• Technical Topics —

The Clapp High-Stability Circuit

As a result of our note in August *QST* commenting on the similarity between E. O. Seiler's VFO in the November, 1941, issue[1] and J. K. Clapp's series-tuned oscillator circuit, described in May *QST* of this year,[2] Mr. Clapp has written us pointing out some rather important differences between the two circuits. Superficially, the two are alike in that the tube is loosely coupled to the tuned circuit and large "swamping" capacitances are connected across the tube elements. If these features completely disposed of the stability problem the fact that in the Clapp circuit the tuning condenser is in series with the coil while in the Seiler circuit it is in parallel with it would merely be a question of choice based on convenience. The explanation below, quoted from Mr. Clapp's letter, shows why the way the tuning condenser is connected *does* affect the stability of the oscillator, and thereby makes the series-tuned circuit basically different:

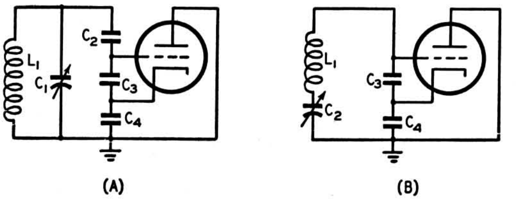

Fig. 1 — **The two oscillator circuits discussed in the text. Blocking condensers, etc., are omitted in these simplified circuits, not being essential to the discussion.**

"The resemblance (between the two circuits shown in Fig. 1) lies in the use of large capacitances across the tube. However, the network L_1C_1 in Fig. 1A must be an equivalent inductance and C_2 is the effective *series* tuning capacitance. Because of the circulating current in L_1C_1 the combination will not be as good an inductance as L_1 alone.

"Though not described in the *I.R.E. Proceedings*, I have analyzed and experimented with the 'parallel' version (C_2 omitted in Fig. 1A), particularly with a view to applications at low frequencies. The over-all results are distinctly poorer than with the 'series' version (Fig. 1B). We are also in the same trouble in using 'butterfly' circuits, which are 'parallel' circuits.

"For a quick review of the differences, consider a tube with coupling capacitances C_3, C_4 (Fig. 2A). The IRE article shows the equivalent impedance as a negative resistance in series with the net reactance of C_3 and C_4 in series. If a coil of the same reactance, and a resistance slightly less than the negative resistance, are connected to the tube network, a 'high-C' oscillator results (Fig. 2B).

"If we use a *much* bigger coil, L'_1, in series with a small tuning capacitance, C_2, of nearly the same reactance as this coil so that the *net* reactance of coil and condenser in series is the same as before (Fig. 2C), we will again obtain oscillations at the same frequency as before. (This is *not* the series-resonant frequency of the coil and tuning capacitance.) In Fig. 3, the dotted curves show the reactances of the coil and tube circuit of Fig. 2B with operation at series resonance. The point A marks the net positive reactance which must be supplied by L'_1 and C_2 of Fig. 2C in series, for 'series' operation at the same frequency as before. The increased slope of the net reactance curve through point A is one reason for improved stability.

"Next consider the coil L_1 and capacitance C_1 in parallel (Fig. 4A). The combination acts as an inductance at frequencies below the resonant frequency (Fig. 4B). The effective Q is the effective inductive reactance divided by the effective resistance, and is given by the equation below the figures. (Note that the effective Q is *zero* when the circuit is parallel resonant at the operating frequency of the oscillator. It is ob-

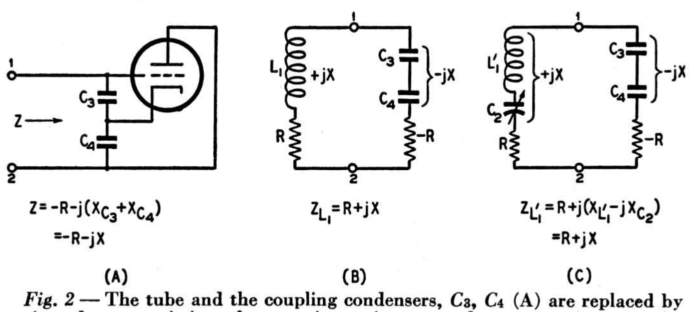

Fig. 2 — **The tube and the coupling condensers, C_3, C_4 (A) are replaced by an impedance consisting of a negative resistance and reactance in series (to the right of the terminals *1*, *2*, in B and C) for purposes of analysis. B shows the equivalent of a high-C circuit and C the equivalent of the series-tuned circuit.**

[1] E. O. Seiler, "A Low-C Electron-Coupled Oscillator."
[2] "A High-Stability Oscillator Circuit," Tech. Topics.

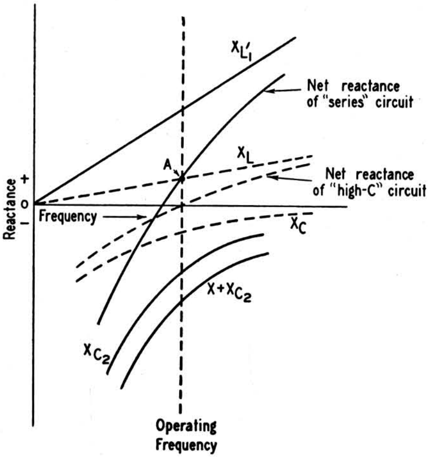

Fig. 3 — **Operating characteristics of high-*C* and series-tuned circuits. At the operating frequency, the inductive reactance X_L and capacitance reactance X_C are equal. The dashed curves show how these reactances vary with frequency in a high-*C* circuit. In the series-tuned circuit (solid curves) the same amount of inductive reactance must be supplied (point *A*) but is obtained as the *difference* between the inductive and capacitive reactances of the series-connected coil and condensers. The steeper slope of the net-reactance curve in this case represents an increase in the effective *Q*; this improves the stability just as the high *Q* of a quartz crystal improves the stability of an oscillator in which it is used.**

viously impossible to operate the circuit of Fig. 1A at the frequency of L_1C_1.) The maximum effective Q (Q_e) comes at $\delta = -0.4$, approximately, and the maximum value is a small fraction of Q_0 — $0.38Q_0$, in fact. The parallel-tuned circuit, operated to act as an equivalent inductance, has *at best* only one-third the Q_0 of the coil you start with. The nearer you operate to the parallel-resonant frequency the poorer the Q_e becomes.

"Furthermore, at frequencies much lower than the parallel-resonant frequency the effective series reactance of L_1 and C_1 in parallel is but little more than that of L_1 alone. Thus the only possible benefit that could result from parallel tuning — that is, an effectively larger inductance — is not realized. What reactance is realized is obtained at the cost of spoiling the Q."

It may throw a little more light on the situation depicted in Fig. 4 to adopt a somewhat different viewpoint than that used by Mr. Clapp. The formulas in Fig. 4 are based on varying the frequency applied to a circuit, L_1C_1, of specified constants, whereas, in the case of an oscillator operating on a specific frequency, we are more interested in the effect of different values of capacitance at C_1 when L_1C_1 is used in the oscillator circuit of Fig. 1A. In comparing the performance of the circuits at A and B in Fig. 1 there are two cases of particular interest. One is the case where C_2 has the same value (at the same operating frequency) in both circuits. The other is the case where L_1 has the same inductance value in both circuits (this obviously calls for a lower value of C_2 in Fig. 1A than in Fig. 1B).

In the first case, L_1C_1 must always show the same value of inductive reactance, the inductance of L_1 being adjusted to that end as different values of capacitance are used at C_1. The circuit action can best be visualized graphically by means of the simple vector diagrams shown in Fig. 5. In A the relationship between voltage and current is shown (on an exaggerated scale) for a coil and resistance in series, without a parallel condenser. Because of the resistance, the current I_L and applied voltage E are not exactly 90 degrees out of phase but have some smaller phase angle a. The resistance is the internal resistance of the coil, and the Q of the coil is equal to $2\pi fL/R$, where f is the operating frequency. The ratio of the distance X to distance Y is equal to the coil Q and determines the phase angle.

When a condenser is added in parallel, as in B, a current I_C flows through it, 90 degrees ahead of the applied voltage. To bring the net reactance back to its former value (and thus meet the conditions for the same operating frequency as outlined above) the inductance must be decreased so that the current I_L through it can increase to the point where the projection of the resultant current, I, on the vertical axis is again equal to the distance X. If we assume that the new smaller coil has the same Q as the original coil, the phase angle of I_L will not change. However, the phase angle between the resultant current, I, and the applied voltage, E, is now smaller and is equal to the angle b. The *effective Q* of the parallel circuit is equal to X/Y and is

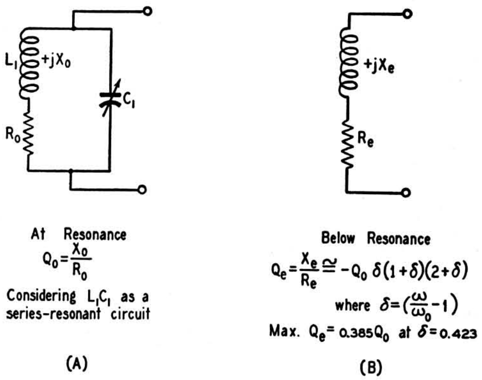

Fig. 4 — **Behavior of a circuit consisting of a coil and condenser in parallel. When operating below the resonant frequency the circuit shows inductive reactance and resistance, and can be represented by the equivalent series circuit shown at B. The effective *Q* is always less than that of the coil alone when the *Q* of the latter is measured at the resonant frequency of the circuit.**

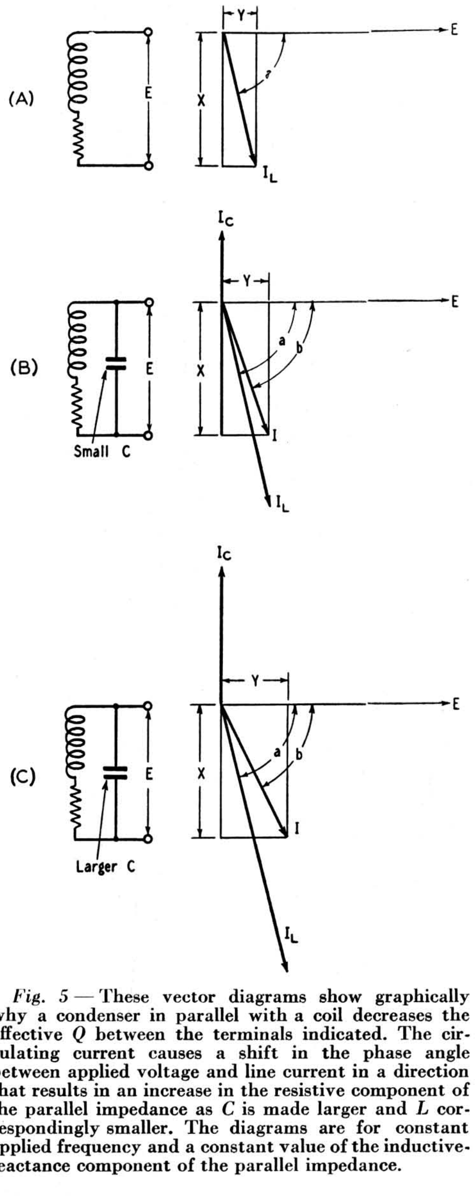

Fig. 5 — These vector diagrams show graphically why a condenser in parallel with a coil decreases the effective Q between the terminals indicated. The circulating current causes a shift in the phase angle between applied voltage and line current in a direction that results in an increase in the resistive component of the parallel impedance as C is made larger and L correspondingly smaller. The diagrams are for constant applied frequency and a constant value of the inductive-reactance component of the parallel impedance.

obviously less than before, since Y has increased.

In C the effect of a still larger capacitance is shown. Because of the increase in I_L (which is still assumed to have the same phase angle, a, as before; in other words, the Q of the still smaller coil is the same as the others) the resultant current I is at a still smaller phase angle with respect to E. The ratio X/Y, the effective Q, is therefore smaller. It is not hard to see that the larger the parallel condenser becomes the worse the effect on the over-all Q of the circuit. In addition, it is doubtful if the smaller coils actually would have as good inherent Q as the larger one. Since the stability of the circuit depends on the steepness of the net-reactance curve shown in Fig. 3 (the slope of this curve in turn is determined by the effective Q) it should be clear that the larger the parallel capacitance the poorer the stability of the oscillator.

In the second case the same coil, L_1, is to be used in both oscillator circuits. If we assume that the capacitances of C_3 and C_4, Fig. 1, are sufficiently large to have no material effect on the tuning, the series-tuned circuit simplifies to Fig. 6A. The source of r.f. is inserted in series at X, and the Q of the circuit is equal to the Q of the coil. The equivalent of the circuit of Fig. 1A is shown at B in Fig. 6, under the same assumption with regard to C_3 and C_4. C_1 plus C_2 in B must be equal to C in A, since the frequency is to remain the same, and the r.f. is inserted between the two condensers as shown. By the argument above, the effective Q of this circuit is less than that of the coil alone, and thus less than that of the circuit of Fig. 6A. Hence the stability is not as good with the parallel condenser as with pure series tuning. Again the reduction in stability depends on how much capacitance is in C_1, Fig. 6B; the smaller C_1 the better the stability becomes.

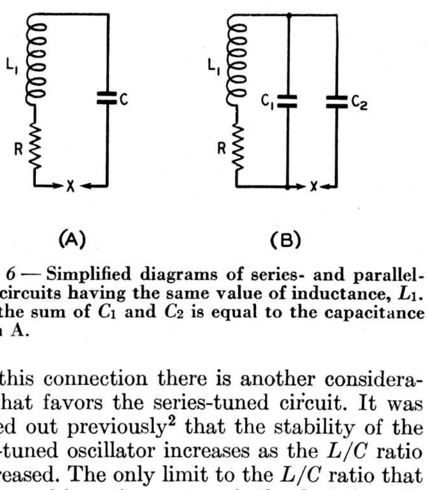

Fig. 6 — Simplified diagrams of series- and parallel-tuned circuits having the same value of inductance, L_1. In B, the sum of C_1 and C_2 is equal to the capacitance of C in A.

In this connection there is another consideration that favors the series-tuned circuit. It was pointed out previously[2] that the stability of the series-tuned oscillator increases as the L/C ratio is increased. The only limit to the L/C ratio that can be used in a given set-up is the Q of the coil; the higher the Q the higher the L/C ratio at which the circuit can be made to oscillate. Now if the capacitance is split into two parts as in Fig. 6B, the series condenser, C_2, is necessarily made smaller than C by the amount of capacitance shifted to C_1. If the circuit of Fig. 6B will oscillate at all under these conditions, it will also oscillate if C_1 is omitted entirely and a larger inductance of the same Q is used at L_1 to restore resonance. The circuit then reverts to Fig. 6A — with a further improvement in stability because of the higher L/C ratio.