16x1-½x3-⅛	2.45	1.47
PBS 450	2	½x ¾x2-7/16	.65	.39
PBS 450	4	9/16x1 x2-7/16	.75	.45
PBS 450	6	11/16x1-⅛x2-7/16	.90	.54
PBS 450	8	11/16x1-⅛x2-7/16	.95	.57
PBS 450	10	11/16x1-⅛x3-3/16	1.15	.69
PBS 450	12	11/16x1-⅛x3-3/16	1.30	.78
PBS 450	16	1-7/16x1-⅛x2-7/16	1.45	.87
PBS 250	2	½x ¾x2-7/16	.55	.33
PBS 250	4	½x ¾x2-7/16	.65	.39
PBS 250	6	9/16x13/16x2-7/16	.75	.45
PBS 250	8	9/16x13/16x2-7/16	.80	.48
PBS 250	10	11/16x1-⅛x2-7/16	.90	.54
PBS 250	12	11/16x1-⅛x2-7/16	.95	.57
PBS 250	16	11/16x1-⅛x2-7/16	1.05	.63
PBS 250	20	11/16x1-⅛x2-7/16	1.20	.72
PBS 250	25	11/16x1-⅛x3-3/16	1.25	.75
PBS 250	30	11/16x1-⅛x3-3/16	1.40	.84
PBS 100	5	9/16x1 2-7/16	.55	.33
PBS 100	10	11/16x1-⅛x2-7/16	.70	.42
PBS 50	5	½x ¾x2-7/16	.50	.30
PBS 50	10	9/16x1 x2-7/16	.65	.39
PBS 50	25	11/16x1-⅛x3-3/16	.80	.48
PBS 25	5	½x ¾x2-7/16	.50	.30
PBS 25	10	½x ¾x2-7/16	.50	.30
PBS 25	25	11/16x1-⅛x2-7/16	.65	.39

DOUBLE- AND TRIPLE-SECTION PBS ELECTROLYTICS

Cap. Mfds.	Size-Ins. D.—W.—L.	List Price	Net Price
Type PBS450—Double Section 525v. Surge Pk.—450v. D.C. Work.			
4-4	1¼x1⅛x2-7/16	$1.20	$0.72
4-8	1-7/16x1⅛x2-7/16	1.35	.81
8-8	1-7/16x1⅛x2-7/16	1.50	.90
8-16	1¼x1½x3	1.90	1.14
Type PBS450—Triple Section			
8-8-8	1¼x1½x3	$2.20	$1.32
Type PBS250—Double Section 300v. Surge Pk.-250v. D.C. Work.			
4-4	1-1/16x ¾x2-7/16	$0.90	$0.54
4-8	1-3/16x13/16x2-7/16	1.15	.69
8-8	1-3/16x13/16x2-7/16	1.25	.75
8-16	1¼x1⅛x2-7/16	1.45	.87
12-16	1-7/16x1⅛x2-7/16	1.60	.96
16-16	1-7/16x1⅛x2-7/16	1.65	.99
Type PBS250—Triple Section			
8-8-8	1⅞x13/16x2-7/16	$1.90	$1.14
8-8-16	1-7/16x1⅛x2-7/16	2.10	1.26

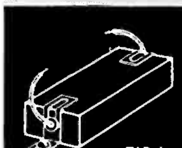

FIG. 1

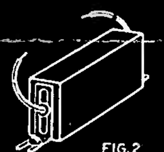

FIG. 2

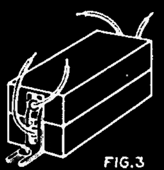

FIG. 3

Type PBS Electrolytics

● If you're short on space or money, or both, Type PBS Cardboard Case Electrolytics are the answer to your problem.

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