18

Special Problems in Oscillators

18.1 INTRODUCTION

This chapter considers some problems encountered in oscillators. Some of these problems exist in all high-frequency circuitry. Others are peculiar to oscillators. Many of these problems are due to transistor parasitic elements and to the oscillator physical layout and could, therefore, not be included in the design procedures. Others could have been anticipated by the designer and the design should therefore have been performed so that these problems are not encountered.

The chapter discusses the probable cause of these problems and suggests some possible cures.

18.2 SPURIOUS OSCILLATIONS

Spurious oscillations are oscillations other than those due to the crystal responses. Most spurious oscillations are caused by the parasitic inductance and capacitances in the transistors, by the parasitic inductances and capacitances created by poor design and circuit layout, and by ground loop couplings caused by poor design and circuit layout.

Oscillations are also caused by inductors used for adjusting the oscillator frequency and for neutralizing the C_0 of the crystal.

18.2.1 Transistor Parasitic Elements

Spurious oscillations due to transistor parasitic elements can be eliminated by resistors placed in series with the transistor collector and base circuits, preferably located adjacent to the transistor. At very high frequencies, lossy ferrous beads are effective.

18.2.2 Layout Parasitic Elements and Couplings

One of the most important steps in designing the completed oscillator is making the physical layout of the components for the oscillator. Unfortunately, this task is usually relegated to a draftsman who makes the layout on the basis of fitting the components into the available space with little or no regard to, and understanding of, the lead inductances and capacitances and undesirable couplings between the various circuits. This causes spurious oscillations as well as poor isolation. These spurious oscillations an be eliminated by additional bypassing and inserting lossy elements in the circuits, but at the cost of deteriorating the basic oscillator performance. It is not a rare occurrence for the breadboard model to operate well but for the final layout model to be plagued by spurious oscillations. This indicates that more attention should have been paid to the layout.

18.2.3 Spurious Oscillations Due to Poor Design

Poor design includes insufficient or incorrect decoupling and the creation of unnecessarily large circulating currents in the ground plane. Figure 18.1 shows an example of a tuned circuit having a Q of about 10. Figure 18.1*a* shows the correct method of bypassing since the bypass capacitor, C_{bp}, and the ground plane carry only 1 mA. Figure 18.1*b* shows the incorrect method since C_{bp} and the ground plane carry 9 mA, which can cause much larger undesirable coupling to adjacent circuits. In addition, the latter method also requires a larger value and better C_{bp} since it is a larger part of the tuned circuit.

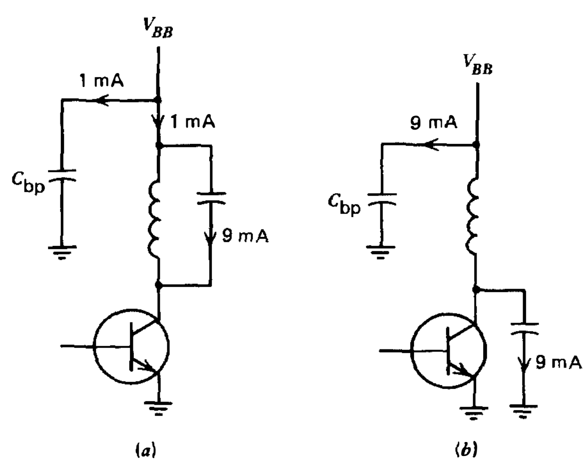

Figure 18.1 Examples of bypassing. (*a*) Correct. (*b*) Incorrect.

18.2.4 Oscillation Caused by the Frequency Adjusting and C_0 Neutralizing Inductors

Frequently, because of the crystal calibration error or because it is desired to pull the oscillator frequency a relatively large amount as in VCOs, an inductor is placed in series with the crystal. Also, at very high frequencies, where the crystal operates near series resonance, a C_0 neutralizing capacitor is placed in parallel with the crystal. Both of these inductors produce an additional resonance which may cause spurious oscillations. These oscillations may be suppressed by "de-Qing" the inductor, which consists of placing a resistor in parallel with the inductor. A recommended value for the resistor is

$$R \geqq 10 X_L \tag{18.1}$$

where X_L is the reactance of the inductor at the operating frequency.

The price of the resistor is that the oscillator performance is deteriorated by decreasing the operating Q.

18.3 SPURIOUS SIGNALS DUE TO CRYSTAL RESPONSES

Figure 3.16 shows that the true crystal equivalent circuit is not that of Fig. 3.5 but is much more complex. Each branch of the circuit, called a mode, can produce a signal near the mode resonant frequency, provided that the oscillator circuit conditions are such as to maintain the signal. The strength of the mode is measured by the mode resistance, being inversely proportional to the resistance.

Typical modes are:

1 Fundamental, third overtone, and so on, which are predictable.
2 a, b, and c modes in SC-cut crystals, which are also predictable. Each overtone has a set of a, b, and c modes.
3 Spurious modes which are generally unpredictable as they depend upon the crystal manufacturing process. These modes are normally weak compared to modes 1 and 2.

18.3.1 Spurious Overtone Signals

These can be easily suppressed using the techniques described in Chapter 5.

18.3.2 Strong Spurious Mode Signals[18.1]

These, too, can be suppressed by means of techniques described in Chapter 5, but with greater difficulty. If the techniques are not properly applied, it is possible for a strong spurious signal to exist at the b mode frequency, particularly in self-limiting oscillator circuits. To minimize the possibility of generating the spurious signal, the mode selector circuitry should be checked for adequate safety margin as described in Section 19.6.3.2.

Reference 18.2 discusses a circuit configuration wherein the desired modes can be selected by adjusting the transistor-bias conditions. However, it is not considered practical.

There are cases where it is desired that both the b and c modes exist simultaneously. In those cases, it is usually required that the oscillator output signal magnitudes be almost equal, but the crystal b mode drive be controllably less than the c mode drive. Oscillators with these characteristics have been constructed and operate as desired.

18.3.3 Weak Spurious Signals

Often when the oscillator output spectrum is examined, very weak signal components corresponding to the weak modes are found. Their amplitude may be 60 dB below the principal signal or smaller. These weak signals are not true oscillations but noise enhanced by the crystal spurious modes. The mechanism, by which the noise is enhanced, is not well understood. Qualitatively, it seems reasonable that such enhancement could result from a recirculation of the noises, at the weak mode frequencies, at those discrete frequencies where the corresponding mode motional impedance can provide essentially 360° loop phase closure even though the gain condition for the oscillation cannot be satisfied.

The above type of spurious oscillations can only be effectively reduced by additional filtering.

18.4 SQUEGGING

By squegging (sometimes called motorboating) is meant the self-produced amplitude modulation of the high-frequency oscillation. This is caused by interaction between the time constants of the bias and coupling circuits and the time constants of the high-frequency tuned circuits of the oscillator loop. The low-frequency variations of the envelope of the high-frequency signal may be sinusoidal, exponential, or trapezoidal.

This phenomenon is more likely to be present in self-limiting oscillators having relatively low operating Q's. Crystal oscillators have high operating Q's and are therefore free from squegging. Where squegging does appear to be present in a crystal oscillator, it is more likely to be a spurious oscillation at a frequency close to the desired frequency and should be eliminated in the same manner as any other spurious oscillation.

Squegging can be stopped by

1 Reducing the bias and coupling time constants (the coupling time constant has greater effect).

2 Raising the operating Q.

3 Reducing the active element driving voltage.

For a more detailed treatment of squegging see Ref. 2.3.

18.5 CRYSTAL PHYSICAL LOCATION AND CONNECTIONS

Another oscillator problem, associated with poor layout, is the location of the crystal and its connections to the rest of the oscillator circuitry. It is important that the crystal leads be made as short as possible so as not to increase the effective C_0. This is particularly true for ovenized oscillators where the crystal is operated in its inductive region and, for thermal reasons, it is located relatively distant from the circuitry. The result of increasing the effective C_0 is to make it harder to set the oscillator to its specified operating frequency and to magnify the effective crystal resistance, R_{df}, which in turn decreases the operating Q and may even cause the cessation of oscillation.

If the leads to the crystal must be long, then the means of adjusting the oscillator frequency, such as the trimming capacitor, inductor, and varactors should be located very close to the crystal.

18.6 OSCILLATOR STARTING

After the steady state performance of the oscillator has been evaluated as being satisfactory, the oscillator should be checked for good starting characteristics. A rule of thumb is that the starting time does not exceed $\frac{1}{2}$ s unless the specifications require a shorter starting time. In general, higher Q circuits tend to have larger starting times.

If the starting time is excessive or it does not start, the small signal loop gain should be increased sufficiently to insure satisfactory starting. As described in Chapter 3, the crystal resistance at zero current, which is the current at the moment of starting, is considerably larger than the resistance at the operating current. Therefore, the actual small signal loop gain is smaller than that calculated with the normal resistance and due allowance should be made for this increase of crystal resistance.

The larger zero current resistance phenomenon also goes far toward explaining many of the hystereris effects such as that illustrated in Fig. 18.2.

The starting problems are more pronounced in the self-limiting and gate type oscillators. The ALC oscillator has the advantage that the small-signal gain can be made very large since the frequency generating function is independent of the limiting function and therefore starting can be readily facilitated. Some oscillators are so difficult to start that they are provided with auxiliary starting circuits. A contrary situation, wherein the oscillator does not start because of excessive small-signal gain is described in Ref. 18.3.

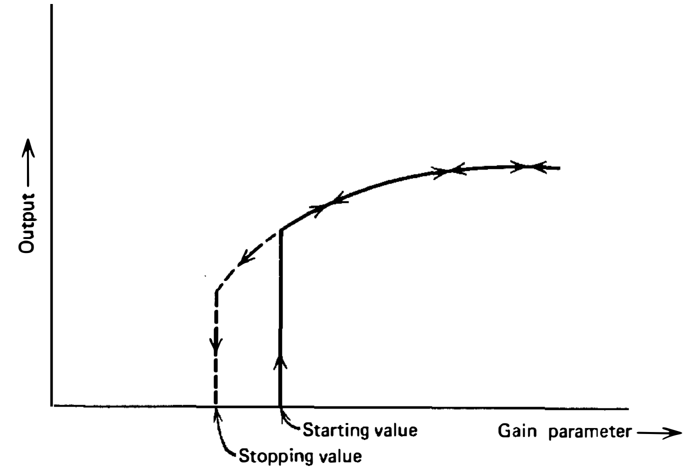

Figure 18.2 Hysteresis effects in oscillator stopping and starting.

18.7 ISOLATION

By isolation is meant the effect of changes in the load impedance upon the oscillator frequency. As stated in Table 12.1, the isolation of the basic oscillators is relatively poor. To improve the isolation, the cascode amplifier of Fig. 13.10 and/or the neutralized C_{cb} amplifier of Fig. 18.3 are interposed between the oscillator and the load. Using these types of amplifiers, almost any degree of isolation required can be obtained. However, where extremely good

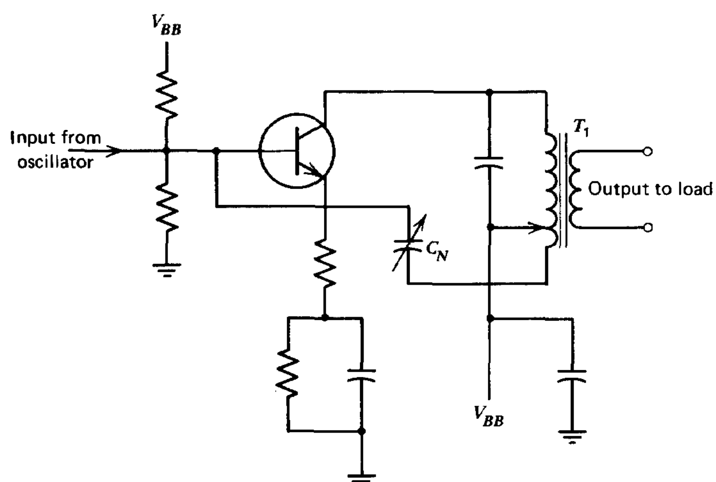

Figure 18.3 Neutralized C_{cb} isolating amplifier.

isolation is necessary, care must be taken that the power supplies are adequately decoupled and that coupling via ground currents is minimized.

18.8 AGING OF COMPONENTS

In addition to the noise generated by the various components, as described in Chapter 14, the components also have long-term effects which can be classified as aging. Over long periods of time the components gradually change value which, in turn, cause oscillator frequency changes which cannot be distinguished from the aging of the crystal. The aging of the components set limits to the minimum possible aging of any oscillator. On the other hand, if the aging of the components and the crystal can be controlled, it can be used to cancel the crystal aging and thus a morstable oscillator may result.

The total aging of the components can be evaluated using the llator evaluation technique described in Chapter 17.

Typical aging rates per day are:

2-μH toroid coil wound on phenolic form with O.D. of 0.12 in.	− 2 ppm
Porcelain capacitor	± 3 ppm
Silver mica capacitor	− 30 ppm
Glass capacitor	− 70 ppm
Ceramic capacitor	± 10 ppm

18.9 *OSCILLATOR* TESTING

To ensure that none of the problems described in this chapter are present in the prototype models or final units of the oscillator, the prototypes and sample quantities of the final units should be tested for the presence of these problems.

The overall performance of the *oscillators* should be checked for compliance with the applicable items of Section 4.8 of Ref. 13.8 and the sample specifications in Section 1.4.3.