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Basic Electronic Oscillators

10.1 Instabilities, Oscillations and Oscillators

The possibility of instabilities in amplifiers has been introduced earlier. Because of internal feedback in the active devices, external feedback paths, or connections in the amplifier, a feedback signal proportional to the output is produced. If this feedback signal is in phase with the input, a regenerative situation exists, and if the magnitude of the feedback is large enough, an unstable circuit is obtained. That is, if any input, including noise, is applied to or is present in a circuit which is initially at rest, growing transients occur. After a period of time, these growing transients are sufficiently large to produce a nonlinear response of the circuit elements, and these nonlinearities finally stop the growth of the signals. Eventually, then, steady-state oscillations can occur, and the circuit becomes an (unwanted) oscillator.

The problem in amplifiers is to avoid the possibilities of oscillation by proper design. Ideally, we desire an absolutely stable circuit; however, we may have to settle for a potentially unstable situation. In the latter, cf., Section 9.1, oscillations are possible for some tuning or operational conditions which, of course, are to be avoided for our amplifier.

To achieve the oscillator circuit function, in contrast to the amplifier situation, we must insure an unstable situation. However, we cannot be content with the mere fact that a circuit will oscillate. Our task also includes the development of the oscillatory power at a desired frequency, with a given, adequate amplitude, and with excellent constancy of envelope amplitude and frequency. Therefore, even though an oscillation of some kind is relatively easy to produce, the task of realizing a true oscillator can be even more difficult than for an amplifier. This is true at least for one important reason: nonlinearities are a basic necessity in the oscillator, as indicated above; thus, the governing equations of an oscillator are nonlinear, differential equations. On the other hand, for the amplifier, the basic description can be linear, at least initially, and nonlinearities can often be introduced as perturbations. As a consequence, oscillator analysis and design cannot be as advanced as that for linear circuits.
By and large, typical oscillator analysis involves reasonably simple approximate analyses of linearized or piece-wise-linear-circuit models of the oscillator together with perturbation and power-series techniques. However, there are a few oscillator circuits for which the nonlinear equations can be solved, at least approximately. These are the emphasis of the next two chapters. The results from these special cases provide guides, checks, and insight into the operation and design of all oscillators.

The introduction above implies that the feedback approach is the key issue in oscillators. Feedback, however, is not the entire story. Devices such as the tunnel diode exist which produce a negative-conductance characteristic. These devices, associated with resonant circuits or even $RC$ circuits, can produce oscillations and oscillators. In addition, circuits such as potentially unstable feedback amplifiers can be viewed on the basis of the negative conductance that appears at a port. The situation is, in some respects, like the familiar ‘chicken-and-egg’ controversy. We have two points of view, both of which can be used to achieve and to study oscillators. By suitable manipulation, one can always move from one basis to the other for a given circuit. Nonetheless, each approach has its advantages, and it is helpful to have an appreciation for both. To this end, we consider, in the next section, the negative-conductance (negative-resistance) approach to oscillators. The feedback approach is used with other examples later in the chapter.

For the active devices in this chapter, the bipolar junction transistor (BJT) and the MOS field effect transistor (MOSFET) are used, as well as one negative-conductance device, the tunnel diode. The analysis techniques in this chapter include linear, piece-wise-linear and nonlinear analyses. In this chapter, two basic oscillators are considered that, in a sense, operate in an almost Class-A manner. The excursion into the ‘off’ regions of the device behavior is not great. In the last example in this chapter and in the next chapter, operation corresponding to Class-C behavior is introduced. Deep penetration into the off region of the devices usually is present. From the study of both classes of oscillator, a general oscillator situation usually can be explored leading to adequate design and operational information.

### 10.2 The Ideal Electronic Oscillator

An electrical model of an ideal, harmonic oscillator is shown in Figure 10.1a and is a lossless $LC$ circuit. Since the circuit is lossless, energy is conserved once the circuit is excited and alternates between electrical and magnetic forms. The voltage and current are pure sinusoids.

The electrical-circuit equations for this circuit lead to the differential equation

$$\frac{d^2v}{dt^2} + \omega_0^2 v = 0$$

(10.1)