CHAPTER 24

OSCILLATORS

BY B. SANDEL, A.S.T.C.

SECTION 1 : INTRODUCTION

In this chapter it is proposed to consider, briefly, some of the fundamental types of oscillator circuits (used in conjunction with valves) which are commonly employed in radio receivers. Of course there are numerous variations of the fundamental circuits, but generally these changes are only a practical convenience for obtaining some required special condition of operation from the basic circuit.

The types of circuits to be considered are :

(a) The tuned-plate oscillator
(b) The tuned-grid oscillator
(c) The Hartley oscillator
(d) The Colpitts oscillator
(e) The electron-coupled oscillator
(f) The negative transconductance oscillator.

For those interested in the general theory of oscillation, and in the many special circuits available, a list of suitable references is given at the end of the chapter which will serve as a starting point, at least, for a more complete survey of this field of knowledge. Crystal oscillator circuits are not discussed here but a number of useful circuits are given in Refs. 27 (page 164), 26 (page 97) and 31 ; the latter giving a discussion of overtone (harmonic mode) crystal oscillators.

Before proceeding to a discussion of particular types of oscillator circuits, a few of the fundamental principles will be briefly reviewed.

The simplest form of electrical oscillator consists of a combination of inductance (L) and capacitance (C) connected together (as shown in Fig. 24.1), to which has been added, initially, electric or magnetic energy. Suppose that the capacitor C has been charged by some means. The energy stored in the capacitor is then $\frac{1}{2}CE^2$, where E is the maximum potential difference between the plates. At this instant, when E has its maximum value, the current in the circuit is zero. The presence of the inductor will allow the energy stored

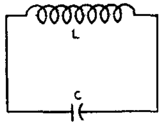

FIG. 24·1

in the electric field of the capacitor to be transferred, and to form a magnetic field around the inductor. The capacitor discharges until finally E becomes zero and the current I becomes a maximum. At the instant at which I is a maximum the energy in the magnetic field is $\frac{1}{2}LI^2$, all the available energy is stored in the magnetic field and there is no electric field. The process now reverses, the magnetic field collapses and energy is transferred back to the electric field of the capacitor. This process repeats itself indefinitely if there is no loss of energy in the circuit (radiation is not considered here).

Since the total energy which is stored in each field in turn, is the same, it is permissible to write

$$\tfrac{1}{2}CE^2 = \tfrac{1}{2}LI^2 \qquad (1)$$

where E and I have their maximum values.

Also $E = 1/\omega C$ (2)

and so $1/\omega^2 C = L$ (3)

or $f = 1/2\pi\sqrt{LC}$ (4)

where f is natural resonant frequency of the oscillations occurring in the circuit.

Since there is always some resistance (R) present with practical circuit elements, the amplitude of each successive oscillation will decrease until eventually all of the energy is dissipated—mainly in the form of heat in the resistance—and the oscillations will cease. (This is discussed further in Chapter 9, Sect. 1). The addition of extra energy to the circuit from some external source, such that the added energy equals that being lost, would allow the oscillations to continue indefinitely. In the circuits to be considered the power supply is the external source of energy, and the valve is the device controlling the energy which is added to the L C R circuit, in the correct phase and amplitude, to maintain oscillations.

With any valve oscillator an exact analysis of the method of operation is very difficult, if not impossible, and it is usual to treat the circuits as being linear (at least for simple design procedure) although they depend on conditions of non-linearity for their operation. This simplification is valuable because the mathematical analysis which can be carried out yields a great deal of useful information concerning the behaviour of the circuits. That the circuit operation is non-linear can be readily appreciated by considering the fact that the amplitude of the oscillations, once started, does not continue to build up indefinitely. The energy gain of the system reaches a certain amplitude and then progressively falls until equilibrium is established. The limits are usually set by the valve—plate current cut-off occurs beyond some value of the negative grid voltage swing, and plate current saturation or grid current damping will limit the amplitude of the grid swing in the positive direction. For a discussion of the factors governing oscillation amplitude, the reader should consult Refs. 1 and 2.

In the sections to follow, typical circuits applicable to radio receivers will be discussed. It is not proposed to give a mathematical analysis or detailed physical explanations of the operation of the circuits, as this has been more or less adequately done in many text books and periodicals. Suitable references are 1, 3, 5, 7, 10, 11, 24.

At the outset it may be mentioned that, since high oscillator efficiency is not usually as important a factor as some other requirements in radio receivers, the design is generally a combination of empirical and experimental techniques. A large number of the circuit component values are pre-determined by such considerations as tracking the tuned circuit with signal circuits over a band of frequencies and maintaining constant oscillator amplitude over the tuning range. Other factors will be discussed in Sect. 9 of this chapter.

Design procedures such as those used for class " C " power oscillators in transmitters are not carried out in detail for receiver oscillators, although obviously the basic principles are the same in both cases ; this will receive further consideration in Sect 9.

SECTION 2 : TYPES OF OSCILLATOR CIRCUITS

(i) Tuned-plate (ii) Tuned-grid (iii) Hartley (iv) Colpitts (v) Electron-coupled (vi) Negative transconductance oscillators.

(i) Tuned-plate oscillator

Fig. 24.2 shows three arrangements for the tuned plate oscillator. Circuits (A) and (B) use series feed, and circuit (C) uses shunt feed. Circuit (B) is the usual practical arrangement of (A) ; P is a padding and C a blocking capacitor.

The shunt feed circuit (C) is generally preferred in receivers for the following reasons :

(1) The rotor plates of the tuning capacitor can be directly earthed without using additional series blocking capacitors directly in the tuned circuit.

(2) The resistor R_1 can often be selected to assist in maintaining a constant amplitude of oscillation over the tuning range, since it will give greater damping of the tuned circuit as the frequency increases.

Either arrangement of the grid-leak resistor (R_g) shown in circuits (B) and (C) is satisfactory, but in circuit (C) it gives increased damping on the feedback winding (L_f) which may be advantageous in maintaining constant grid voltage amplitude over a range of frequencies.

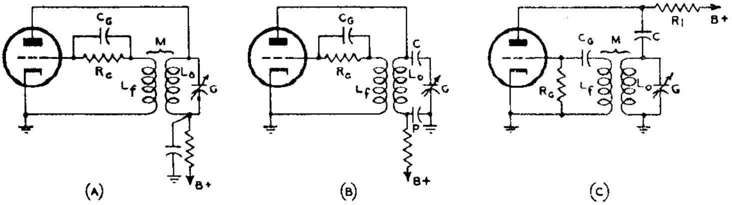

FIG. 24·2 TUNED-PLATE OSCILLATOR

Tight coupling and low values of mutual inductance (M) are helpful in maintaining frequency stability with mains voltage variations, as these factors tend to make the circuit relatively independent of valve constants other than interelectrode capacitances (see Ref. 21). L_f is made as small as possible, to reduce M, and also to keep its natural resonant frequency well above the tuning range ; this latter factor means that stray capacitance across the feedback winding must be kept as small as possible. The high natural resonant frequency for the feedback circuit is helpful in reducing variations in the tuned circuit (due to reflected impedance), this being particularly important since it reduces tracking error and limitations on the maximum possible tuning range.

The resonant frequency (f) of the tuned-plate oscillator is given approximately by

$$f = \frac{1}{2\pi\sqrt{L_0 G}}\sqrt{1 + \frac{R}{r_p}} = f_0\sqrt{1 + \frac{R}{r_p}} \tag{5}$$

where L_0 = inductance in tuned circuit

G = capacitance in tuned circuit (this strictly includes any additional stray capacitances shunted across G, e.g. in circuit (C) some capacitive reactance due to C would be present, depending on the value of R and the frequency of operation)

R = total series r-f resistance in tuned circuit [including in circuit (C) the equivalent series resistance due to C and R_1 being shunted across the circuit]

r_p = plate resistance of valve

and f_0 = natural resonant frequency of tuned circuit alone.

For our purposes it is sufficiently close to take

$$f = f_0 = \frac{1}{2\pi\sqrt{L_0 G}} \tag{6}$$

where G is the actual capacitance (including trimmers, padders etc.) tuning L_0.

The important point to observe is that other components, including the valve, affect the frequency of oscillation. As these components are capable of variation with voltage or temperature fluctuations they will affect oscillator stability, and their effects should be minimized as far as possible. Some improvement in stability is possible by making the grid current small, which agrees with the condition of a low value for L_f, but this is also governed by the permissible value of the grid resistor (R_g).

The condition for the maintenance of oscillation is given by

$$M = -\left[\frac{L_0}{\mu} + \frac{GR}{g_m}\right] \tag{7}$$

where L_0, G and R have the same meanings as previously,

M = mutual inductance = $k\sqrt{L_f L_0}$ (in the absence of additional capacitance coupling)
k = coefficient of coupling
μ = amplification factor of valve
and g_m = mutual conductance of valve.

The negative sign for M indicates that oscillation will only occur for one connection of the feedback winding.

A suitable factor of merit for an oscillator valve is the product μg_m, which should be as high as possible. This is also a suitable factor for power output valves, and explains why types such as the 6V6 beam power valve work well in feedback oscillator circuits.

The advantages claimed for the tuned-plate oscillator are its relative freedom from frequency changes due to mains voltage variations and, when the circuit is used with converter valves, freedom from signal-grid bias voltage changes.

The tuned plate oscillator in its standard form is not very satisfactory for use at frequencies above about 50 Mc/s.

(ii) The tuned-grid oscillator

The general circuit arrangement for a tuned-grid oscillator is shown in Fig. 24.3. Much of the general discussion given in connection with the tuned-plate oscillator is applicable to this circuit.

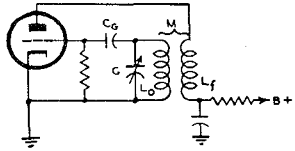

FIG. 24·3 TUNED-GRID OSCILLATOR

The tuned-grid oscillator is probably the most widely used in receivers for the standard long-, medium- and short-wave bands. One of its features is the ease with which oscillation can be obtained. The arrangement of the components offers little difficulty, and one particular advantage is that the tuned circuit is completely isolated from the plate supply voltage.

The approximate frequency of oscillation (f) for this circuit is given by

$$f = \frac{f_0}{\sqrt{1 + \dfrac{L_f R}{L_0 r_p}}} \tag{8}$$

where f_0 = $1/2\pi\sqrt{L_0 G}$ = natural resonant frequency of tuned circuit
L_0 = tuned circuit inductance
r_p = plate resistance of valve
L_f = feedback winding inductance
R = series r-f resistance (total) in tuned circuit
and G = total tuning capacitance.

The minimum value of M required to maintain oscillation is given approximately by

$$M = -\left[\frac{L_f A}{\mu(1 + A)} + \frac{GR}{g_m}\right] \tag{9}$$

where $A = L_f R / L_0 r_p$
μ = amplification factor of valve
g_m = mutual conductance of valve
r_p = plate resistance of valve
and L_f, R and G are as previously.

If r_p is large and R is small, frequency variation from the natural resonant frequency is reduced, as can be seen from an examination of the equation. Also, as a point of interest, it is seen that f is less than f_0 for the tuned-grid oscillator, and greater than f_0 for the tuned-plate circuit ; so that the tuned circuit acts as an inductive reactance (neglecting resistance effects) in the first case, and as a capacitive reactance for the tuned-plate oscillator. These points are further discussed in Ref. 5. The useful upper frequency limit for the tuned-grid circuit is about 50 Mc/s, as the value of the feedback-winding inductance and the resonant frequency of the feedback circuit become troublesome. This applies also to the tuned-plate arrangement.

(iii) Hartley oscillator

Fig. 24.4 shows two possible arrangements for the Hartley oscillator circuit. The circuit (A) is the conventional series-fed circuit, but is not very convenient for use in radio receivers for several reasons.

(1) The tuning capacitor G cannot be earthed without using blocking capacitors.
(2) The presence of blocking capacitors presents tracking difficulties.
(3) The coil L_0 has H.T. applied which may be awkward when making adjustments, particularly during developmental work.
(4) Untracked stray capacitances are likely to be high.

The alternative arrangement of Fig. 24.4 (B) is the circuit most commonly employed in receivers. The tuned circuit is connected directly to ground. This arrangement avoids the difficulties of circuit (A) ; furthermore it is particularly convenient for use with converter valves of the 6SA7, 6BE6 pentagrid type.

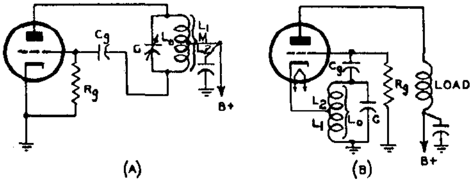

FIG. 24·4 HARTLEY OSCILLATOR

The angular frequency of oscillation for the Hartley circuit of Fig. 24.4(A) (see Ref. 5) is given approximately by

$$\omega = \omega_0 \sqrt{1 + R_1/r_p} \qquad (10)$$

where $\omega_0 = 1/\sqrt{L_0 G}$
$\omega_0 = 2\pi \times f_0$ (f_0 is natural resonant frequency of tuned circuit)
R_1 = r-f resistance of L_1
r_p = plate resistance of valve
L_0 = oscillator coil inductance ($= L_1 + L_2 + 2M$)
and G = tuning capacitance.

For the maintenance of oscillation

$$\mu = \frac{L_1 + M}{L_2 + M} + \frac{G r_p (R_1 + R_2) L_0}{(L_1 + M)(L_2 + M)} \qquad (11)$$

where μ = amplification factor of valve.
L_1 and L_2 are the two sections of L_0 coupled by mutual inductance
M and R_1 and R_2 are the r-f resistances of L_1 and L_2 respectively.

The frequency equation shows that the oscillation frequency f is higher than f_0, and to reduce this difference r_p should be high and R_1 small. Also, for the circuit to oscillate readily, the mutual conductance of the valve should be high.

A Hartley oscillator offers advantages over the tuned-plate and tuned-grid circuits at frequencies in excess of about 40 Mc/s, the greatest advantage being that the feedback winding, being a part of the tuned circuit, does not offer the same difficulties as the other cases, in which the natural resonant frequency approaches the operating frequency.

In the case of the other two types of oscillators mentioned, if the feedback winding has greater inductance than the tuned winding, the oscillator can easily change over from one type to the other (i.e. tuned-plate becomes tuned-grid and vice-versa) and satisfactory tuning is obviously impossible. This trouble is not as unlikely as may be thought since it is often very difficult to obtain sufficient amplitude of oscillation as the frequency increases.

The Hartley circuit can be made to give satisfactory operation to frequencies at least as high as 150 Mc/s, even with multi-grid converter valves (depending, of course, on the valve type used), but its chief disadvantages are

(1) Its liability to parasitic oscillations as the frequency increases,
(2) The possibility of the circuit acting like a modified Colpitts oscillator because of stray and valve interelectrode capacitances,
(3) That it is rather awkward to find the optimum tapping point for the best conditions of oscillation, particularly when the frequency becomes fairly high. This is particularly so with valve types such as the 6BE6 on the F-M broadcast band since the tapping point on the oscillator coil has a large effect on conversion gain.

(1) and (2) generally manifest themselves as sudden changes in oscillation frequency when tuning over the working range, or as " dead " spots, or through the oscillator stopping altogether when the gang capacitance becomes less than a certain value.

It may be mentioned finally that the Hartley circuit has been extensively used on all broadcast bands including the F-M 88-108 Mc/s band ; its application in receivers has been largely confined to use with pentagrid converters such as types 6SA7, 6BE6, 6SB7-Y and 6BA7.

(iv) Colpitts oscillator

A circuit for a shunt fed Colpitts oscillator is shown in Fig. 24.5(A). A suitable arrangement (Ref. 9) for use in radio receivers operating at frequencies of the order of 100 Mc/s is that of Fig. 24.5(B). In this latter circuit C_B is the self-capacitance (plus added capacitance if required) of the choke L in the cathode circuit, and C_A is the grid-to-cathode capacitance ; L_0 is the oscillator coil inductance and G the variable tuning capacitor. The cathode impedance can readily be controlled by connecting a variable trimmer across L.

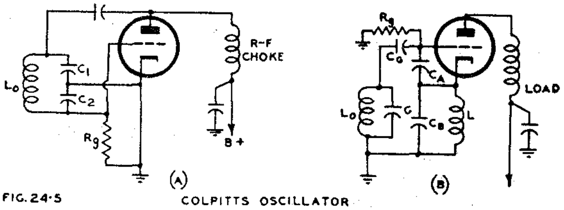

FIG. 24·5 COLPITTS OSCILLATOR

The circuit of Fig. 24.5(B) has been successfully used with type 6BE6 converters tuning the 88-108 Mc/s F-M broadcast band and avoids the necessity for tapping the oscillator coil as in the Hartley circuit.

The angular frequency of oscillation of the Colpitts oscillator, from the solution of the circuit of Fig. 24.5(A), is given by

$$\omega = \omega_0 \sqrt{1 + \frac{R}{r_p}\left(\frac{C_2}{C_1 + C_2}\right)} \tag{12}$$

The condition for oscillation maintenance is that

$$\mu = \frac{C_2}{C_1} + \frac{r_p R(C_1 + C_2)}{L_0} \tag{13}$$

where $\omega_0 = 2\pi \times f_0$ (f_0 is the natural resonant frequency of the tuned circuit alone)
R = r-f resistance of L_0
r_p = plate resistance of valve
μ = amplification factor of valve
L_0 = oscillator coil inductance

and C_1 and C_2 tune L_0 ; they also form a capacitive voltage divider across L_0 ; and the excitation voltage on the grid is proportional to $C_1/(C_1 + C_2)$.

This circuit is most convenient for use at v-h-f, it is very easy to make oscillate, and is not so liable to parasitic oscillations as the Hartley circuit. Its use on the medium and short-wave bands has been rather limited because of difficulties in circuit arrangement when covering frequency bands of about 3 : 1, and also because of the very simple and satisfactory manner in which the tuned-grid and tuned-plate circuits can be made to operate over these ranges. The Colpitts circuit readily lends itself to inductance tuning and with this arrangment has been used satisfactorily on all of the frequency ranges encountered in normal broadcast receiver design.

(v) Electron-coupled oscillator

Electron-coupled oscillators (Refs. 1, 22) can use a large variety of fundamental circuits, such as the Hartley or Colpitts, for generating oscillations. The circuit usually employs a tetrode or pentode valve, or, most often in receivers, is used with a pentagrid converter. Valves having suppressor grids will generally give better frequency stability.

The fundamental principle is that the actual oscillating circuit is connected to the load circuit only by means of the electron stream within the valve. In this way changes in load conditions and high tension voltages have a reduced effect on the actual frequency of oscillation. The improvement in frequency stability with voltage variations appears to be closely bound up with compensating effects due to simultaneous voltage changes on the plate and screen. Variation in load conditions would, ideally, leave the oscillation frequency unchanged since the two circuits are only connected unilaterally through the electron stream. Actually, of course, interelectrode capacitances and stray coupling prevent this condition from being completely fulfilled.

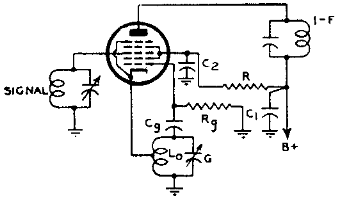

FIG. 24·6 PENTAGRID CONVERTER USING ELECTRON-COUPLED HARTLEY OSCILLATOR

Those pentagrid converters which commonly use the Hartley oscillator circuit arrangement are typical examples of the application of electron-coupling. One such arrangement is shown in Fig. 24.6. It is often advantageous in this type of circuit to connect the screen to the rectifier output through R as this reduces "flutter" ; the high tension for the plate is obtained from the power supply in the usual manner. With this latter arrangement C_2 generally consists of an electrolytic capacitor and a mica capacitor (to act as a r-f by-pass) connected in parallel.

(vi) Negative transconductance oscillators

Several types of negative transconductance oscillators have been suggested using r-f pentode valves. These circuits have a negative bias on the suppressor grid and rely for their operation on the fact that, over a particular range of negative voltage on this grid, the suppressor-screen transconductance is negative. With suitable operating conditions a positive increment in the negative suppressor grid voltage will allow the plate current to increase and the screen current to decrease even when the screen voltage is increased ; the changes in screen and suppressor voltage being approximately equal. The screen and suppressor are coupled together by means of a capacitor, and the tuned circuit is connected in a suitable manner between plate and screen. Detailed descriptions of this type of oscillator can be found in Refs. 7 and 23. Circuits using this arrangement with pentode valves are not very convenient since the negative transconductance is only of the order of -250 micromhos.

Since this oscillator is a two terminal type it is often a very convenient arrangement ; one particular example is its use as a beat-frequency oscillator in a radio receiver. A particular form of the negative transconductance oscillator (Ref. 13)—which employs, also, the principle of electron coupling—using a pentagrid converter valve (e.g. type 6A8, but **not** 6SA7, 6BE6 etc.) is shown in Fig. 24.7. The negative transconductance is brought about as follows. Electrons moving towards the plate are turned back to the inner screen (G_3) and the oscillator anode (G_2) when the control grid (G_4) has a more negative voltage applied to it. The net effect of an increase of negative voltage on the signal grid is to increase the current to the oscillator-anode and to grid G_3.

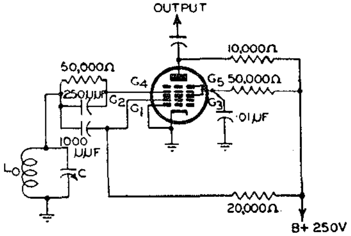

FIG. 24·7 NEGATIVE TRANSCONDUCTANCE OSCILLATOR

Any increase in the current to G_3 is practically offset by a decrease in the current to G_5, the outer part of the screen grid, and the result is that the screen current remains fairly constant for wide variations in signal-grid voltage. The variation in oscillator-anode current, however, is equivalent to a negative transconductance between the control grid (G_4) and the oscillator-anode (G_2). In type 6A8 this amounts to about −400 micromhos. Because of this negative transconductance it is possible to create an oscillatory condition by coupling G_4 to G_2, provided that the rest of the circuit is suitably arranged.

The circuit of Fig. 24.7 has been used at frequencies up to 18 Mc/s. It has also been employed in several types of communications receivers (having intermediate frequencies of from 255 Kc/s to 3 Mc/s) as a beat-frequency oscillator and has given very good results as regards stability of operation, particularly when temperature compensation has been applied to the tuned circuit.

It is near enough, for practical purposes, to take the frequency of oscillation as being

$$f_0 = 1/(2\pi\sqrt{L_0C}) \qquad (14)$$

SECTION 3 : CLASS A, B AND C OSCILLATORS

An oscillator can be made to work under a variety of conditions. The impulses applied to the tuned circuit, to maintain oscillation, can be such that the valve plate current may be flowing from something less than 180° of the electrical cycle to almost the full 360°. Depending on the period for which the impulses are applied, the oscillator may be classified as Class A, B or C.

High quality laboratory oscillators often use the Class A condition, while high power oscillators, such as those sometimes used in transmitters (where efficiency might occasionally be more important than obtaining an output voltage relatively free from harmonics) might possibly use Class C operation ; of course even in high power transmitters a master oscillator is the usual arrangement and efficiency is not an important factor in its operation. Oscillators in superheterodyne receivers do not need to have very high efficiency, but the output must be relatively free from harmonics if whistle interference is not to be a serious problem ; this generally leads to something approaching Class B operation (Ref. 5).

It should be noted that, for all usual operating conditions, grid current flows for at least part of the input voltage cycle.

SECTION 4 : CAUSES OF OSCILLATOR FREQUENCY VARIATION

(i) General (ii) Changes in supply voltage (iii) Temperature and humidity changes (iv) Oscillator harmonics.

(i) General

Frequency drift in the oscillator section of superheterodyne receivers (F-M or A-M) is important for a number of reasons. The most obvious is that as a result of such drift the actual intermediate frequency output from the frequency changer will not be that to which the i-f amplifier is tuned, giving a loss in amplification and the added possibility of considerable frequency distortion in A-M receivers, and non-linear distortion in F-M receivers. Other special effects will be discussed separately.

Oscillator frequency variations which can be offset in the original design may be due to changes in

(a) Supply voltage
(b) Temperature
(c) Humidity
(d) A.V.C. bias on the signal grid of multielectrode converter valves. This will be discussed in Chapter 25 Sect. 2.

Also, it should be noted that a high percentage of oscillator harmonics can lead to oscillator instability. Mechanical stability of the circuit is a prime requirement.

Detailed discussion regarding oscillator frequency stability can be found in Refs. 1, 4, 5, 10, 11, 15, 19, 20, 21 and 28.

(ii) Changes due to supply voltage

Some change in oscillator frequency always occurs when there is a change in the voltages on the valve electrodes, because of changes in valve " constants."

For the simple triode oscillator, plate voltage changes may be minimized by using a supply voltage having good regulation ; the regulation requirement is often determined by the variations in the total current drawn by the complete receiver when the signal voltages are changing. This may necessitate a separate voltage supply for the oscillator valve, and where extremely high oscillator stability is required a separate voltage regulator valve (e.g. OD3/VR150) may be incorporated. A common manifestation of poor regulation of the H.T. is the " flutter " experienced on the short-wave bands.

For screen grid valves the same precautions are taken as for a triode, but often very appreciable improvement is possible, with some valve types, by offsetting screen and plate current changes one against the other. Although the principle of offsetting changes due to various electrodes against each other is of assistance, it should be noted that with some converter valves in which voltage changes are additive (e.g. 6J8-G), better stability is possible than with other valve types (e.g. 6A8, 6K8) in which the plate and screen voltage variations are subtractive. Pentagrid converter valves of the 6SA7 class are particularly critical as to screen voltage changes and a separate screen supply is often essential.

(iii) Temperature and humidity changes

After a receiver has been switched on, it is found that the oscillator frequency tends to alter for some considerable time, up to say an hour or more. Usually it is found that the internal effects of the valve heating up become negligible after a period of about ten minutes. The base of the valve is responsible for a certain amount of drift, but this can be minimized by the use of high-quality porcelain or micanol bases. With the miniature valve types the electrode connections come straight through the button stem instead of through a glass pinch, and the temperature variations due to the complete valve assembly are kept to an absolute minimum.

The most serious frequency drift through temperature changes is generally caused by capacitance variations due to the heating of the various dielectrics in the circuit.

This is minimized by the use of high quality dielectrics such as special grades of porcelain.

Inductance changes due to temperature rise also cause frequency variation, and low-loss dielectric formers are essential. If sufficient mechanical stability is possible air cored coils are often preferable, but not always.

Good circuit layout is an essential requirement and all sources of heat should be kept away from tuning capacitors and coils.

When all the requirements as to dielectrics, circuit layout etc. have been met as far as is possible, final temperature compensation is made by using capacitors having negative temperature coefficients. These capacitors are available commercially in a wide range of capacitance values, and with various negative temperature co-efficients. The manufacture of this type of capacitor is possible because of the availability of ceramic materials having dielectric constants which decrease with an increase in temperature*. It should be realized that exact compensation by simple capacitance adjustment is only feasible, in general, at one point in a given tuning range, but a very appreciable improvement over a band of frequencies is possible without exact compensation at any one point. A method for obtaining exact compensation at two points (although here again a compromise adjustment may be preferable) in a given tuning range, using the principles of superheterodyne tracking, has been given by Bushby (Ref. 19) ; it is also shown that a compromise adjustment is possible, although exact compensation is not practicable, at three points in the tuning range. Methods for carrying out long period frequency-drift compensation, due to temperature changes, are outlined in Ref. 19.

Changes in oscillator frequency with humidity can be minimized by using coils, capacitors and insulating materials which are properly baked to remove moisture and then impregnated (with suitable waxes or varnishes) to prevent the absorption of moisture.†

It may be worth noting here that carbon resistors have negative temperature co-efficients. Wire-wound resistors have positive or negative temperature co-efficients depending on the type of resistance wire used.‡

(iv) Oscillator harmonics

There is an effect, supposed to be due to cross modulation between the fundamental frequency and its harmonics and between the harmonics themselves, which results in the production of currents at the fundamental frequency. These new currents may be out of phase with the original current at the fundamental frequency and so tend to shift the frequency of oscillation. Most of the evidence regarding this effect is experimental and a complete explanation has not been given (see Ref. 1, p. 82). However, it does provide an additional reason for having a minimum of oscillator excitation.

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*See also Chapter 4 Sect. 9(ii)f and Chapter 38 Sect. 3(vi).

†See Chapter 11 Sect. 7.

‡See Chapter 4 Sect. 9(i).

SECTION 5: METHODS OF FREQUENCY STABILIZATION

Some of the causes of oscillator frequency variations have already been discussed, and some general methods of reducing the frequency changes have been outlined. A large number of methods have been detailed in the literature for obtaining frequency stability, such as the use of negative feedback, resistance stabilization and the various methods using reactances as given by Llewellyn (Ref. 21). Since this subject is extensive, we shall content ourselves here with stating a few of the main factors which should be observed when designing an oscillator for a superheterodyne receiver. Suitable references are listed at the end of this chapter.

(A) **Mechanical stability** of all components and wiring should be as good as possible. Care is necessary to avoid mechanical vibration (such as that due to sound waves from the loudspeaker).

(B) **Circuit layout** should be such that sources of heat (e.g. valves) are kept as far away as possible from frequency determining elements. In some cases it may be feasible to place the oscillator coil and tuning capacitor under the chassis, with the oscillator valve mounted on the top of the chassis.

(C) For feedback type oscillators, such as tuned-plate and tuned grid circuits, **the windings should be closely coupled.** The feedback winding should be as small as possible and stray capacitances across it should be low.

(D) **Grid current** should be kept as low as possible consistent with stable operation.

(E) All **supply voltages** should be as constant as possible. With pentodes it may be possible to offset plate and screen current changes.

(F) All **dielectrics** in the circuit should have low temperature coefficients and be non-hygroscopic. This applies particularly to the valve socket which becomes hotter during operation than most other sections of the oscillator circuit.

(G) Efforts should be made to stabilize the electrical constants of all components by suitable **heat treatment and impregnation.**

(H) When designing the oscillator and signal circuits it will be found from the data on superheterodyne tracking given in Chapter 25 Sect. 3, that there is some choice of inductance and capacitance values (due to the distribution of trimming capacitances) even though the frequency coverage and type of tuning capacitor are pre-determined by other conditions. Where it is permissible, **the L/C ratio of the oscillator tuned circuit** should be arranged so that it is as small as possible.

(I) The ***Q* of the oscillator tuned circuit** should be as large as possible consistent with other circuit requirements.

(J) Better stability is possible if the valve can be connected across only part of the tuned circuit. Often this is not convenient in radio receivers because of the reduction in available oscillator voltage, but considerable improvement in stability is possible in those cases where **tapping down** can be applied.

(K) When all other precautions have been taken, **temperature compensation** should be carried out, using capacitors having negative temperature co-efficients [see Chapter 4 Sect. 9(ii)f also Chapter 38 Sect. 3(vi)].

(L) When possible causes of frequency drift are being considered it should not be overlooked that **valve interelectrode capacitances** will change during the initial warm-up period. A typical example occurs in the Hartley circuit of Fig. 24.4(B) in which the heater-cathode capacitance is directly across part of L_0; in this case connecting one side of the heater directly to cathode and adding a suitable r-f choke in series with the other heater lead will minimize the trouble. This arrangement is also helpful in reducing microphonics caused by heater-cathode capacitance variations.

(M) Judicious **location of negative temperature co-efficient capacitors** is helpful. For example if part of the compensating capacitance is located at the valve socket terminals, short-time drift due to the valve and socket warm-up period can often be very appreciably reduced.

(N) The values of R_G and C_G should be selected carefully to **avoid " squegging "** (see Sect. 6). This should be checked with a large number of representative valves of the same type.

(O) Selection of the most suitable **valve type** has received some discussion in previous sections. Usually the choice is rather limited in receiver applications.

(P) **Electron coupling** to the load circuit is often helpful, and is used in many applications. Most frequency changers employ this principle.

(Q) **Harmonic operation of the oscillator** may be advantageous in some cases, since better frequency stability is sometimes possible when the fundamental frequency of operation is reduced. The disadvantage of this arrangement is the greatly increased possibility of spurious frequency combination.

The majority of receivers use the oscillator fundamental frequency, and this frequency is generally (but not always) higher than the received signal frequency. This includes all broadcast bands up to 108 Mc/s.

(R) **Increased spacing between the plates of variable capacitors** is helpful in obtaining good oscillator stability, as the effects of small variations in the position of plates, during operation, is reduced. The opportunity to make use of this occurs, for example, with the variable capacitors used in F-M receivers, where the capacitance range may be approximately 5-20 $\mu\mu$F. In this case it is often possible to use double spacing between the plates of the oscillator tuning capacitor.

SECTION 6 : UNSTABLE OSCILLATION

Unstable oscillation can be due to a number of causes, some of which have been mentioned in Sections 4 and 5.

Flutter has received some consideration and the cure is generally to use a separate series resistor from the power supply to provide the B+ for the oscillator plate (or screen in some converters), by-passed by a large capacitor (say an 8 μF electrolytic).

Squegging (see Refs. 5 and 8) is caused by excessive oscillator-grid voltage amplitude and incorrect proportioning of the values for the grid resistance and capacitance. The effect manifests itself as a variation in oscillator output which changes at an audio or ultrasonic rate. The only precautions usually required are to select suitable values for R_g and C_g and to adjust the oscillator grid current to the lowest suitable value. Most valve manuals suggest that values for C_g should lie between 20 to 100 $\mu\mu$F depending on the operating frequency. Small values of the product $R_g C_g$ are called for at the higher frequencies. The effect should be carefully checked with several valves of the same type. In some cases " squegging " occurs at the high frequency end of the tuning range only, and this often calls for the use of a series grid " stopping " resistor, or a parallel resistor shunted across the oscillator tuned circuit ; these resistors provide greater damping at the higher frequencies and so serve to equalize the oscillator grid voltage across the tuning range.

Other miscellaneous effects which are of interest are :

(A) Hum causing amplitude or frequency modulation of the local oscillator in a receiver.

In A-M receivers the selectivity of the i-f amplifier can cause the frequency modulation to give rise to amplitude modulation (superimposed on the desired carrier) and the hum, after detection, appears in the receiver output, in addition to the hum due to amplitude modulation of the oscillator. With F-M receivers the hum provides additional frequency modulation of the carrier. The cure is generally to improve the power supply filtering.

(B) Frequency modulation, at an audio frequency rate, caused by vibration of the oscillator tuning capacitor plates, or some other part of the oscillator circuit, by sound waves from the loud speaker (often called " microphonics "). This effect is particularly troublesome at the higher carrier frequencies. The natural period of the tuning capacitor is important and any method of altering this often provides a cure ;

this frequency should not coincide with the bass resonant frequency of the loud speaker. Often it is necessary to mount the capacitor on rubber and provide flexible leads to the dial, etc.

(C) Microphonics caused by heater-cathode capacitance variations. This effect is minimized by connecting one side of the heater directly to cathode, where this is possible, and using a r-f choke in the other heater lead to avoid shunting the tuned circuit with the heater circuit, e.g. see Fig. 24.6 where the result of omitting a r-f choke would be to short out part of the tuning inductance.

Microphony in superhet. oscillators is covered in Ref. 32.

SECTION 7 : PARASITIC OSCILLATIONS

" Parasitic oscillation " is the name given to any undesired oscillation in a circuit. Tuned circuits will always have at least one additional resonance point determined by the leads and stray capacitances. Usually in radio-frequency circuits these parasitic oscillations have very high frequencies, but they become troublesome and lead to " dead " spots and large fluctuations in oscillator amplitude if sufficient care is not taken with the arrangement of leads and components. Audio frequency circuits are also liable to this form of oscillation which in this case is generally apparent as distortion.

The usual cure for these troubles is the use of " stopping " resistors (or neutralization in some converter circuits) in series with one or more of the valve electrodes concerned. Care is necessary, however, as the presence of the resistors may adversely affect the performance of the stage concerned.

Carelessness in shunting large capacitors with small ones may result in an undesired resonance. The leads provide the inductance and the circuit may be series resonant in the working range of frequencies. Band-switching in all-wave receivers needs to be carried out carefully if an undesired resonance is not to appear in a tuning range.

For a further discussion of parasitic oscillations the reader is referred to Ref. 8 (Chapter 12, p. 264) and Ref. 5 (Chapter 6, p. 269). Some useful data are also given in Ref. 9, p. 9.

SECTION 8 : METHODS USED IN PRACTICAL DESIGN

In the design of oscillator circuits for radio receivers many of the component values required are specified by other circuit considerations. This is readily seen from the procedure given in Chapter 25 Sect. 3 (in connection with tracking) for determining the value of inductance, and the tuning, trimming and padding capacitance values for the oscillator circuit.

In most cases, once a suitable valve has been selected (the choice here is usually restricted), details of the required grid-leak resistance, oscillator grid current (which in conjunction with R_g determines the grid voltage) electrode voltages etc. are directly available from the valve data sheets. The type of circuit is usually restricted to the tuned-plate, tuned-grid, or the Hartley for frequencies up to about 50 Mc/s and to the Hartley and Colpitts for frequencies above this. It is required of the receiver designer to reproduce, if possible, the specified operating conditions (although this is often a rather tricky job) together with such modifications as he deems necessary.

For the feedback type of oscillator a useful " rule of thumb " is to make the number of feedback turns about half to one third of the total on the main winding ; correct amplitude is obtained by selecting the number of turns to give the required oscillator-grid current. The tapping point on Hartley and Colpitts circuits also approximates, very roughly, to this rule, which provides a convenient starting point for the necessary experimental work.

With the feedback type of circuit, provided that the coupling between the windings is sufficiently high, the number of turns on the feedback winding suggested by the above procedure will usually be somewhat greater than is necessary, and it is only necessary to strip off the excess turns until the required conditions are approached. Of course, this does not immediately ensure that the circuit will be satisfactory in all respects, since the oscillator normally tunes over a band of frequencies. Owing to the tolerances permitted in the manufacture of all valve types, it is necessary to check the circuit with a number of valves. These, preferably, should include samples which fall on the upper and lower limits of the permissible range of g_m allowed by the particular manufacturer, otherwise satisfactory results may not be obtained in the mass production of receivers.

Where the available operating data are given for voltages somewhat different from those required, valve conversion factors (see Chapter 2, Sect. 6) can be applied to obtain the new conditions.

Occasionally a receiver designer is faced with the problem of using a valve for which some data are available, but for which conditions for oscillator operation are not given. Several procedures are available. Exact or approximate methods of analysis can be used, just as for power oscillators (see Refs. 10, 11 and 24), but often it is possible to arrive at a suitable set of operating conditions on the basis of past experience (or by comparison with similar valve types for which the required data are given). The only important factor, as far as the use of the valve is concerned, is that the maximum ratings—including the peak plate current—should not be exceeded. Other factors previously discussed, such as keeping the oscillator grid current as low as possible and operating the valve so that harmonic generation is not excessive, suggest that conditions more nearly approaching Class B operation are called for, particularly as high efficiency with receiving type valves is not often (if ever) a design requirement in a radio receiver.

Once a suitable set of operating conditions has been obtained, experimental techniques are resorted to, exactly as before. Preliminary calculations other than the empirical methods suggested, as to tapping points, number of feedback turns etc., can be made if so desired, but the extra trouble involved is hardly worth the effort.

Methods for calculating the inductance required for feedback windings have been suggested (see Ref. 8, page 117) but generally the results give values which are too low. For this reason the experimental approach is generally the best procedure since it must be resorted to finally, in any case, before a design is completed.

SECTION 9 : BEAT FREQUENCY OSCILLATORS

The use of a beat-frequency (or heterodyne) oscillator is called for in the communications type of receiver ; for example when receiving Morse signals from a c.w. transmitter. The principles involved are fully explained in the usual text books (see Ref. 10, page 446 and Ref. 25, pages 63, 67-70). The output from the local beat oscillator is injected at a suitable point in the i-f amplifier, and when the resultant voltage is applied to the detector circuit together with the received carrier voltage, one of the currents at the detector output has a frequency which is equal to the difference between the frequency of the two applied voltages ; this difference frequency is the one heard in the receiver output.

The amplitude of the local oscillator voltage introduced into the i-f amplifier should be sufficiently large so that it is always considerably greater than the voltage, at the same point, due to the strongest signal likely to be received. If this condition is not observed there will be appreciable loss in signal-to-noise ratio, and so one of the main advantages of this method of reception will be lost. Because the amplitude of the oscillator voltage should be large, very careful screening is necessary if spurious frequency responses are to be avoided, or at least be reduced to negligible proportions.

If locking between the local beat-oscillator and a very strong signal is to be avoided, very loose coupling into the i-f amplifier is called for. This often suggests an oscillator which can be electron-coupled to the load. The circuit of Fig. 24.7 is a particularly useful one for this application, and only requires a single winding for the tuning coil.

However, almost any oscillator circuit is suitable. Variation of the beat-frequency is best accomplished by variation of the beat-oscillator tuning (say a range of ± 3 Kc/s) since it should be clear that the best conditions for reception normally occur when the receiver is tuned exactly to the required carrier frequency.

The a.v.c. should not be operated by the beat oscillator as this would cause a serious loss in receiver sensitivity. For this reason a.v.c. is often disconnected when heterodyne reception of this type is being carried out.

Some receivers have the beat-oscillator voltage injected directly into the diode circuit, but it does not necessarily follow that this is the most suitable point. At the detector the incoming carrier voltage has its largest amplitude, and so the beat oscillator voltage also has to be correspondingly high. A simple solution which is helpful in some cases is to inject the oscillator output voltage into the grid circuit of the last i-f amplifier valve, which can be operated with fixed bias to provide constant gain.

Harmonic operation of the beat oscillator is sometimes helpful in obtaining improved stability and in reducing undesired interference effects.

Considerations as to stability of operation are of prime importance, and the factors previously discussed should be kept in mind when designing this circuit.

Useful data on beat oscillator circuits are given in Ref. 8 (page 128), and also in Refs. 26 and 27.

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Additional references will be found in the Supplement commencing on page 1475.