



# Design Notes on the Resistance-Capacity Oscillator Circuit

*(The following is the concluding portion of Mr. Bauer's article that was begun in the November issue)*

## Part II

### ACCURACY

**O**VERALL accuracy as applied to a variable-frequency oscillator is a general term that includes many factors such as the inherent stability of the circuit, mechanical stability and resetability of the tuning system, readability of the tuning dial, care with which the dial was calibrated, effects of aging on the various component parts, and the effects of power supply variations and ambient temperature changes. Some of these

factors affect the short-time stability; others affect the long-time stability.

The accuracy specification of within 2% that is usually given for resistance-capacity oscillators is intended to include the majority of these factors. Consequently, the actual accuracy is different for different combinations of conditions and is generally better than this figure under normal operating conditions.



Figure 6. Model 201B Audio Oscillator

**L**ONG-TIME stability—the stability over a period of several months or more—is a function of the quality of the circuit components and the mechanical stability of the tuning system. For best long-time stability it is desirable to use only wire-wound resistors in the frequency-determining network. However, at frequencies up to the mid-audio range the use of wire-wound resistors is impractical in most applications because of the high resistance values necessary. Composition resistors have been developed to the point where accuracies within 1% are practical and where their long-time stability is good. A very satis-

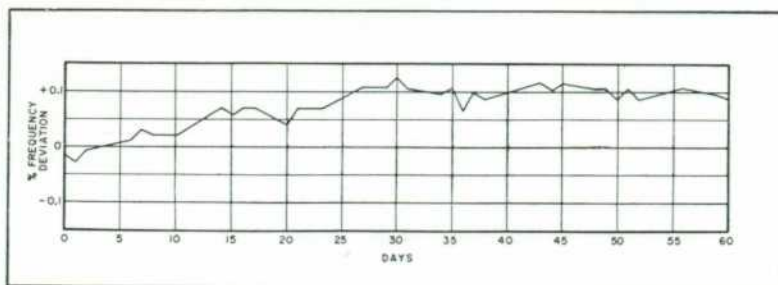


Figure 7. Long Time Stability Curve of Circuit Using Wire-wound Resistors and Temperature Compensation

factory type consists of inactive carbon deposited on a ceramic tube. Detailed descriptions\* of these resistors have appeared in the literature. Through the use of such precision composition resistors, the long-time stability of the oscillator is increased to the point where accuracies within 1 to 2% are practical. Controls can be provided so that the calibration of the oscillator can be reset against a frequency standard. Such controls usually consist of resistance verniers located in the frequency-determining network. If the oscillator calibration is corrected from time to time with these controls, accuracies within 1% can be easily maintained.

At frequencies above a few kilocycles where wire-wound resistors can be used in the frequency-determining network, it is practical to increase the long-time accuracy to within approximately 0.5%. Ordinarily in these applications it is necessary to temperature-compensate the circuit to avoid the drifts that are associated with warm-up and ambient temperature changes. Figure 7 shows a long-time stability curve of a circuit in which wire-wound resistors and temperature-compensation are used. Where the maximum stability is required, it is desirable to reduce the span of the oscillator from 10:1 to 3:1 or 2:1.

\*P. R. Coursey, *Fixed Resistors For Use in Communication Equipment*. The Proceedings of the Institution of Electrical Engineers, Vol. 96, Part III, p. 169, May, 1949.

This reduction lessens the effects of stray circuit capacity by increasing the minimum value of the tuning capacity.

Some applications require oscillators having long-time accuracies within tolerances narrower than 0.5% and a number of circuits have been developed to meet this requirement. One of the most practical systems is the use of a precision fixed-frequency check oscillator in the same cabinet with the resistance-capacity oscillator. This arrangement allows convenient standardization of the calibration of the variable oscillator at intervals throughout its frequency range. The frequency comparison can be made by means of Lissajous figures on either a self-contained or external oscilloscope. At supersonic frequencies and above, a quartz plate is used to control the fixed-frequency oscillator while at lower frequencies a temperature-compensated tuning-fork is used. Standardizing of the variable oscil-

lator at a number of check points can be accomplished with a simple capacitive vernier.

The use of a precision check oscillator allows an accuracy of 0.1% or better to be maintained throughout the life of the oscillator. However, because of the elaborate circuitry and the necessary use of a tuning drive commensurate in quality with the quality of the electrical systems, such oscillators tend to be large and involve considerable expense.

For low-frequency narrow-range oscillators of high long-time stability, it is often practical to incorporate an electron-ray or "tuning eye" in the circuit to permit checking the frequency of the generated voltage against the power line frequency. This arrangement will allow good accuracy over long periods of time. However, random fluctuations in the frequency of the power systems should be anticipated and may cause short-time errors approaching 1% in extreme cases.

Short-time stability — considered here to mean the stability over periods not exceeding one-half hour after sufficient warm-up—is a function of the effective Q of the circuit and of random effects such as regulation of the voltage supply, the effects of vibration, etc. In the resistance-capacity oscillator the frequency-determining network has an equivalent Q of 1/3. The action of the positive feedback loop increases the effective Q approximately 30

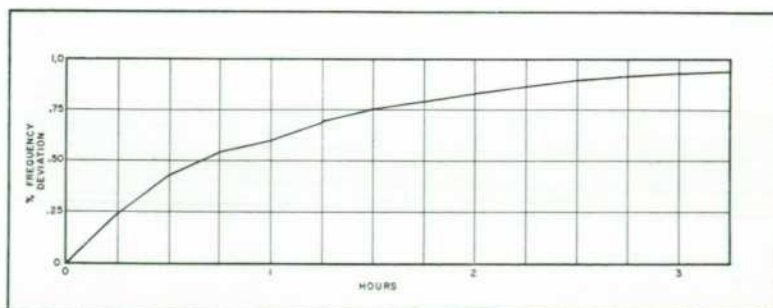


Figure 8. Short Time Stability Curve of Resistance-Capacity Oscillator

times, resulting in an effective operating Q of about 10. The short-time stability of the circuit is that obtainable with Q's of this order. This relatively low Q is contrasted with LC oscillators with which it is possible to obtain Q's of several hundred. A typical short-time stability curve is shown in Figure 8.

With further reference to short-time stability, the effect of power line voltage variations must often be considered. A number of studies of line-voltage conditions at the point of usage indicate that  $\pm 10$ -volt or more line variations on nominal 115-volt lines are the rule rather than the exception. Although the effects of line voltage variations are minimized by the negative feedback in the circuit, line voltage effects do increase at the higher frequencies where the gain of the circuit is less. Line voltage effects can be reduced by a factor of about three at these frequencies by the use of plate supply regulation. It is therefore customary to use such regulation at the higher frequencies when best stability is required.

The above discussion of accuracy concerns the oscillator circuit itself. It should be noted that in order to achieve the practical use of the accuracy of the circuit it is necessary to use an isolating amplifier between the oscillator circuit and the load.

## SYNCHRONIZATION

Occasionally it is desirable to synchronize the resistance-capacity oscillator to obtain the accuracy and stability of a device such as an external frequency standard. Synchronization can be obtained on a 1:1 basis or as high as 12:1 by the arrangement shown in Figure 9. The synchronizing voltage is applied to the screen grid of the first oscillator tube through an isolating amplifier. With this arrangement the synchro-

nizing voltage can be either sinusoidal or square. Synchronization on a 1:1 basis can also be obtained by coupling capacitively with a wire laid near the main tuning capacitor or by wrapping a few turns around the grid lead of the first tube with a wire connected to the synchronizing voltage.

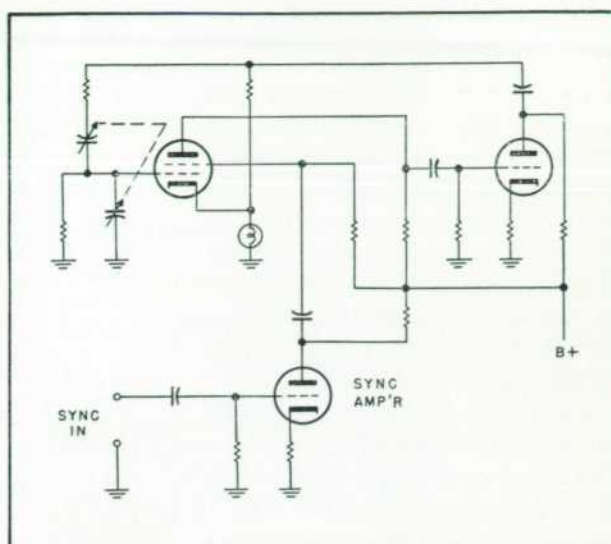


Figure 9. Circuit for Synchronization of Resistance-Capacity Oscillator

## AMPLITUDE STABILITY

A form of stability not often considered but which is of importance in some bridge and magnetic circuits is that of constancy of oscillator output with time. The resistance-capacity oscillator inherently has good amplitude stability because of the negative feedback circuit. In applications where amplitude stability is of importance, it is desirable to remove all variable resistances from the circuit and to regulate the plate voltage supply. When these precautions have been taken, long-time variations in amplitude of less than 0.3% can be expected from the resistance-capacity circuit at medium frequencies with somewhat greater variations at the low and high frequencies.

## SPECIAL CONTROLS

Although capacitive tuning has proved the more satisfactory method over a long period of time, tuning can also be accomplished by varying the resistance in the frequency-determining network, as indicated by the "resonance" formula. Applications wherein it is desired to remote-control an oscillator or wherein the

frequency of oscillation must be varied in accordance with the rotation of a mechanical part indicate the use of a precision potentiometer or slide-wire for tuning purposes. Resistance tuning, while useful in some applications, is inferior to capacitive tuning owing to a combination of factors. Using composition controls, these factors include wear and poor resetability. Using wire-wound controls, these factors include wear and discrete breaks or steps in resistance as the control is rotated. These steps in resistance cause the incremental frequency changes to be much greater when only a small portion of the resistance of the control is in the circuit than when a large portion of the resistance is in the circuit. In addition, resistance tuning causes the impedance of the frequency-determining network to vary throughout each frequency band, resulting in undesirable variations in performance throughout the band. When variable resistors are used for remote tuning purposes, the oscillator should be calibrated with a specific length of a given cable connecting the resistance to the remainder of the circuit to insure proper calibration.

A type of oscillator frequently required is that with a vernier frequency control. Such controls fall into two classes, depending upon whether the control is calibrated or uncalibrated. In capacitively-tuned oscillators calibrated controls are provided as resistive verniers in series with the resistances of the frequency-determining network. The controls are calibrated in per cent deviation rather than directly in frequency, because a given incremental resistance change produces a different frequency increment at one setting of the main tuning capacitor than at any other setting. However, a given resistance change causes the same percentage variation in frequency at any setting of the tuning capacitor.

Capacitive frequency verniers are often used in capacitively-tuned circuits because of the smooth change in frequency obtainable. However, in such applications the range of control of such verniers varies widely, depending upon the setting of the main tuning capacitor. For this

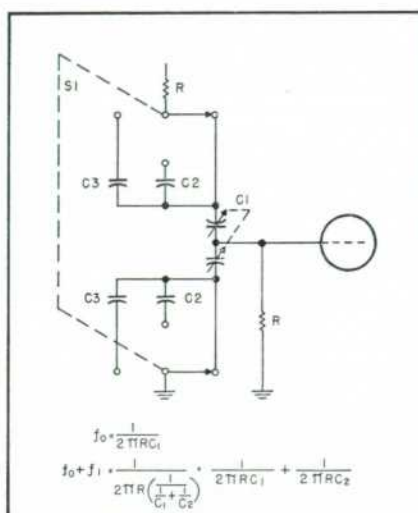


Figure 10. Step-Frequency Deviation Control

reason capacitive verniers are not calibrated in capacitively-tuned circuits. Capacitive verniers can be calibrated in per cent frequency deviation when used in circuits that are tuned by varying the resistance in the frequency-determining network. This arrangement is possible because the capacity in the circuit is

constant.

Figure 10 shows the elements of a deviation control that is used where deviations consisting of fixed steps are desired. A series of capacitors selectable by a switch are connected so that one of them will be in series with the main tuning capacitor on either side of the grid connection. By selecting the desired set of capacitors with a switch, a fixed-frequency step is obtained regardless of the setting of the main tuning capacitor. The action of the additional capacitors can be seen by referring to the expressions shown for the frequency of oscillation in Figure 10. There it is shown that the frequency of oscillation is increased by a factor corresponding to the frequency of oscillation of the resistance and vernier capacity considered separately.

#### SUMMARY

The characteristics discussed above are summarized for reference purposes in the following table.

—Brunton Bauer.

### TYPICAL CHARACTERISTICS OF RESISTANCE-CAPACITY OSCILLATORS

CHARACTERISTICS	LOW FREQUENCY RANGE	MEDIUM FREQUENCY RANGE	HIGH FREQUENCY RANGE
Frequency Range	1/2 – 100 cps	100 cps – 100 kc	100 kc – 1 mc
Distortion	1% at 2 cps; increases below 2 cps	Less than 1%; less than 1/4% in special cases	Approx. 1% at 200 kc; approx. 3% at 1 mc
Long-time stability	Depends on circuit compo- nents; 2% typical; 1% in special cases	Depends on circuit compo- nents; 2% typical; 0.1% in special cases	Depends on circuit compo- nents; 2% typical; 0.5% in special cases
Short-time stability	0.3%	0.1%	Approx. 0.2% below 500 kc; poor above 500 kc
Amplitude stability	Within 0.5%	Within 0.3%	Within 1% below 500 kc; poor above 500 kc
Incremental control	Percentage calibrated resistive control; uncalibrated capacitive control	Percentage calibrated resistive control; uncalibrated capacitive control	Percentage calibrated resistive control; uncalibrated capacitive control