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Electronic Oscillators

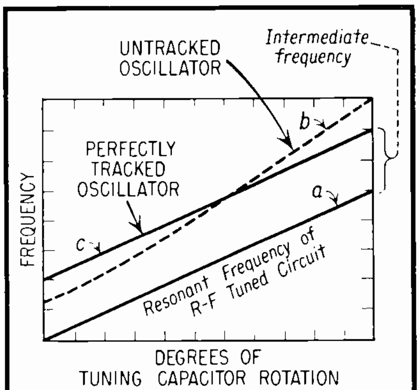
Part 3 - Tracking

By the Engineering Department, Aerovox Corporation

ONE of the most important problems connected with local oscillators in gang-tuned radio receivers is *tracking*. Lower-priced AM broadcast receivers dispense with variable oscillator padders because tolerances of tracking and dial accuracy are relatively large. On the other hand, the better AM broadcast receivers, all-wave receivers, and especially communications receivers, are designed rather carefully for good tracking. Even in a receiver in which the oscillator padder is not variable, the fixed padder capacitor value should be carefully calculated.

The local oscillator frequency must, of course, tune so as to be always separated from the resonant frequency of the r-f tuned circuits by an amount equal to the intermediate frequency. This means that the oscillator tuning range in kilocycles or megacycles must be exactly equal to the tuning range of the r-f tuned circuit.

Suppose the r-f circuit and the oscillator circuit are both tuned by identical sections of a gang capacitor, and the oscillator coil inductance made smaller accordingly. The oscillator frequency cannot be kept equally spaced from the resonant frequency of the r-f section without special tracking measures. Instead, the oscillator frequency varies as indicated by curve *b* of Fig. 1 where curve *a* is that of the r-f tuned circuit. Note that the actual heterodyne signal frequency changes from a relatively small difference frequency at the low end of the range to a relatively high difference frequency at the high end. It is the purpose of tracking circuits to make the oscillator frequency variation such that the r-f to oscillator frequency difference approaches a constant value equal to the intermediate frequency, as illustrated by curve *c*.



RELATION BETWEEN R-F TUNING AND OSCILLATOR TUNING

FIG. 1

One simple way of providing tracking is by use of a smaller gang capacitor section for the oscillator, and "shaping" the rotor plates of the section. This shaping changes the capacitance vs rotation relation of the oscillator section of the capacitor so that it compensates for the deviation of curve *b* from the desired curve *c*. A typical shaped plate appearance is illustrated by Fig. 2. This method of tracking is widely used in low-priced AM broadcast receivers. It has two limitations: (1) it cannot be used in receivers providing more than one frequency band, because the plate shaping is good for only one range and (2) it provides no alignment adjustment for future correction for changes in the circuit constants due to temperature, humidity, dust, aging, etc.

Because of these limitations, the best available tracking method is considered to be that in which two adjustable capacitors are added to the oscillator circuit, as illustrated in Fig. 3. One is connected across the variable tuning capacitor (C_T)

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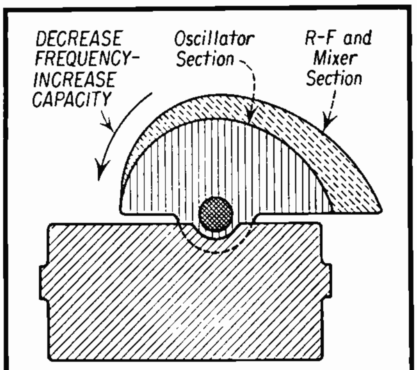


HOW OSCILLATOR CAPACITOR PLATE MAY BE SHAPED FOR TRACKING

FIG. 2

and is called a "shunt trimmer" or sometimes just "trimmer." The other is connected in series with one of the leads between the variable tuning capacitor and the oscillator coil (C_P) and is called a "series padder" or just "padder."

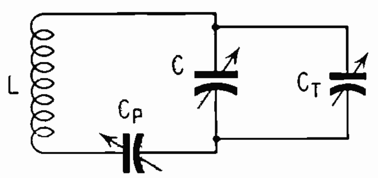
At the high frequency end of the tuning range, the tuning capacitor C is at its minimum value, and the shunt trimmer has a relatively appreciable capacitance. Accordingly the shunt trimmer has a marked effect on the oscillator tuning curve at and near the high frequency end of the range, but negligible effect toward the low frequency end, where the tuning capacitor value becomes very large in comparison.

On the other hand, the series padder has an important effect at and near the low frequency end of the tuning range and negligible effect toward the high frequency end. This follows from the basic fact that when two capacitors are connected in series, variation of one capacitor has its greatest effect on the combined series capacitance when the other capacitor is at its maximum value.

Thus, when the oscillator tuning inductance is properly chosen, the shunt trimmer corrects the high frequency portion of the tuning curve, and the series padder corrects the low portion. If close tracking is required, both of these adjustments are necessary to overcome production tolerances in inductance, distributed capacitance and stray capacitance.

Method of Calculating Tracking Component Values

In order to ensure good tracking, the designer must compute the proper values of L, C_T and C_P to make the oscillator tuning curve approach perfect relation to the r-f tuning curve. To do this, expressions can be set up for the resonant frequency of the



BASIC OSCILLATOR TRACKING CIRCUIT

FIG. 3

combination of the three components in the tuned circuit plus the tuning capacitor section for each point at which oscillator tracking error is to be zero. Absolutely zero tracking error is of course not possible over the entire tuning range. However, the maximum error anywhere can be kept small by calculating circuit constants to give zero error at one or more frequencies. If these frequencies have been properly chosen, the remainder of the tuning curve will be very close to that desired.

The quality of a tracking circuit can be expressed by plotting the oscillator frequency error against frequencies in the r-f tuning range of the receiver, as shown in Fig. 4. Positive errors (oscillator frequency too high) are plotted above the line, negative errors (oscillator frequency too low) below the line. The graph of Fig. 4 shows approximately the error variation resulting from the untracked curve of Fig. 1, curve *b*.

It can be shown that, as L, C_T and C_P approach their proper values, the error curve takes the approximate form shown in Fig. 5. Because of the three variables, the curve equation is a cubic, and crosses the zero axis in three places. These three places are the frequencies of zero error. The proper locations of these frequencies can be determined by making certain assumptions. First, it is assumed that tracking is nearest perfect when the maximum error is the same at all four maximum points; in other words when the curve is symmetrical. By substituting boundary conditions in the general cubic equation, one derives the fact that the zero-error frequencies should be[1]:

$$f_1 = f_c - (f_c - f_a)$$
$$f_2 = f_c$$
$$f_3 = f_c + (f_c - f_a)$$

where

f_1, f_2 and f_3 are the zero-error tracking frequencies

f_c is the center frequency of the r-f tuning range

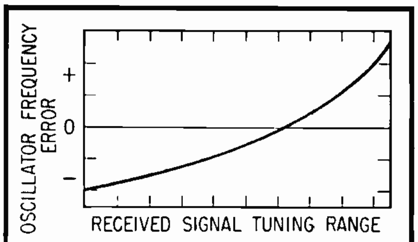
f_a is the frequency at the low edge of the r-f tuning range

For the standard U. S. AM broadcast band of 550-1600 kc, these frequencies come out to be f_1 — 620.35 kc, f_2 — 1075 kc, and f_3 — 1529.65 kc. Of course, individual manufacturers may have other considerations which have led to the use of different tracking frequencies; 600 kc and 1400 kc are widely used for the low and high points. These points (f_1 and f_2) are the ones at which the padder and trimmer capacitors, respectively, are adjusted. The center point should then fall automatically into place, providing the inductance is correct.

In the derivation of design expressions for the values of the shunt and series padder and the oscillator coil inductance, a general expression for the resonant frequency of the oscillator tank including the padder and trimmer plus tuning capacitor is set up. This general expression is then modified to form three expressions, one for each tracking frequency. These are in terms of the r-f tuning capacitor value (usually the same as the oscillator capacitor) and r-f tuning inductance. Solution of these three expressions simultaneously results in equations for the trimmer, padder and inductance. These mathematical operations and the resulting expressions for trimmer and padder capacitance and inductance are quite cumbersome, so will not be repeated here. However, several approaches will be found in the literature[1,2,3].

Practical Modifying Factors

The previously-described treatment is one of several similar approaches to the problem. As mentioned above, other positions may be assumed for the end tracking frequencies, so they are within the tuning range instead of at its edges. Thus, it is common practice to use 600 kc and 1400 kc as low and high frequency alignment points, respectively, for the 550-1600 kc AM broadcast band. The design may also call for the center "zero-error" point to fall at the geometric mean (895 kc for the above range) instead of at the arithmetic mean frequency. Of



ERROR CURVE FOR UNTRACKED OSCILLATOR

FIG. 4

course, this center tracking frequency is important only in initial design, single if the latter is correct the zero point automatically falls into place in subsequent alignment.

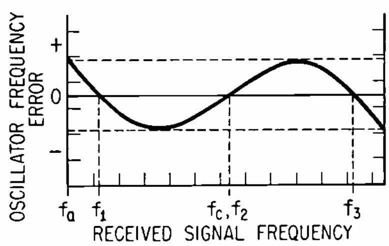
In practice, there must always be a certain amount of "cut-and-dry" adjustment of design values, after the latter have been theoretically determined. This is necessary because of modifying factors such as mutual inductance.

One of the assumptions of most analyses of tracking is that both the signal and oscillator tuned circuits are isolated and that the tuned coil and connected capacitance are the sole factors determining resonant frequency. Without this assumption, the mathematical expressions would become overly cumbersome.

Obviously signal and oscillator coils would be of no use if not coupled to anything. The practical approach is to minimize the reactive component due to coupling, so the calculated tracking values still have practical meaning.

In the signal circuits, this would seem to favor the use of inductive coupling over capacitive coupling. It would also encourage the use of an electrostatic shield between primary and secondary windings of each tuned r-f transformer. By the same token, the oscillator would preferably be inductively coupled to the mixer, when separate tubes are employed, and such coupling would be as loose as possible. In pentagrid converters, a certain amount of space-charge capacitance coupling is of course inevitable.

When the oscillator is of the inductive feedback type, serious modification of the tracking design can result if the tickler coil has too much



THREE-POINT TRACKING ERROR CURVE

FIG. 5

inductance. Tight coupling with low inductance is best, so that the self-resonant frequency of the tickler coil is well above the tuning range limits. If the coupled reactance is too large, it also limits the tuning range, an important factor when the latter is required to be relatively large.

Use of Slug-tuned Coils

In the idealized three-point tracking arrangement of Fig. 5, it is assumed that, although the series and shunt capacitance is adjustable during alignment, the inductance is fixed. This is true in a majority of cases.

Thus, in practical design, the engineer must anticipate what tolerance in fixed inductance value can be allowed consistent with permissible maximum tracking error. Figure 6 shows the effect on three-point tracking of changes in inductance, assuming that, each time the inductance is changed, the trimmer and padder capacitors are readjusted to the predetermined edge or tracking frequencies. Note that as the inductance gets far away from its proper value, there becomes only one point of maximum tracking error, instead of two in the ideal case. The new maximum-error point is also shifted in frequency from its proper value.

In some receivers, notably those of the communications type, the oscillator coil is "slug-tuned" so its inductance can be varied for alignment purposes. Normally, this adjustment substitutes for the series padder adjustment, so the latter can be made fixed. However, since there is only one pair of values for inductance and series capacitance which will satisfy the three-point design, the tolerance of the fixed padder capacitor is now the factor governing the maximum tracking error. The variation of tracking by adjustment of L when the padder capacitance is fixed is shown in Fig. 7. It can be seen that for perfect coincidence with the ideal tracking curve (Fig. 5) both L and series C, as well as shunt capacitance, must be adjustable. This is seldom done in receivers, except in those in which both amplitude and phase of tracking must meet unusually rigid specifications (such as, for example, receivers used with goniometers.)

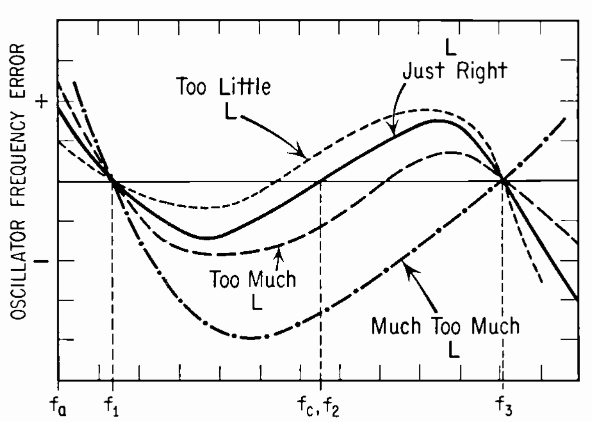
In many selective communications receivers, the *signal* circuits also have series padders or are slug tuned. This is necessary to overcome manufacturing tolerances in both oscillator and signal circuit components, and provides a high degree of tracking accuracy.

REFERENCES

[1]For a complete discussion of this, see "Radio Receiver Design" by K. R. Sturley, pp. 274-280.

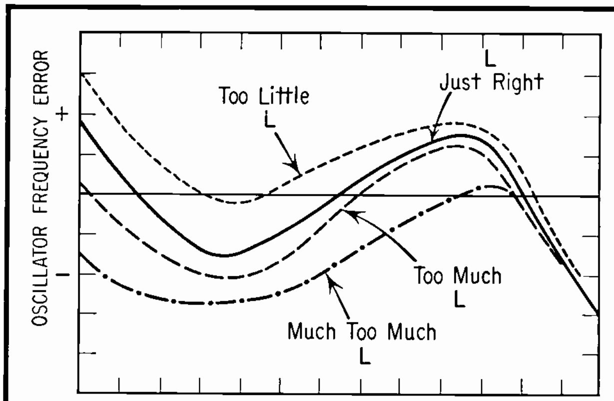
[2]F. E. Terman, Radio Engineer's Handbook, pp. 649-652.

[3]Keith Henney (Ed) Radio Engineering Handbook, pp. 213-215.



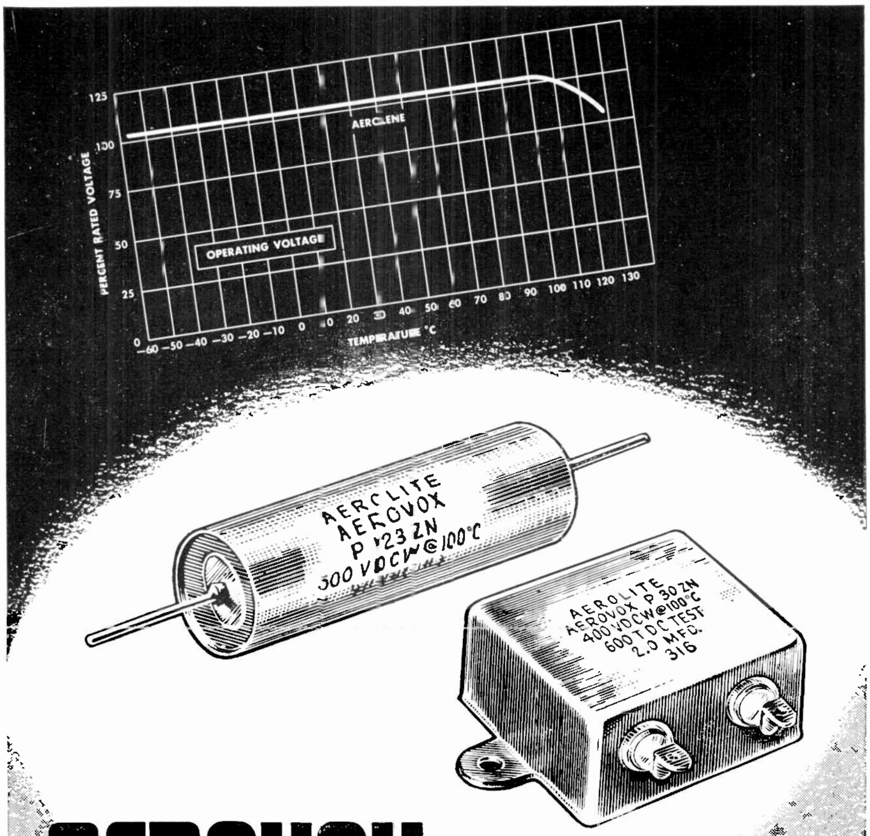
EFFECT OF VARIATION OF L WITH ALIGNMENT ALWAYS ADJUSTED AT f_1 AND f_3

FIG. 6



EFFECT OF VARIATION OF L WITH PADDER AND TRIMMER FIXED

FIG. 7



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