PRACTICAL OSCILLATOR HANDBOOK

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Preface

The subject of oscillators has been somewhat of a dilemma; on the one hand, we have never lacked for mathematically oriented treatises—the topic appears to be a fertile field for the 'long-haired' approach. These may serve the needs of the narrow specialist, but tend to be foreboding to the working engineer and also to the intelligent electronics practitioner. On the other hand, one also observes the tendency to trivialize oscillator circuits as nothing more than a quick association of logic devices and resonant circuits. Neither of these approaches readily provides the required insights to devise oscillators with optimized performance features, to service systems highly dependent upon oscillator behaviour, or to understand the many trade-offs involved in tailoring practical oscillators to specific demands. Whereas it would be unrealistic to infer that these two approaches do not have their place, it appears obvious that a *third* approach could be useful in bringing theory and hardware together with minimal head-scratching.

This third approach to the topic of oscillators leans heavily on the concept of the universal amplifier. It stems from the fact that most oscillators can be successfully implemented with more than a single type of active device. Although it may not be feasible to directly substitute one active device for another, a little experimentation with the d.c. supply, bias networks, and feedback circuits does indeed enable a wide variety of oscillators to operate in essentially the same manner with npn or pnp transistors, N-channel of P-channel JFETs, MOSFETs, op amps or ICs, or with electron tubes. Accordingly, this book chooses to deal with basic operating principles predicated upon the use of the universal active-device or amplifier. This makes more sense than concentrating on a specific device, for most oscillator circuits owe no dependency to any single type of amplifying device.

Once grasped, the theory of the general oscillator is easily put to practical use in actual oscillators where concern must be given to the specific active device, to hardware and performance specifications, and to component values. To this end, the final section of the book presents numerous solid-state oscillators from which the capable hobbyist and practical engineer can obtain useful guidance for many kinds of projects.

It is felt that the reader will encounter little difficulty acclimatizing to the concept of the universal amplifier, for it is none other than the triangular symbol commonly seen in system block diagrams. Although it hasn't been widely used in conjunction with other circuit symbols, the combination works very well with oscillators. It is respectfully submitted that this book will thereby serve as a unique format for useful information about oscillators.

The symbol used for a.c. generator is usually assumed to be a constant voltage generator, i.e., with zero internal resistance. However, in many instances in this book, it must be assumed to be a constant current generator, or at least to have a high internal resistance. For example, this is the case in Fig. 1.41, where if the generator shown is an ideal voltage generator, it will short out L_1. This will alter circuit operation and make the quoted formula for f_0 wrong. It is recommended therefore that the reader bear this in mind when presented with an a.c. generator in this book.

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1 Frequency-determining elements of oscillators

A good way to understand oscillators is to view them as made up three essential sections. These are:

- the frequency-determining section
- the active device
- a source of d.c. power

The validity of this viewpoint does not require that the three sections be physically separate entities. This chapter will treat the characteristics of the elements involved in the frequency-determining section.

Parallel-tuned LC circuit

Academically and practically, the parallel LC arrangement known as a 'tank' circuit is the most important element for us to become familiar with. In its simplest and most frequently encountered form, it is made up of a single inductor and a single capacitor. Whether or not we desire it, the inevitable 'uninvited guests', a number of dissipative losses, are always present. (See Fig. 1.1.) In the circuit, these losses behave as resistances. Their presence can, indeed, be closely simulated by simple insertions of resistance into the tank circuit. In Fig. 1.2 we see a possible way in which this can be done. This is the most convenient method and will be used frequently in the equations for computing the various tank circuit quantities.

Losses in a tank circuit

Different losses predominate under different situations. In general, the higher the frequency, the greater the radiation loss. Magnetic hysteresis is

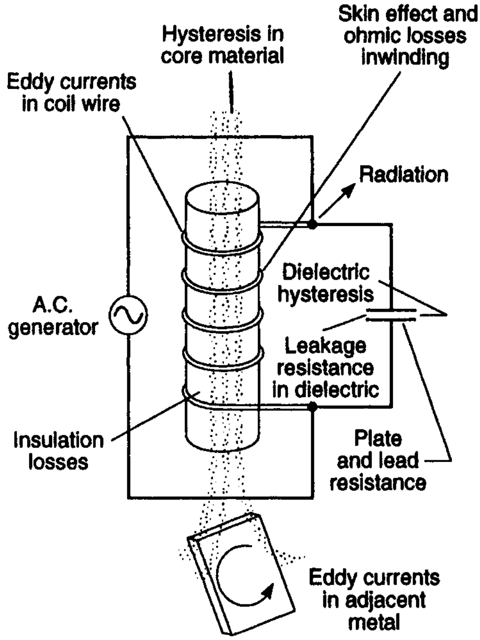

Fig. 1.1 *Some possible losses in an LC tank circuit*

only of consequence when a ferromagnetic core is used, such as powdered iron. The losses due to eddy currents are, in reality, brought about by transformer action in which the offending material constitutes a short-circuited 'secondary'. This being true, we must expect eddy-current losses in the cross-section of the coil winding itself. Skin effect is an a.c. phenomenon that causes the current to concentrate near the surface of the conductor. This is because the more central regions of the conductor are encircled by more magnetic lines than are the regions closer to the surface (see Fig. 1.3). The more lines of magnetic force encircling a conductor, the greater the inductance of the conductor. Hence, the central regions of a conductor carrying alternating current offer higher inductive reactance to the flow of current.

The higher the frequency, the more pronounced is this effect; that is, the greater the tendency of current to concentrate at or near the surface, thereby reducing the effective cross-section of the conductor. Because of skin effect, the resistance offered to the passage of high-frequency current is much higher than the d.c. resistance. (Inductance does not affect the flow or distribution of d.c.) We are not surprised that skin-effect losses are reduced by using hollow conductors of copper content equal to small gauge wire, but which possess a much greater surface area. Also, stranded wire offers more surface for high-frequency conduction than does its 'd.c. equivalent'

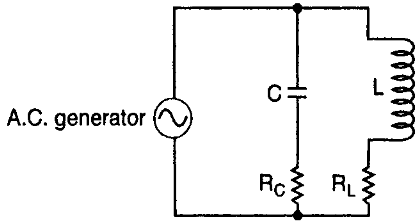

Fig. 1.2 *Representation of losses in an LC tank circuit by series resistances* R_L *and* R_C

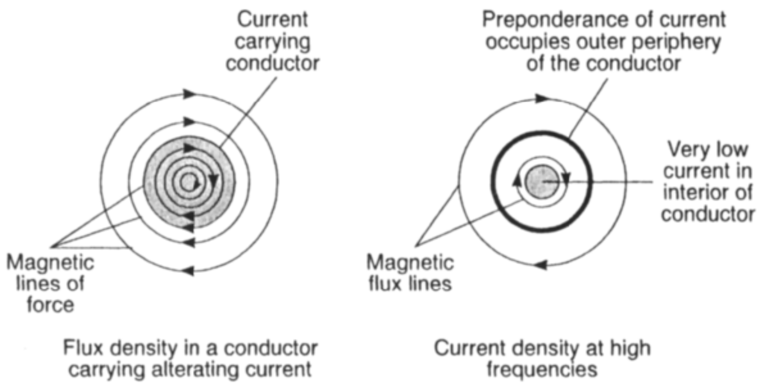

Fig. 1.3 *Flux-density from A.C. in a conductor and the high frequency skin-effect. At low frequencies most of the current flows throughout the cross-section of the conductor. At high frequencies, almost all current is in the outer 'skin' of the conductor*

in solid wire. Stranded wire with each individual wire insulated (Litz wire) is particularly well suited for the flow of high-frequency current.

Dielectric hysteresis in insulating materials is the electrostatic counterpart of magnetic hysteresis in magnetic materials. A frictional effect is displayed by the polarized molecules when they are urged to reverse their charge orientation under the influence of an alternating electric field. There are other losses. Those described and those shown in Fig. 1.1 are, however, the most important. Significantly, in many applications, only the losses in the inductor are of practical consequence, for capacitors often have negligible losses from the standpoint of many practical oscillator circuits.

Characteristics of 'ideal' LC resonant circuit

We find ourselves in a much better position to understand the proprieties of an actual 'lossy' tank circuit by first investigating the interesting characteris-

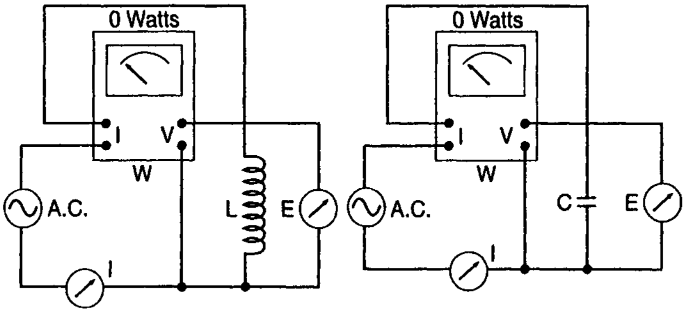

Fig. 1.4 *Voltage and current in an ideal inductor and capacitor*

tics displayed by an 'ideal' tank circuit in which it is postulated that no losses of any kind exist. It is obvious that such an ideal tank circuit must be made up of an inductor and a capacitor that, likewise, have no losses. In Fig. 1.4, we see the important feature of such ideal elements, i.e., when an a.c. voltage is impressed across an ideal inductor or an ideal capacitor, current is consumed, but no power is dissipated. Although there is current through these elements, and voltage exists across them, the wattmeters show a zero reading. This may seem strange at first; such a situation is the consequence of the 90° difference in phase between voltage and current. This phase condition is shown in Fig. 1.5 for the ideal conductor, and in Fig. 1.6 for the ideal capacitor.

In both instances, power is drawn from the source for a quarter cycle, but is returned to the source during the ensuing quarter cycle. This makes the power frequency twice that of the voltage or current waves. This need not be cause for surprise, since the same situation prevails for a resistance energized from an a.c. source. It turns out that the double-frequency power curve is of little practical consequence as such. Of great importance is the fact that the negative portions of the power curves in Figs 1.5 and 1.6 represent power returned to the source; conversely, in the resistance circuit of Fig. 1.7 we note there are no negative portions of the power curve. (All the power drawn by the resistance is dissipated as heat and/or light; *no* power is returned to the source at any time.)

Negative power

We observe in Figs 1.5 and 1.6 that sometimes the voltage is positive when the current is negative and vice versa. By the algebraic law of signs (the product of quantities having unlike signs yields a negative number) it is just such occurrences that produce the negative excursions of the power waveform. Also, every time either voltage or currently crosses the zero axis, the power wave must also cross the zero axis. (Zero times any number is zero.) Inasmuch as the power curve results from multiplying instantaneous voltage