Modified Locked-Oscillator Frequency Dividers*

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***Summary*—A simple locked-oscillator frequency divider is described. The circuit, which consists of an *LC* oscillator modified to facilitate locking, is capable of operating over a 7-to-1 plate-supply-voltage range when dividing by a factor of 30.**

Introduction

FREQUENCY DIVIDERS have seen wide application where precise time intervals or accurate audio frequencies are required. This results from the fact that it is possible, with present techniques, to obtain the highest oscillator frequency stability at frequencies of the order of 50 or 100 kc. Lower frequencies may be required for running clocks, for interpolation, or for many other purposes, and therefore frequency division is required.

Although several types of frequency dividers have been employed,[1–7] a need was found for a simple but reliable circuit capable of dividing by steps of 10 or greater in a single stage.

Improved Locked Oscillator

In developing the frequency divider to be described, an attempt was made to combine the frequency stability of the locked sinusoidal oscillator with locking ability of the multivibrator.

An analysis has shown[7] that if a voltage of frequency Nf_0 is injected into an oscillator of frequency f_0, synchronization may occur because of cross modulation between the injected voltage and harmonics of f_0. The modulation product can be considered as a synchronizing signal for locking with a one-to-one frequency ratio. It is well known that one-to-one locking is comparatively easy in any nonlinear oscillator.[8,9] Thus it might appear that the synchronizing ability of a sinusoidal oscillator as a frequency divider might be improved by increasing its harmonic content.

A regenerative sinusoidal oscillator may be regarded as a positive-feedback amplifier with a filter in the feedback loop. This filter—normally a tuned circuit or a tuned transformer—permits little loop gain at the harmonic frequencies. By-passing the filter with an all-pass network will increase the gain at harmonic frequencies; however, if this process is carried too far, the tuned circuit will lose control of the operating frequency, and relaxation oscillations will be produced.

As an example, consider the cathode-coupled oscillator[10–12] shown in Fig. 1(a). With proper design, a sine

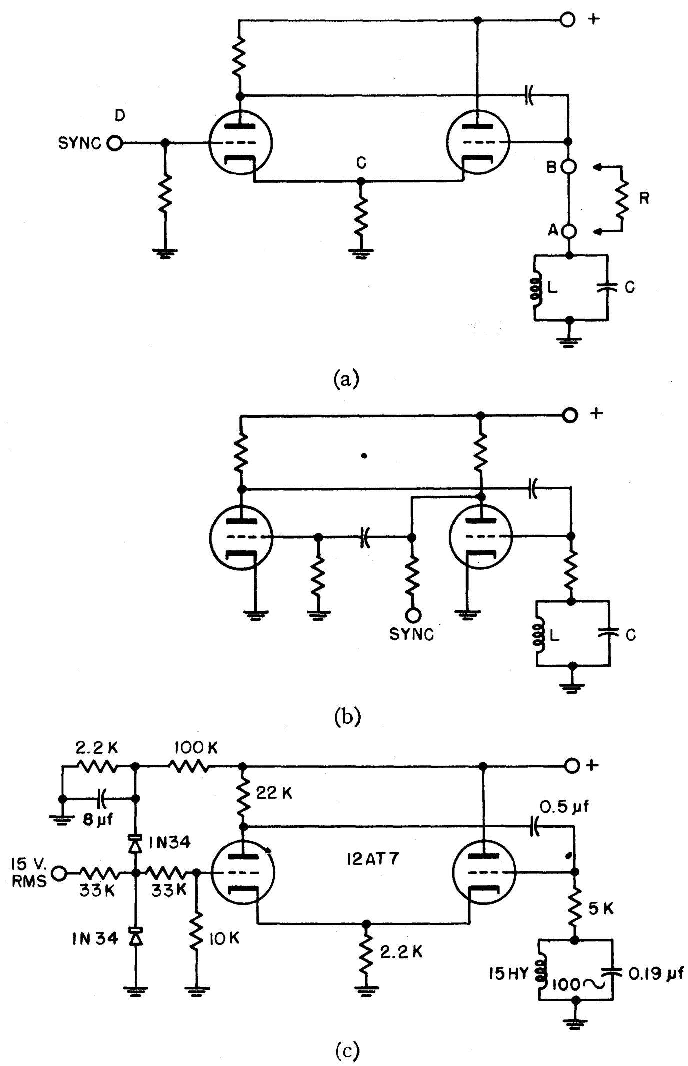

Fig. 1—Locked-oscillator frequency dividers.

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wave is produced at points *A* and *B*, while a half-sine wave is produced at *C*. Hence harmonics are present, and frequency division by factors of two or three is possible if sufficient synchronizing voltage is inserted at point *D*. It is found, however, that there is little tendency for stable operation at larger frequency ratios, indicating, from the above, a possible need for greater high-order harmonic content.

A simple way of increasing the loop gain at harmonic frequencies is to insert a resistance *R* at points *A* and *B*. As the value of *R* is increased, a sine wave continues to be produced at *A*, but rapid transitions are obtained in the wave form at *B*, indicating the presence of the desired high-order harmonics. With a moderate value of *R*, the tuned circuit *LC* retains control of the oscillator frequency. As *R* is increased, however, a critical point is reached at which relaxation oscillations are obtained. The oscillograms of Fig. 2, taken from the circuit of Fig. 1(c), show this process.

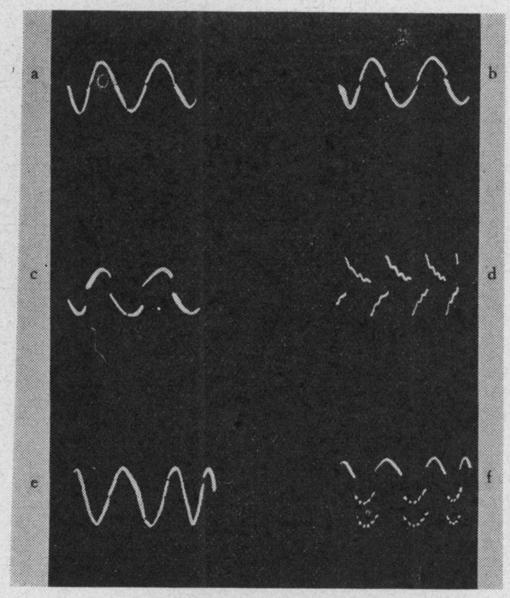

Fig. 2—Oscillograms showing the voltage at point *B* for the following conditions: (a) $R=0$; (b) $R=3,000$ ohms; (c) $R=10,000$ ohms; (d) $R=11,000$ ohms (relaxation oscillations—sweep frequency was decreased by factor of 10); (e) $R=0$, with 5 volts peak-to-peak applied to point *D*; (f) $R=10,000$ ohms, same synchronizing voltage.

With an intermediate value of *R*, excellent locking is obtained and stable frequency division by large integers is possible. At the same time, division by rational numbers is observed. Thus an output at 60 cycles can be obtained with an input of 100 cycles, or 50 cycles can be obtained from 60 cycles. The optimum value of *R* for this or any other condition is best determined by experiment. It appears to be a function of the frequency ratio, the impedance presented by the negative-resistance circuit, and the resonant impedance and *Q* of the tuned circuit. In any case, the setting of *R* is a compromise; harmonic content sufficient for locking is required, but excessive harmonic content may decrease the frequency stability of the oscillator to such an extent that synchronization is lost.

A second feedback oscillator[13] that is capable of being modified for frequency division is shown in Fig. 1(b). It is possible that the transitron[14] and screen-coupled[15] oscillators might also be useful in this application. The use of single-tube, transformer-coupled oscillators has not been considered, although a wide-band transformer might permit the use of this type of circuit.

Circuit Performance

Although it may be difficult to establish a criterion for judging the reliability of the circuit, measurement of the plate-supply-voltage range over which locking occurs at a desired frequency ratio appears to be a reasonable choice. Thus the circuit of Fig. 1(c), when dividing by 10, will lock as the plate supply is varied from 26 to 350 volts. This compares favorably with the range of 180 to 350 volts obtained with a well-designed astable multivibrator operating at the same frequency ratio.[16]

One requirement of the modified locked oscillator is that the synchronizing voltage be made proportional to

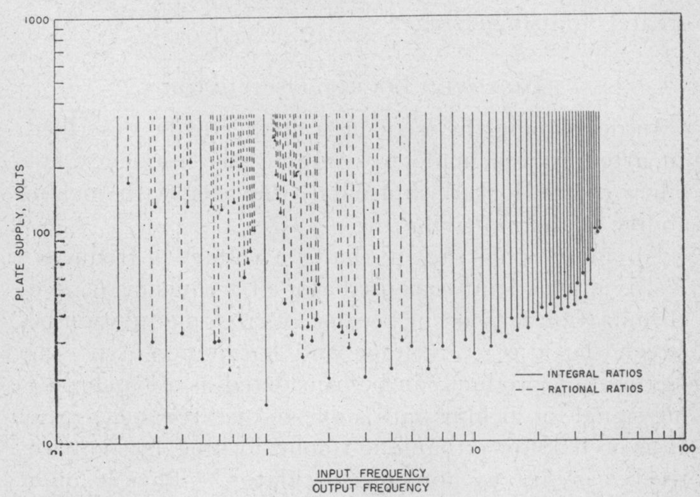

Fig. 3—Plate-supply-voltage range over which locking was obtained versus frequency ratio. Solid lines indicate integral ratios; dashed lines indicate rational frequency ratios.

the plate-supply voltage. This is accomplished in Fig. 1(c) by means of a biased clipper. Such clippers are not required between stages when several dividers are connected in a chain.

Fig. 3 shows the performance of the circuit of Fig. 1(c) at many different frequency ratios. Here the vertical-line length indicates the plate-voltage range over which locking was obtained at the frequency ratio shown by the horizontal scale. It will be noted that synchronization was obtained at frequency ratios from

[13] F. E. Terman, "Radio Engineers' Handbook," McGraw-Hill Book Co., Inc., New York, N. Y., p. 509; 1943.

[14] C. Brunetti, "The transitron oscillator," Proc. I.R.E., vol. 27, pp. 88–94; February, 1939.

[15] P. G. Sulzer, "Applications of screen-grid-supply impedance in pentodes," *Communications*, vol. 36, pp. 10–12; August, 1948.

[16] B. Chance, "Waveforms," McGraw-Hill Book Co., Inc., New York, N. Y., p. 577; 1949.

1/5 to 40. If a plate-supply voltage range of 7-to-1 is taken as indicative of reasonably good stability, frequency ratios up to 30 are possible.

It is worth mentioning that the circuit under consideration divided by 10 with a wide range of type 12AT7 tubes. In addition it functioned with other tube types, including the 12AU7, 12AX7, 6SN7GT, and 6SL7GT, without readjustment. Although long-time tests have not been completed, this is believed to be an indication that a long effective tube life will be obtained, barring accidents such as open heaters or short circuits.

Design and Adjustment

In designing locked oscillators for use as frequency dividers it appears to be necessary to employ empirical methods; however, the following suggestions may be found helpful:

1. The negative-resistance circuit employed should be designed to present the lowest possible value of negative resistance[17] consistent with the available plate-supply voltage and desired plate dissipation. This will aid in obtaining a rapid transition, which will produce high harmonic content.

2. It has been found by experiment that the optimum tuned-circuit Q is approximately equal to the frequency ratio employed, when the circuit is used as a frequency divider. A lower value of Q will produce poor frequency stability which may cause a loss of synchronization, while a much higher Q will make adjustment difficult, and will also result in a poor phase lock and restricted operating bandwidth.

The tuned circuit must contain linear elements. Molybdenum-permalloy inductors have been found very satisfactory. When very high inductances are required, nickel-iron alloy cores can be used if a sufficiently large gap is provided to stabilize the value of the inductance under conditions of changing flux density. If this precaution is not observed, variations in oscillation amplitude due to supply-voltage or tube changes may cause sufficient detuning to effect loss of synchronization.

In selecting the value of the inductance it is satisfactory to take product henrys × cycles (operating frequency) equal to 1,000. Deviations by factors of 1/3 to 3 from this rule will permit satisfactory results providing a sufficiently high Q can be obtained.

3. In aligning the circuit, a small synchronizing voltage is applied, and the resonant circuit is set for locking at the desired frequency ratio by means of a decade capacitor. The synchronizing voltage is then increased until the oscillator stops functioning. The optimum synchronizing voltage is approximately one half this value. If an excessive amount of synchronization is applied, oscillation will cease at low plate-supply voltage or with low-transconductance tubes.

Divider-Chain Example

The circuit of Fig. 4 is used to divide from 100 kc to 1 kc to obtain driving voltage for a 1-kc clock. Sine-wave and pulse outputs are provided for timing purposes.

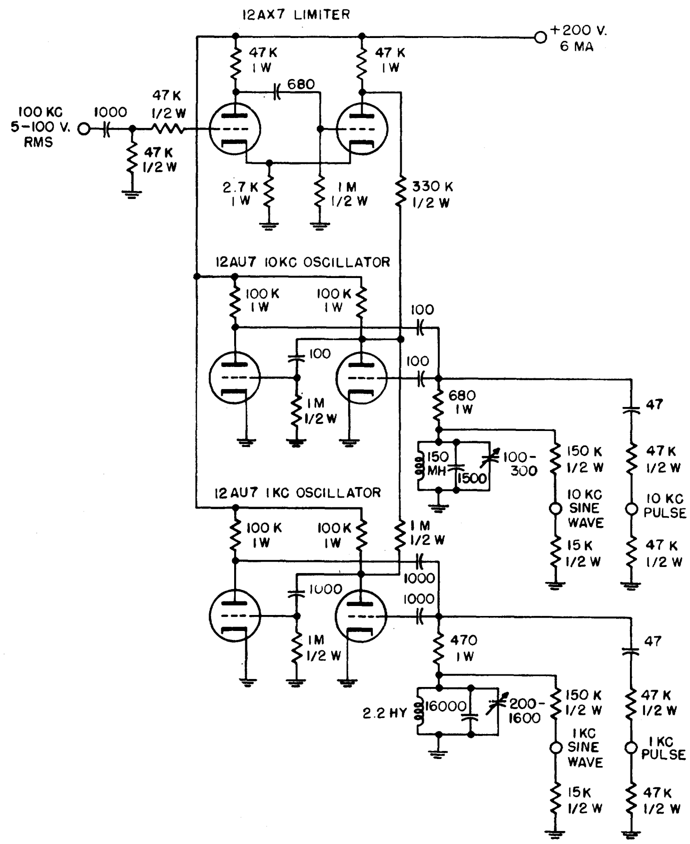

Fig. 4—Divider chain producing 10-kc and 1-kc sine waves and pulses from a 100-kc input. All capacitances in $\mu\mu$f. $K=10^3$. $M=10^6$.

The divider chain will operate properly as the plate supply is varied from 30 to 350 volts; at the same time, the heater supply can be varied from 2.8 to 12 volts.

The approach used in this paper has involved the modification of a sinusoidal oscillator; however, the same result can be obtained by considering the process as one of stabilizing a multivibrator by means of a tuned circuit. Builder[18] has described a successful gas-tube divider using resonant stabilization, although performance data were not given.

[17] P. G. Sulzer, "Cathode-coupled negative-resistance circuit," Proc. I.R.E., vol. 36, pp. 1034–1039; August, 1948.

[18] Geoffrey Builder, "A stabilized frequency divider," Proc. I.R.E., vol. 29, pp. 177–181; April, 1941.