# 12

# Algorithms

## 12.1 INTRODUCTION

This chapter presents the algorithms for the single bipolar transistor self-limiting oscillators described in Chapters 7 to 11. Obviously, the reader must first select the circuit most suitable for a particular application. Table 12.1 has been prepared to aid in making the selection. This table lists the relative performance characteristics of each circuit.

Strong efforts have been exerted to list quantitative data but, unfortunately, this has been found impractical in the cases of isolation and frequency stability because of the complex nature of these characteristics.

The table shows that, in most of the circuits, the isolation is poor, particularly for reactive changes in the load. In those cases where good or excellent isolation is required, the oscillator must feed an isolating amplifier. This subject is further discussed in Chapter 18. Although the characteristics in the table have already been fully defined, for convenience the table column headings are explained below.

### 12.1.1 Explanation of Column Headings for Table 12.1

#### *12.1.1.1 Frequency Range*

By frequency range is meant the frequency $f$ at which the circuit will operate with a suitable crystal. As indicated by the notes, the frequency range is influenced by many factors.

#### *12.1.1.2 Relative Frequency Stability*

This indicates the contribution of the circuit to the stability of the oscillator, assuming that the same crystal is used and the circuit is properly designed for that crystal.

**Table 12.1 Self-Limiting Bipolar Transistor Oscillator Circuit Selection**

| Oscillator Type | | $f$ Freq. Range MHz | Relative Frequency Stability | $\frac{P_L}{P_x}$ | Isolation | Alg. | Chap. | Notes $a$ |
|---|---|---|---|---|---|---|---|---|
| Normal Pierce | Coll. lim. | 0.5 to 50 | Medium | $< \frac{1}{2}$ | Poor | 12.1 | 7 | 2, 4 |
| | *be* lim. | 0.5 to 75 | Highest | $< \frac{1}{2}$ | Poor | 12.2 | 7 | 1, 2, 4 |
| Isolated Pierce | | 1 to 30 | Medium | to 200 | Good for $R$ Poor for $X$ | 12.3 | 8 | 5 |
| Normal Colpitts | Coll. lim. | 1 to 40 | Medium | $< \frac{1}{2}$ | Poor | 12.4 | 9 | 2, 4 |
| | *be* lim. | 1 to 60 | High | $< \frac{1}{2}$ | Poor | 12.5 | 9 | 1, 2, 4 |
| Semi-Isolated Colpitts | $M = 1$ | 1 to 30 | Medium | to | Poor to | 12.6 | 10 | 2, 3, 4, 5 |
| | | | High for Lo $\frac{P_L}{P_x}$ | 20 | Good | 12.6 | 10 | 4, 5, 6 |
| | $M \neq 1$ | 1 to 60 | High | to 100 | Very Good | | | |
| Butler | $X_A = 0$ | 20 to 200 | Medium | to 100 | Poor | 12.7 | 11 | |
| | Stable | 20 to 200 MHz | Medium | to 100 | Poor | 12.8 | 11 | |

[a]Please note the following: (1) $P_L$ dependent on $R_{df}$. (2) Suitable for a range of frequencies without tuning, for $N = 1$. $P_L$ dependent on $f$. (3) Upper frequency increases as $P_L/P_x$ decreases. (4) Upper frequency decreases as $I_x$ increases. (5) $P_L/P_x$ decreases as $f$ increases. (6) $f_L = Mf$.

#### *12.1.1.3* $P_L / P_x$

This signifies the ratio of the output power $P_L$ to the crystal dissipated power $P_x$. The reader is cautioned that, while high values of $P_L / P_x$ appear desirable, as $P_x$ decreases, in general, the long-term stability improves and the short-term stability deteriorates.

#### *12.1.1.4 Isolation*

By isolation is meant the effect of changes in the load impedance upon the frequency $f$.

#### *12.1.1.5 f and Mf*

By $f$ is meant the frequency actually generated in the oscillator. $Mf$ is the frequency available at the output terminals of the semi-isolated Colpitts oscillator. It is derived from $f$ by multiplying action with the multiplication factor $M$.

## 12.2 GENERAL DISCUSSION OF THE ALGORITHMS

### 12.2.1 Resonator Description

The algorithms have been prepared for oscillators with crystals and associated components, operating in all the useful overtones and modes. However, the algorithms are easily adaptable for replacement of the crystal network by another two-terminal network as described in the discussion chapter (see Chapters 7 to 11) for the particular algorithm. Of course all the material in the algorithm concerning overtone and mode operation should be then disregarded.

### 12.2.2 Form of the Algorithm

#### *12.2.2.1 A Common Input Section*

Each algorithm consists of a common input section and additional pages as required by the specific oscillator being designed.

The input section contains the input information which falls into the following four categories:

**a** Oscillator performance requirements and the power supply voltage.

**b** Crystal resonator characteristics both directly specified and calculated as described in Chapter 3. Much of this information is not strictly necessary for the basic oscillator design but will be necessary for computing the frequency changes due to variations in parameters. The $R_{df_{max}}$ is always used to ensure that the oscillator loop gain always increases with other crystals of smaller $R_{df}$.

**c** Transistor characteristics. The information in this category is most difficult to obtain and very often estimates must be made from whatever data are available. At times one must even resort to guesswork, particularly as to the values of the various capacitances. For completeness, this category includes several parameters, $BV_{CB}$, $BV_{EB}$, and $P_{dis}$ not mentioned in the design algorithm, but which may be exceeded, so one should be aware of them.

**d** Circuit Parameters. These are parameters usually associated with the type of limiting used in the specific circuit.

The algorithms do not allow for component losses except where specifically stated in the algorithm. Therefore, when highly lossy components are used, the calculated circuitry may be substantially in error, unless they are included in $R_L$.

#### *12.2.2.2 Schematic Diagram*

Each algorithm includes a schematic diagram which shows all the physical components, except $R_L$, exactly as they will be installed in the oscillator. $R_L$ is the load that the transistor sees and must be converted into a form suitable for the user, as described in Section 5.7.

One should be aware that, as in all schematics, the stray elements which are a function of the physical layout are not shown; these stray elements can strongly influence the oscillator performance, especially at higher frequencies.

The schematic diagram may also be used as a form for recording design data.

#### 12.2.2.3 Calculation of Component Values

This part of the algorithm presents the step-by-step procedure for transforming the input information given on Page 1 into the specific oscillator design. The format has been planned to be useful both to the novice who is merely interested in obtaining the final design and to the person who may desire to learn why each step is executed in the manner shown.

### 12.2.3 Supplementary Information Contained in the Algorithm

1. The algorithm steps are frequently annotated with notes, guides, restrictions, references, and comments. These should be read and observed carefully, as they will lead to greater accuracy and fuller understanding.
2. The reader who is interested in learning the derivation of, and/or reason for, any step may consult the applicable text equation referenced for

each step. In some cases the notation SE is shown in lieu of an equation number. SE signifies Self-Explanatory.

### 12.2.4 Design Examples

Each chapter discussing circuit configurations for which algorithms are supplied includes several design examples, which were prepared using the algorithms. The input information is given in the table and the output information is shown on the schematic. The component values shown are those computed. In practice, the nearest standard values will be used.

### 12.2.5 Use of the Algorithms

The algorithms can be used for the following purposes:

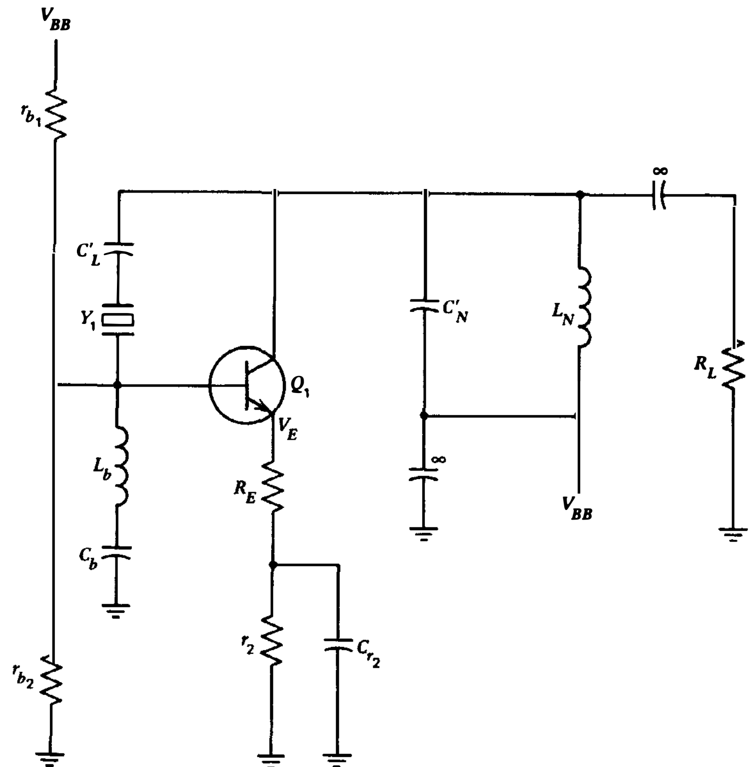
1 For designing an oscillator to obtain a specified performance as shown in the design examples of Section 12.2.4.
2 To investigate the effects of variations in parameters.

It is recommended that the algorithms be used for programming a computer or one of the more powerful hand-held calculators in order to facilitate their use for design and investigation. To help in the programming, each step includes references to the applicable preceding steps.

### 12.2.6 Conversion Efficiency in the Algorithm Designs

It will be noted that almost all the algorithms have been prepared on the basis of the maximum practical conversion efficiency. Each chapter describes the procedure to be followed when characteristics other than maximum conversion efficiency are preferred, especially in the isolated Pierce oscillator. The recommendations in the "Comments" columns alert the user to the design problems caused by the maximum conversion efficiency design.

## Algorithm Figure 12.1 Pierce Oscillator, Collector Limiting




All units in . . .

℧ MHz Ω mW pF μH
mA, mV dc or rms

| | Item | Value |
|---|---|---|
| Oscillator Performance | $f$ | |
| | $P_L$ | |
| | $P_x$ | |
| | $V_{BB}$ | |
| | | |
| Principal Crystal Data | $R_{df}$ | |
| | $I_x$ | |
| | Cut | |
| | $N$ | |
| | | |
| Transistor Data | $\beta_o$ | |
| | $f_T$ | |
| | $BV_{CE}$ | |
| | $C_{cb}$ | |
| | $C_{bet}$ | |
| | $C_{ce}$ | |
| | $P_{dis}$ | |
| | Type | |
| Circuit Parameters | $A_{L_0}$ | |
| | $\eta$ | |
| | | |
| | | |
| Calculated Data | $I_{BB}$ | |
| | $g_m$ | |
| | $V_E$ | |
| | | |
| | | |

**Algorithm 12.1 Pierce Oscillator, Collector Limiting**

| | Oscillator Performance<br>Crystal and Transistor Characteristics | | | | | | |
|---|---|---|---|---|---|---|---|
| | Step No. | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
| | a1 | $f$ | Specified | MHz | | | |
| | a2 | $P_L$ | | mW | | **Oscillator** | |
| | a3 | $P_x$ | | mW | | | |
| | a4 | $V_{BB}$ | | mV | | **performance** | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | b1 | Cut | Specified | | | | |
| | b2 | $N$ | | | | **Crystal** | |
| | b3 | $df$ | | Hz | | | |
| | b4 | $R_L$ | | Ω | | **Characteristics** | |
| | b5 | $C_L$ | | pF | | Notes: | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | b6 | $C_1$ | | pF | | 1. For production runs | |
| | b7 | $C_0$ | | pF | | $R_{df}$ = max | |
| | b8 | $C_0'$ | | pF | | 2. $P_x$ will decrease | |
| | | | | | | as $R_{df}$ decreases | |
| | b9 | $Q_x$ | $10^6/(2\pi C_1 f R1)$ | | b6, b11, a1 | 3. $P_L$ will | 3.29a |
| | b10 | $\Delta X/$ | $10^6/(\pi C_1 f)$ | Ω | b6, a1 | remain constant | 3.20a |
| | | $(\Delta f/f)$ | | | | as $R_{df}$ decreases | |
| | b11 | $R_1$ | $[(C_L/(C_L + C_0)]^2 R_L$ | Ω | b5, b7, b4 | | 3.19 |
| | b12 | $R_{df}$ | $R_1/[1 - C_0'/(C_L + C_0) -$ | Ω | b11, b6, b7 | | 3.26a |
| | | | $2C_0' df/(C_1 f 10^6)]^2$ | | a1, b5, b8 | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | b13 | $I_x$ | $(1000 P_x/R_{df})^{1/2}$ | mA | a3, b12 | | 3.27a |
| | b14 | $C_{L_{df}}$ | $\left[\dfrac{1}{C_L + C_0} + \dfrac{2(10)^{-6} df}{C_1 f}\right]^{-1} - C_0'$ | pF | b5, b7, b3<br>b6, a1, b8 | | 3.24a |
| | | | | | | | |

**Algorithm 12.1 (*Continued*)**

Oscillator Performance
Crystal and Transistor Characteristics

| | Step No. | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
|---|---|---|---|---|---|---|---|
| | c1 | Type No. | Specified | | | | |
| | c2 | $\beta_o$ | | | | $\beta_o > 1200\, g_m$ | 5.116 |
| | c3 | $f_T$ | | MHz | | $f_T > 600 f g_m$ | 5.113 |
| | c4 | $C_{bet}$ | | pF | | | |
| | c5 | $C_{cb}$ | | pF | | **Transistor** | |
| | c6 | $C_{ce}$ | | pF | | | |
| | c7 | $BV_{CB}$ | | mV | | **Characteristics** | |
| | c8 | $BV_{CE}$ | | mV | | | |
| | c9 | $BV_{BE}$ | | mV | | | |
| | c10 | $P_{\text{dis}}$ | | mW | | **at maximum temperature** | |
| | c11 | $r_{bb}$ | | Ω | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | **Circuit Parameters** | | | | |
| | d1 | $A_{L_0}$ | Specified | | | Recommend $A_{L_0} = 2$ | 6.18 |
| | | | | | | | |
| | | | *Calculation of Component Values* | | | | |
| | | | *Note: ⊕ signifies physical component* | | | | |
| | 1 | $\eta$ | $P_L/P_x$ | | a2, a3 | | 7.10 |
| | 2 | $V_L$ | the smaller of | mV | | see discussion of | |
| | 2a | | $0.33BV_{CE}$ or | | c8 | $R_L$ and $V_L$ | 7.23a |
| | 2b | | $\sqrt{10^7 P_L/\sqrt{f}}$ | | a2, a1 | | 7.30 |
| ⊕ | 3 | $R_L$ | $V_L^2/(10$[illegible] $P_L)$ | Ω | 2, a2 | | 7.9 |
| | 4 | $R_2$ | $\eta R_{df} - R_{df}^2/R_L$ | Ω | 1, b12, 3 | | 7.16 |
| | 5 | $X_2$ | $\sqrt{R_L R_2}$ | Ω | 3, 4 | | 7.4 |
| | 6 | $R'_T$ | $R_2 + R_{df}$ | Ω | 4, b12 | | 7.17 |
| | 7 | $(g_m X_1)$ | $R'_T/X_2$ | | 6, 5 | | 7.1 |
| | 8 | $I_e$ | $I_x(g_m X_1)$ | mA | b13, 7 | | 7.7 |
| | 9 | $I_E$ | $\geqq 1.4 I_e$ | mA | 8 | | 6.17 |

**Algorithm 12.1** (*Continued*)

Oscillator Performance
Crystal and Transistor Characteristics

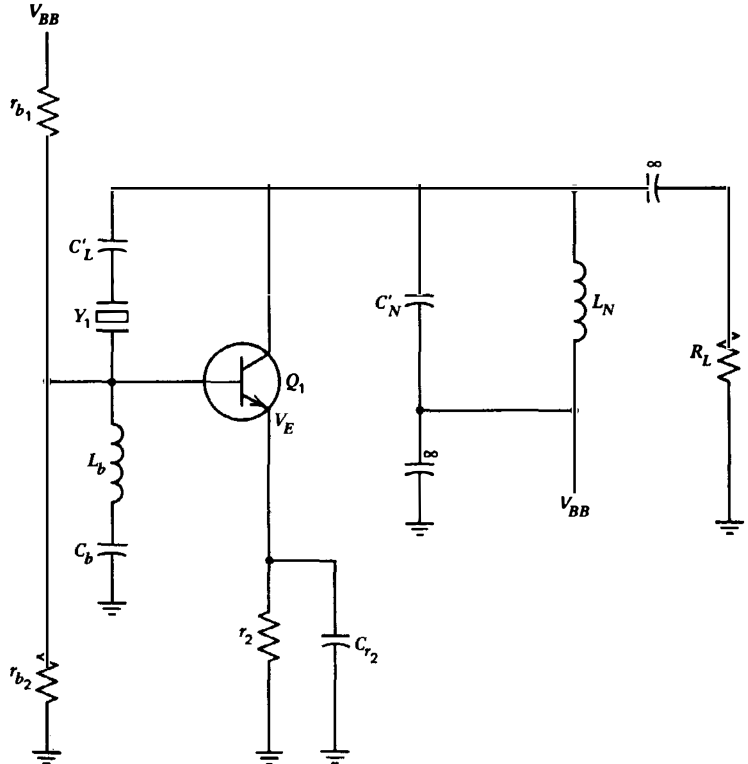
| | Step No. | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
|---|---|---|---|---|---|---|---|
| ⊕ | 10 | $R_E$ | $5[26/I_E + 1]$ | Ω | 9, c11, c2 | | 6.20 |
| | 11 | $g_{m_{L_0}}$ | $0.83/R_E$ | $\mho$ | 10 | | 6.20a |
| | 12 | $g_m$ | $g_{m_{L_0}}/A_{L_0}$ | $\mho$ | 11, d1 | | 6.18 |
| | 13 | $X_1$ | $g_m X_1/g_m$ | Ω | 7, 12 | | SE |
| | 14 | $V_b$ | $I_x X_1$ | mV | b13, 13 | | 7.5a |
| | 15 | $V_E$ | $V_{BB} - 1.4(V_L + V_b)$ | mV | a4, 2, 14 | > 2000 | 7.27 |
| ⊕ | 16 | $r_2$ | $V_E/I_E - R_E$ | Ω | 15, 9, 10 | | 2.99 |
| | 17 | $r_b$ | $\beta_o(r_2)/5$ | Ω | c2, 16 | | 2.100 |
| ⊕ | 18 | $r_{b_2}$ | $.83r_b[V_{BB}/(V_E + 700)]$ | Ω | 17, a4, 15 | | 2.103 |
| ⊕ | 19 | $r_{b_1}$ | $1/(1/r_b - 1/r_{b_2})$ | Ω | 17, 18 | | 2.104 |
| | 20 | $R_{in}$ | $g_m X_1^2/\beta_o$ | Ω | 12, 13, c2 | | 6.21 |
| | 21 | $R_b$ | $X_1^2/r_b$ | Ω | 13, 17 | | 7.3 |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 22 | $R_T$ | $R_{df} + R_2 + R_{\text{in}} + R_b$ | Ω | b12, 4, 20, 21 | $R_T$ should $\approx R'_T$ | 7.1 |
| | 23 | $C_1$ | $159{,}000/X_1 f$ | pF | 13, a4 | | 7.36 |
| | 24 | $C_{bed}$ | $g_m(159{,}000/f_T)$ | pF | 12, c3 | | 6.22 |
| | 25 | $M_M$ | $V_b/V_L$ | | 14, 2 | | 5.70 |
| | 26 | $C_{1M}$ | $C_{cb}(1 + 1/M_M)$ | pF | c5, 25 | | 5.75 |
| | 27 | $C'_1$ | $C_1 - C_{bed} - C_{1M}$ | pF | 23, 24, 26 | | Fig. 7.2*b* |
| | 28 | | Check whether $N = 1$ | | b2 | | |
| | 28a | | If yes, $s^2 = 0.2$ | | | | 5.82a |
| | 28b | | If no, $s = 1 - 1.5/N$ | | | | 5.82b |
| | 29 | $X_{CN}$ | $(1 - s^2)X_2$ | Ω | 28, 5 | | 5.83 |
| | 30 | $C_N$ | $159{,}000/(X_N f)$ | pF | 29, a1 | | 5.84 |
| ⊕ | 31 | $C'_N$ | $C_N - C_{cb}(1 + M_M) - C_{ce}$ | pF | 30, c5, 25, c4 | | 5.73 |
| | | | | | | | and Fig. 7. |
| | 32 | $X_{LN}$ | $X_{CN}/s^2$ | Ω | 29, 28 | | 5,85 |
| ⊕ | 33 | $L_N$ | $X_{LN}/6.28f$ | μH | 32, a1 | | 5.85a |
| | 34 | | Check if the crystal cut | | | | |
| | | | is SC | | b1 | | |

**Algorithm 12.1 (*Continued*)**

| Oscillator Performance Crystal and Transistor Characteristics | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Step No. | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
| ⊕ | 35a | $C_b$ | if no: $C_1'$ | pF | 27 | | SE |
| | 35b | $L_b$ | 0 | | | Continue at Step 37 | SE |
| ⊕ | 36a | $C_b$ | if yes: 0.156 $C_1'$ | pF | 27 | | 5.86 |
| ⊕ | 36b | $L_b$ | $10^6/[C_b(6.84f)^2]$ | μH | 36a, a1 | | 5.87 |
| | 37 | $X_{cr_2}$ | $0.06/g_m$ | Ω | 12 | | 7.38 |
| ⊕ | 38 | $C_{r_2}$ | $> 159{,}000/(X_{cr_2}f)$ | pF | 37, a1 | | 7.35 |
| | 39 | $X_{C_L'}$ | $159{,}000/(C_{L_{df}}f) - (X_1 + X_2)$ | Ω | b14, a1, 13, 5 | | 7.39 |
| ⊕ | 40 | $C_L'$ | $159{,}000/(X_{C_L}'f)$ | pF | 39, a1 | | 7.40 |
| | 41 | $Q_{op}$ | $< Q_X R_{df}/R_T$ | | b12, b9, 22 | | 5.77a |
| | | | | | | | |

## Algorithm Figure 12.2 Pierce Oscillator, *be* Cutoff Limiting




All units in . . .

℧ MHz Ω mW pF μH
mA, mV dc or rms

| | Item | Value |
|---|---|---|
| Oscillator Performance | $f$ | |
| | $P_L$ | |
| | $P_x$ | |
| | $V_{BB}$ | |
| | | |
| Principal Crystal Data | $R_{df}$ | |
| | $I_x$ | |
| | Cut | |
| | $N$ | |
| | | |
| Transistor Data | $\beta_o$ | |
| | $f_T$ | |
| | $BV_{CC}$ | |
| | $C_{cb}$ | |
| | $C_{bei}$ | |
| | $C_{ce}$ | |
| | $P_{dis}$ | |
| | Type | |
| Circuit Parameters | $\alpha$ | 0.3 |
| | $\gamma_1$ | 1.4 |
| | $V_{pe}$ | 113 |
| | | |
| Calculated Data | $I_{BB}$ | |
| | $g_m$ | |
| | $V_E$ | |
| | | |
| | | |

**Algorithm 12.2 Pierce Oscillator, *be* Cutoff Limiting**

| Oscillator Performance<br>Crystal and Transistor Characteristics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Step | Item | Formula or Quantity | | Units | Refer to Step Nos. | Comments | Text Equation No. |
| | a1 | $f$ | Specified | | MHz | | | |
| | a2 | $P_L$ | | | mW | | **Oscillator** | |
| | a3 | $P_x$ | | | mW | | | |
| | a4 | $V_{BB}$ | | | mV | | **Performance** | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | b1 | Cut | Specified | | | | | |
| | b2 | $N$ | | | | | **Crystal** | |
| | b3 | $df$ | | | Hz | | | |
| | b4 | $R_L$ | | | Ω | | **Characteristics** | |
| | b5 | $C_L$ | | | pF | | Notes: | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | b6 | $C_1$ | | pF | | 1. For production runs | |
| | b7 | $C_0$ | | pF | | $R_{df}$ = max | |
| | b8 | $C_0'$ | | pF | | 2. $P_X$ will increase | |
| | | | | | | as $R_{df}$ decreases | |
| | b9 | $Q_x$ | $10^6/(2\pi C_1 f R_1)$ | | b6, b11, a1 | 3. $P_L$ will | 3.29a |
| | b10 | $\Delta X/(\Delta f/f)$ | $10^6/(\pi C_1 f)$ | Ω | b6, a1 | increase | 3.20a |
| | | | | | | as $R_{df}$ decreases | |
| | b11 | $R_1$ | $[(C_L/(C_L + C_0)]^2 R_L$ | Ω | b5, b7, b4 | | 3.19 |
| | b12 | $R_{df}$ | $R_1/[1 - C_0'/(C_L + C_0) -$ | Ω | b11, b5, b7 | | 3.26a |
| | | | $2C_0' df/(C_1 f \times 10^6)]^2$ | | a1, b5, b8 | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | b13 | $I_x$ | $(1000 P_x/R_{df})^{1/2}$ | mA | a3, b12 | | 3.27a |
| | b14 | $C_{L_{df}}$ | $\left[\frac{1}{C_1 + C_2} + \frac{2 \times 10^{-6} df}{C_1 f}\right]^{-1} - C_0'$ | pF | b5, b7, b3 | | 3.24a |
| | | | | | b6, a1, b8 | | |

**Algorithm 12.2** (***Continued***)

Oscillator Performance
Crystal and Transistor Characteristics

| | Step | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
|---|---|---|---|---|---|---|---|
| | c1 | Type No. | Specified | | | | |
| | c2 | $\beta_o$ | | | | $\beta_o > 1200 g_m$ | 5.116 |
| | c3 | $f_m$ | | MHz | | $r_T > 600 f g_m$ | 5.113 |
| | c4 | $C_{bet}$ | | pF | | | |
| | c5 | $C_{cb}$ | | pF | | **Transistor** | |
| | c6 | $C_{ce}$ | | pF | | | |
| | c7 | $BV_{CE}$ | | mV | | **Characteristics** | |
| | c8 | $BV_{CE}$ | | mV | | | |
| | c9 | $BV_{BE}$ | | mV | | | |
| | c10 | $P_{dis}$ | | mW | | at maximum temperature | |
| | c11 | $r_{bb}$ | | Ω | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | **Circuit Parameters** | | | | |
| | d1 | $\alpha$ | 0.3 | | | See Section 7.6.1 | |
| | d2 | $\gamma_1$ | 1.4 | | | | |
| | d3 | $V_{be}$ | 113 | mV | | | |
| | | | **Calculation of Component Values** | | | | |
| | 1 | $\eta$ | $P_L/P_X$ | | a2, a3 | See discussion | 7.10 |
| | | | | | | on $\eta$ | |
| | 2 | $V_L$ | the smaller of | mV | | See discussion on | |
| | 2a | | $0.22BV_{CE}$ or | | c8 | $R_L$ and $V_L$ | 7.26 |
| | 2b | | $\sqrt{10^7 P_L/\sqrt{f}}$ | | a2, a1 | in Section | 7.30 |
| ⊕ | 3 | $R_L$ | $V_L^2/(1000\ P_L)$ | Ω | 2, a2 | 7.2.4 | 7.9 |
| | 4 | $V_E$ | $V_{BB} - [2.1(V_L + V_b)] - 1700$ | mV | a4, 2, d3 | > 2000 See Note A | 7.28a |
| | 5 | $R_2$ | $\eta R_{df} - R_{df}^2/R_L$ | Ω | 1, b12, 3 | NOTE: If $R_2$ is −, | 7.16 |
| | 6 | $X_2$ | $\sqrt{R_2 R_L}$ | Ω | 5, 3 | the design is | 7.4 |
| | 7 | $X_1$ | $V_b/I_x$ | Ω | d3, b13 | unsound, see | 7.5a |
| | 8 | $g_m$ | $((R_{df} + R_2)/[X_1(X_2 - X_1/\beta_o)]$ | ℧ | b12, 5, 7, c2 | Section 7.2.3.1 | 7.34 |

**Algorithm 12.2 (*Continued*)**

| Oscillator Performance Crystal and Transistor Characteristics | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Step | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
| | 9 | $I_e$ | $g_m V_b$ | mA | 8, d3 | | 7.7 |
| | 10 | $I_E$ | $I_e/\gamma_1$ | mA | 9, d2 | | 2.69 |
| ⊕ | 11 | $r_2$ | $V_E/I_E$ | Ω | 4, 10 | | 2.99 |
| | 12 | $r_b$ | $\beta_o r_2/5$ | Ω | c2, 11 | | 2.100 |
| ⊕ | 13 | $r_{b_2}$ | $0.83 r_b V_{BB}/(V_E + 700)$ | Ω | 12, a4, 4 | | 2.103 |
| ⊕ | 14 | $r_{b_1}$ | $1/(1/r_b - 1/r_{b_2})$ | Ω | 12, 13 | | 2.104 |
| | 15 | $R_{\text{in}}$ | $X_1^2 g_m/\beta_o$ | Ω | 7, 8, c2 | | 7.2 |
| | 16 | $R_b$ | $X_1^2/r_b$ | Ω | 7, 12 | | 7.3 |
| | 17 | | check that | | | | |
| | | | $(R_{\text{in}} + R_v) \ll (R_{df} + R_2)$ | | 15, 16, b12, 5 | | |
| | 18 | $C_1$ | $159{,}000/(X_1 f)$ | pF | 7, a1 | | 7.35 |
| | 19 | $C_{bed}$ | $g_m\, 159{,}000/f_T$ | pF | 8, c3 | | 2.75 |
| | 20 | $M_M$ | $\simeq X_1/X_2$ | | 7, 6 | | from |
| | | | | | | | 5.70 |

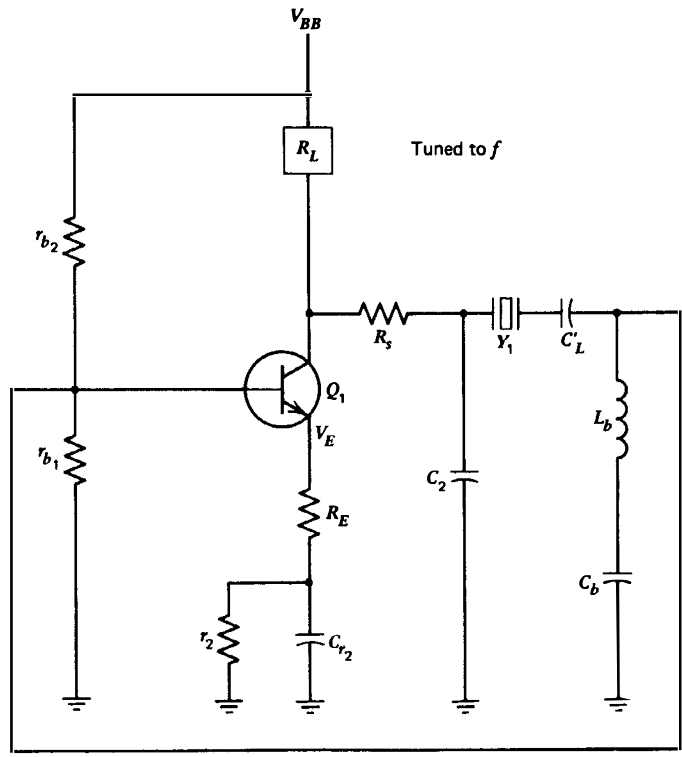
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Note A: If $V_E$ calculates $> V_{BB}/2$, make $V_E = V_{BB}/2$ | | | | |
| | | | | | | | |
| | 21 | $C_{1M}$ | $C_{cb}(1 + 1/M_M)$ | pF | c5, 20 | | 5.71 |
| | 22 | $C_1'$ | $C_1 - C_{bed} - C_{1M} - C_{bet}$ | pF | 18, 19, 21, c4 | | Fig. 7.2 |
| | 23 | | Check whether $N = 1$ | | b2 | | |
| | 23a | $s$ | If yes, $s^2 = 0.2$ | | | | 5.82a |
| | 23b | $s$ | If no, $s = 1 - 1.5/N$ | | b2 | | 5.82b |
| | 24 | $X_{CN}$ | $(1 - s^2) X_2$ | Ω | 23, 6 | | 5,83 |
| | 25 | $C_N$ | $159{,}000/(X_{CN}f)$ | pF | 24, a1 | | 5.84 |
| ⊕ | 26 | $C_N'$ | $C_N - C_{ce} - C_{cb}(1 + M_M)$ | pF | 25, c6, c5, 20 | | 5.73 and |
| | | | | | | | Fig. 7.2b |
| | 27 | $X_{LN}$ | $X_{CN}/s^2$ | Ω | 24, 23 | | 5.85 |
| ⊕ | 28 | $L_N$ | $X_{LN}/6.28f$ | μH | 27, a1 | | 5.85a |
| | 29 | | Check if the crystal | | b1 | | |
| | | | cut is SC | | | | |
| | | | if no | | | | |
| ⊕ | 29a | $C_b$ | $C_1'$ | pF | 22 | | SE |

**Algorithm 12.2 (*Continued*)**

Oscillator Performance
Crystal and Transistor Characteristics

| | Step | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
|---|---|---|---|---|---|---|---|
| ⊕ | 29b | $L_b$ | 0 | | | Continue at Step 31 | SE |
| | | | if yes | | | | |
| ⊕ | 30a | $C_b$ | $0.156C_1'$ | pF | 22 | | 5.86 |
| ⊕ | 30b | $L_b$ | $10^6/[C_b(6.84f)^2]$ | $\mu$H | 30a, a1 | | 5.87 |
| | 31 | $X_{cr_2}$ | $0.05/g_m$ | Ω | 8 | | 7.38 |
| ⊕ | 32 | $C_{r_2}$ | $159{,}000/(X_{cr_2}f)$ | pF | 32, a1 | | 7.35 |
| | 33 | $X_{C_L}$ | $159{,}000/(C_{L_{df}}f) - (X_1 + X_2)$ | | b14, a1, 7, 6 | | 7.39 |
| ⊕ | 34 | $C_L'$ | $159{,}000/(X_{C_L}f)$ | pF | 33, a1 | | 7.40 |
| | 35 | $Q_{op}$ | $Q_X R_{df}/(R_{df} + R_{in} + R_2 + R_b)$ | | b9, b12, 15, 5, 16 | | 5.77a |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

# Algorithm Figure 12.3 Isolated Pierce Oscillator, Collector Limiting




All units in . . .

℧ MHz Ω mW pF μH
mA, mV dc or rms

| | Item | Value |
|---|---|---|
| Oscillator Performance | $f$ | |
| | $P_L$ | |
| | $P_x$ | |
| | $V_{BB}$ | |
| | | |
| Principal Crystal Data | $R_{df}$ | |
| | $I_x$ | |
| | Cut | |
| | $N$ | |
| | | |
| Transistor Data | $\beta_o$ | |
| | $f_T$ | |
| | $BV_{CE}$ | |
| | $C_{cb}$ | |
| | $C_{bet}$ | |
| | $C_{ce}$ | |
| | $P_{dis}$ | |
| | Type | |
| Circuit Parameters | $A_{L_0}$ | |
| | $n$ | |
| | $\eta$ | |
| | | |
| Calculated Data | $I_{BB}$ | |
| | $g_m$ | |
| | $V_E$ | |
| | $R_{df}/R_T$ | |
| | | |

## Algorithm 12.3 Isolated Pierce Oscillator, Collector Limiting

Oscillator Performance
Crystal and Transistor Characteristics

| | Step No. | Item | Formula or Quantity | Units | Refer to Step no. | Comments | Text Equation No. |
|---|---|---|---|---|---|---|---|
| | a1 | $f$ | Specified | MHz | | | |
| | a2 | $P_L$ | | mW | | **Oscillator** | |
| | a3 | $P_x$ | | mW | | | |
| | a4 | $V_{BB}$ | | mV | | **Performance** | |
| | a5 | $\eta$ | $P_L/P_x$ | | a2, a3 | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | b1 | Cut | Specified | | | | |
| | b2 | $N$ | | | | **Crystal** | |
| | b3 | $df$ | | Hz | | | |
| | b4 | $R_L$ | | Ω | | **Characteristics** | |
| | b5 | $C_L$ | | pF | | Notes: | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | b6 | $C_1$ | | pF | | 1. For production runs | |
| | b7 | $C_0$ | | pF | | $R_{df}$ = max | |
| | b8 | $C_0'$ | | pF | | 2. $P_x$ will increase | |
| | | | | | | as $R_{df}$ decreases | |
| | b9 | $Q_x$ | $10^6/\pi C_1 f R_1$ | | b6, b11, a1 | 3. $P_L$ will | 3.29a |
| | b10 | $\Delta X/(\Delta f/f)$ | $10^6/(\pi C_1 f)$ | Ω | b6, a1 | remain constant | 3.20a |
| | | | | | | as $R_{df}$ decreases | |
| | b11 | $R_1$ | $[(C_L/(C_L + C_0)]^2 R_L$ | Ω | b5, b7, b4 | | 3.19 |
| | b12 | $R_{df}$ | $R_1/[1 - C_0'/(C_L + C_0) -$ | Ω | b11, b6, b7 | | 3.26a |
| | | | $2C_0' df/(C_1 f \times 10^6)]^2$ | | a1, b5, b8 | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | b13 | $I_x$ | $(1000\, P_x/R_{df})^{1/2}$ | mA | a3, b12 | | 3.27a |
| | b14 | $C_{L_{df}}$ | $\left[\dfrac{1}{C_L + C_0} + \dfrac{2 \times 10^{-6} df}{C_1 f}\right]^{-1} - C_0'$ | pF | b5, b7, b3<br>b6, a1, b8 | | 3.24a |
| | | | | | | | |

**Algorithm 12.3** (***Continued***)

Oscillator Performance
Crystal and Transistor Characteristics

| | Step No. | Item | Formula or Quantity | | Units | Refer to Step no. | Comments | Text Equation No. |
|---|---|---|---|---|---|---|---|---|
| | c1 | Type No. | Specified | | | | | |
| | c2 | $\beta_o$ | | | | | $\beta_o > 1200\, g_m$ | 5.116 |
| | c3 | $f_T$ | | | MHz | | $f_T > 600 f g_m$ | 5.113 |
| | c4 | $C_{bet}$ | | | pF | | | |
| | c5 | $C_{cb}$ | | | pF | | **Transistor** | |
| | c6 | $C_{ce}$ | | | pF | | | |
| | c7 | $BV_{CB}$ | | | mV | | **Characteristics** | |
| | c8 | $BV_{CE}$ | | | mV | | | |
| | c9 | $BV_{BE}$ | | | mV | | | |
| | c10 | $P_{\text{dis}}$ | | | mW | | at maximum temperature | |
| | c11 | $r_{bb}$ | | | Ω | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | **Circuit Parameters** | | | | |
| | d1 | $A_{L_0}$ | Specified | | | Recommend $A_{L_0} = 2$ | 6.18 |
| | | | | | | | |
| | | | *Calculation of Component Values* | | | | |
| | | | *Note:* ⊕ *signifies physical component* | | | | |
| | | | | | | | |
| | 1 | $V_L$ | The smaller of | mV | | See discussion | |
| | 1a | | $0.33BV_{CE}$ or | | c8 | on $R_L$ and $V_L$ | 7.23 |
| | 1b | | $\sqrt{10^7 P_L/\sqrt{f}}$ | | a2, a1 | | 7.30 |
| ⊕ | 2 | $R_L$ | The smaller of | Ω | | | |
| | 2a | | $V_L^2/(1000\ P_L)$ or | | 1, a2 | | 7.9 |
| | 2b | | $(64{,}000)^2/(f^2 n^2 R_{df}\eta)$ | | a1, b12, a5 | Recommend $n = 5$ | 8.14 |
| | | | | | | | 8.28 |
| | 1c | $V_L'$ | $\sqrt{1000\ P_L R_L}$ | mV | a2, 2 | | 7.9 |
| | 3 | $I_L$ | $V_L'/R_L$ | mA | 1c, 2 | | SE |
| ⊕ | 4 | $R_s$ | $n\sqrt{\eta R_{df} R_L}$ | Ω | 2b, a5, b12, 2 | $R_{s\,max} = 64k/f$ | 8.19 |

**Algorithm 12.3** (*Continued*)

Oscillator Performance
Crystal and Transistor Characteristics

| | Step No. | Item | Formula or Quantity | Units | Refer to Step no. | Comments | Text Equation No. |
|---|---|---|---|---|---|---|---|
| | 5 | $m_r$ | $R_s/R_L$ | | 7, 2 | | 8.7 |
| | 6 | $I_c$ | $(1 + 1/m_r)I_L$ | mA | 8, 3 | | 8.6a |
| | 7 | $I_E$ | $1.4I_c$ | mA | 6 | | 6.17 |
| | 8 | $R_E$ | $5[(26/I_E) + 1]$ | Ω | 7 | | 6.20 |
| | 9 | $g_{m_{L0}}$ | $0.83/R_E$ | ℧ | 8 | | 6.20a |
| | 10 | $g_m$ | $g_{m_{L0}}/A_{L0}$ | ℧ | 9, d1 | | 6.18 |
| | 11 | $g_{me}$ | $g_m(1 + m_r)$ | ℧ | 10, 5 | | 8.10a |
| | 12 | $(g_m X_1)$ | $I_c/I_x$ | | 6, b13 | | 8.9a |
| | 13 | $X_1$ | $(g_m X_1)/g_m$ | Ω | 12, 10 | | SE |
| | 14 | $R_{in}$ | $g_m X_1^2/\beta_o$ | Ω | 10, 13, c2 | | 7.2 |
| | 15 | $R_t$ | $R_{in} + R_{df}$ | Ω | 14, b12 | | 8.13 |
| | 16 | $X_2$ | $nR_t$ | Ω | 2b, 15 | | 8.14 |
| | 17 | $R_T$ | $R_t + X_2^2/(R_s + R_L)$ | Ω | 15, 16, 4, 2 | | 8.12 |
| | 17a | $X_2'$ | $nR_T$ | Ω | 2b, 17 | | 8.23 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
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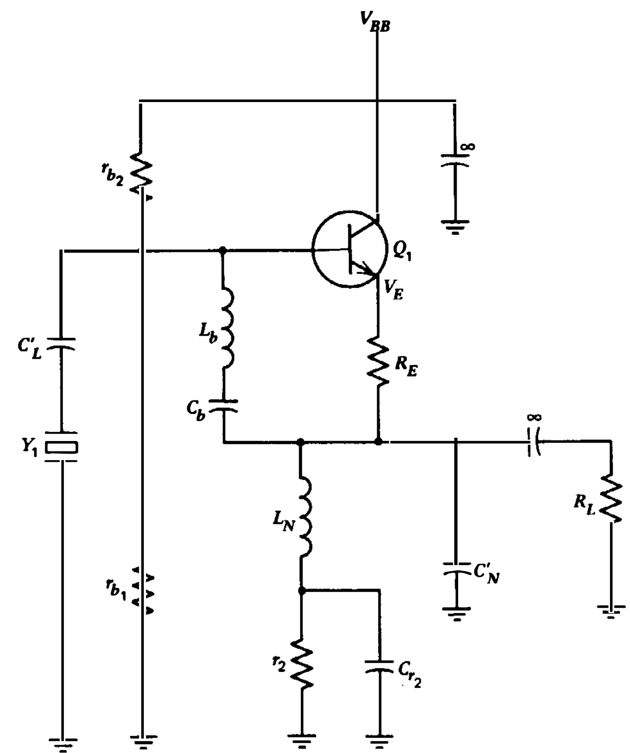
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | 18 | $V_b$ | $I_x X_1$ | mV | b13, 13 | | 8.8 |
| | 19 | $V_E$ | $V_{BB} - 1.4(V_L' + V_b)$ | mV | a4, 1c, 18 | | 7.27 |
| ⊕ | 20 | $r_2$ | $V_E/I_E - R_E$ | Ω | 19, 7, 8 | | 2.99 |
| | 21 | $r_b$ | $\beta_o(r_2 + R_E)/5$ | Ω | c2, 20, 8 | | 2.100 |
| ⊕ | 22 | $r_{b_2}$ | $0.83 r_b V_{BB}/(V_E + 700)$ | Ω | 21, a4, 19 | | 2.103 |
| ⊕ | 23 | $r_{b_1}$ | $1/(1/r_b - 1/r_{b_2})$ | Ω | 21, 22 | | 2.104 |
| | 24 | $C_1$ | $159{,}000/(X_1 f)$ | pF | 13, a1 | | 7.36 |
| | 25 | $C_{bed}$ | $g_m 159{,}000/f_T$ | pF | 10, c3 | | 6.22 |
| | 26 | $M_M$ | $\approx V_L'/V_b$ | | 1c, 18 | | 5.70 |
| | 27 | $C_M$ | $(M_M + 1)C_{cb}$ | pF | 26, c5 | | 5.75 |
| ⊕ | 28 | $C_1'$ | $C_1 - C_{bed} - C_M - c_{bet}$ | pF | 24, 25, 27, c4 | | Fig. 7.2b |
| | 29 | | Check if the crystal cut is SC | | b1 | | |

**Algorithm 12.3 (*Continued*)**

Oscillator Performance
Crystal and Transistor Characteristics

| | Step No. | Item | Formula or Quantity | Units | Refer to Step no. | Comments | Text Equation No. |
|---|---|---|---|---|---|---|---|
| | | | if no | | | | |
| ⊕ | 30a | $C_b$ | $C_1'$ | pF | 28 | | SE |
| | 30b | $L_b$ | 0 | | | Continue at Step 33 | SE |
| | | | if yes | | | | |
| ⊕ | 31a | $C_b$ | $0.156C_1'$ | pF | 28 | | 5.86 |
| ⊕ | 31b | $L_b$ | $10^6/[C_b(6.84f)^2]$ | $\mu$H | 31a, a1 | | 5.87 |
| ⊕ | 32 | $C_2$ | $159{,}000/(X_2 f)$ | pF | 17a, a1 | | 8.25 |
| | 33 | $X_{cr_2}$ | $0.05/g_m$ | Ω | 10 | | 7.38 |
| ⊕ | 34 | $C_{r_2}$ | $159{,}000/(X_{cr_2} f)$ | pF | 33, a1 | | 7.35 |
| | | | | | | | |
| | | | | | | | |
| | 35 | $X_{C_L'}$ | $159{,}000/(C_{L_{df}} f) - (X_1 + X_2)$ | Ω | b14, a1, 13, 18 | | 7.39 |
| ⊕ | 36 | $C_L'$ | $159{,}000/(X_{C_L'} f)$ | pF | 35, a1 | | 7.40 |
| | 37 | $Q_{op}$ | $< Q_x R_{df}/R_T$ | | b9, b12, 17 | | 5.77a |
| | | | | | | | |

## Algorithm Figure 12.4 Colpitts Oscillator Collector Limiting




All units in . . .

℧ MHz Ω mW pF
μH
mA, mV dc or rms

| | Item | Value |
|---|---|---|
| Oscillator Performance | $f$ | |
| | $P_L$ | |
| | $P_x$ | |
| | $V_{BB}$ | |
| | | |
| Principal Crystal Data | $R_{df}$ | |
| | $I_x$ | |
| | Cut | |
| | $N$ | |
| | | |
| Transistor Data | $\beta_o$ | |
| | $f_T$ | |
| | $BV_{CE}$ | |
| | $C_{cb}$ | |
| | $C_{bet}$ | |
| | $C_{ce}$ | |
| | $P_{dis}$ | |
| | Type | |
| Circuit Parameters | $A_{L_0}$ | A |
| | $\eta$ | |
| | | |
| | | |
| Calculated Data | $I_{BB}$ | |
| | $g_m$ | |
| | $V_E$ | |
| | | |
| | | |

**Algorithm 12.4 Colpitts Oscillator Collector Limiting**

| Oscillator Performance<br>Crystal and Transistor Characteristics | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Step No. | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
| | a1 | $f$ | Specified | MHz | | | |
| | a2 | $P_L$ | | MW | | **Oscillator** | |
| | a3 | $P_x$ | | mW | | | |
| | a4 | $V_{BB}$ | | mV | | **Performance** | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | b1 | Cut | Specified | | | | |
| | b2 | $N$ | | | | **Crystal** | |
| | b3 | $df$ | | Hz | | | |
| | b4 | $R_L$ | | Ω | | **Characteristics** | |
| | b5 | $C_L$ | | pF | | Notes: | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | b6 | $C_1$ | | pF | | 1. For production runs | |
| | b7 | $C_0$ | | pF | | $R_{df}$ = max | |
| | b8 | $C_0'$ | | pF | | 2. $P_x$ will decrease | |
| | | | | | | as $R_{df}$ decreases | |
| | b9 | $Q_x$ | $10^6/(2\pi C_1 f R_1)$ | · | b6, b11, a1 | 3. $P_l$ will | 3.29a |
| | b10 | $\Delta X/(\Delta f/f)$ | $10^6/(\pi C_1 f)$ | Ω | b6, a1 | remain constant | 3.20a |
| | | | | | | as $R_{df}$ decreases | |
| | b11 | $R_1$ | $[(C_L/(C_L + C_0)]^2 R_L$ | Ω | b5, b7, b4 | | 3.19 |
| | b12 | $R_{df}$ | $R_1/[1 - C_0'/(C_L + C_0 -)$ | Ω | b11, b6, b7 | | 3.26a |
| | | | $2C_0' df/(C_1 f \times 10^6)]^2$ | | a1, b5, b8 | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | b13 | $I_x$ | $(1000\, P_x/R_{df})^{1/2}$ | mA | a3, b12 | | 3.27a |
| | b14 | $C_{L_{df}}$ | $\left[\frac{1}{C_L + C_0} + \frac{2 \times 10^{-6} df}{C_1 f}\right]^{-1} - C_0'$ | pF | b5, b7, b3<br>b6, a1, b8 | | 3.24a |

**Algorithm 12.4** (***Continued***)

Oscillator Performance
Crystal and Transistor Characteristics

| | Step No. | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | c1 | Type No. | Specified | | | | |
| | c2 | $\beta_o$ | | | | $\beta_o > 1200 g_m$ | 5.116 |
| | c3 | $f_T$ | | MHz | | $f_T > 600 f g_m$ | 5.113 |
| | c4 | $C_{bet}$ | | pF | | | |
| | c5 | $C_{cb}$ | | pF | | **Transistor** | |
| | c6 | $C_{ce}$ | | pF | | | |
| | c7 | $BV_{CB}$ | | mV | | **Characteristics** | |
| | c8 | $BV_{CE}$ | | mV | | | |
| | c9 | $BV_{BE}$ | | mV | | | |
| | c10 | $P_{dis}$ | | mW | | **at maximum temperature** | |
| | c11 | $r_{bb}$ | | Ω | | | |
| | | | | | | | |
| | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | **Circuit Parameters** | | | | |
| | d1 | $A_{L_0}$ | Specified | | | Recommend $A_{L_0} = 2$ | 6.18 |
| | | | | | | | |
| | | | *Calculation of Component Values* | | | | |
| | | | *Note: ⊕ signifies physical component* | | | | |
| | | | | | | | |
| | 1 | $\eta$ | $P_L/P_x$ | | a2, a3 | See discussion | 7.10 |
| | 2 | $V_L$ | The smaller of | mV | | of $\eta$ | |
| | 2a | | $0.33BV_{CE}$ or | | c8 | See discussion of | 9.3 |
| | 2b | | $\sqrt{10^7 P_L/\sqrt{f}}$ | | a2, a1 | $V_L$ and $R_L$ | 7.30 |
| ⊕ | 3 | $R_L$ | $V_L^2/(1000\, P_L)$ | Ω | 2, a2 | | 7.9 |
| | 4 | $R_2$ | $\eta R_{df} - R_{df}^2/R_L$ | Ω | 1, b12, 3 | | 7.16 |
| | 5 | $X_2$ | $\sqrt{R_L R_2}$ | Ω | 3, 4 | | 7.4 |
| | 6 | $R'_T$ | $R_2 + R_{df}$ | Ω | 4, b12 | | 7.17 |
| | 7 | $(g'_m X_1)$ | $R'_T/X_2$ | | 6, 5 | | 7.1 |
| | 8 | $I'_e$ | $I_x(g'_m X_1)$ | mA | c13, 7 | | 7.7 |

**Algorithm 12.4** (*Continued*)

| Oscillator Performance<br>Crystal and Transistor Characteristics | | | | | | |
|---|---|---|---|---|---|---|
| Step No. | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
| 9 | $I'_E$ | $1.4I'_e$ | mA | 8 | | 6.17 |
| 10 | $R'_E$ | $5(26/I'_E + 1)$ | Ω | 9, b11, b2 | | 6.20 |
| 11 | $g'_{m_{L_0}}$ | $0.83/R_E$ | ℧ | 10 | | 6.20a |
| 12 | $g'_m$ | $g'_{m_{L_0}}/A_{L_0}$ | ℧ | 11, d1 | | 6.18 |
| 13 | $X_1$ | $(g'_m X_1)/g'_m$ | Ω | 7, 12 | | SE |
| 14 | $V_{be}$ | $I_x X_1$ | mV | b13, 13 | | 5.52a |
| 15 | $V_E$ | $[V_{BB} - 1.4(V_L + V_{be})]$ | mV | a4, 2, 14 | > 2000 | 9.7 |
| 16 | $r'_2$ | $V_E/I'_E - R'_E$ | Ω | 15, 9, 10 | | 2.99 |
| 17 | $r'_b$ | $\beta_o(r'_2)/5$ | Ω | c2, 16 | | 2.100 |
| 18 | $R_{in}$ | $g'_m X_1^2/\beta_o$ | Ω | 12, 13, c2 | | 6.21 |
| 19 | $R_b$ | $(X_1 + X_2)^2/r'_b$ | Ω | 13, 5, 17 | | 5.57 |
| 20 | $R_T$ | $R_{df} + R_2 + R_{in} + R_b$ | Ω | b12, 4, 18, 19 | | 5.40 |
| 21 | | Check whether $R_T < 1.1R'_T$ | | 20, 6 | | 7.46 |
| 21a | | If yes, go to Step 30 | | | | |

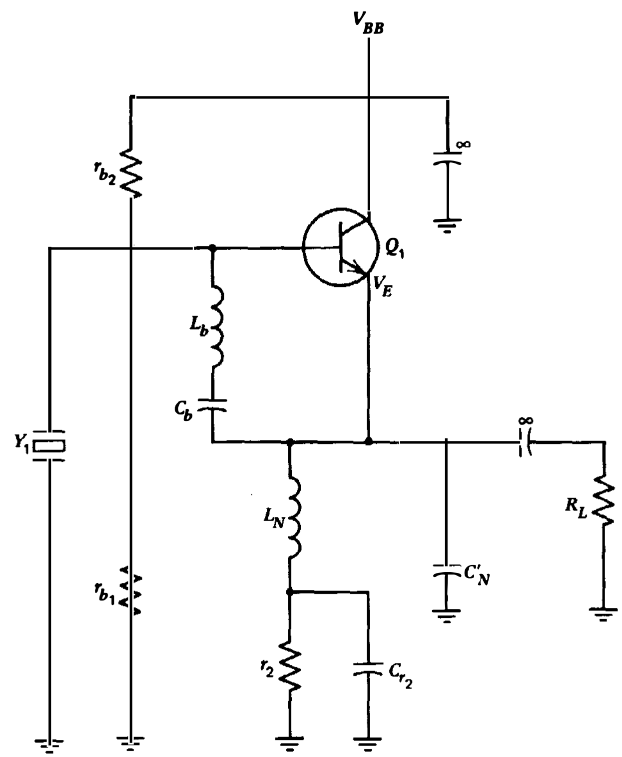
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 21b | | If no, go to Step 22 | | | | |
| | | | | | | | |
| | 22 | $I_e$ | $I_x R_T / X_2$ | mA | b13, 20, 5 | | 5.58a |
| | 23 | $I_E$ | $1.4 I_e$ | mA | 22 | | 6.17 |
| | 24 | $g_m$ | $R_T / (X_1 X_2)$ | | 20, 13, 5 | | 5.40 |
| | 25 | $g_{m_{L_0}}$ | $A_{L_0} g_m$ | | d1, 24 | | 6.18 |
| ⊕ | 26 | $R_E$ | $1/g_{m_{L_0}} - 26/I_E - 1$ | Ω | 25, 23, c11, c2 | | 6.19a |
| ⊕ | 27 | $r_2$ | $(V_E/I_E) - R_E$ | Ω | 15, 23, 26 | | 2.99 |
| | 28 | $r_b$ | $\beta_o r_2 / 5$ | Ω | 27 | | 2.100 |
| | 29 | | Note: in the following Step, substitute $(r_b')$ for $(r_b)$ when | | | | |
| | | | Step 21a is yes. | | | | |
| ⊕ | 30 | $r_{b_2}$ | $0.83 r_b [V_{BB}/(V_E + 700)]$ | Ω | 28, a4, 15 or 17 | | 2.103 |
| ⊕ | 31 | $r_{b_1}$ | $1/(1/r_b - 1/r_{b_2})$ | Ω | 28, 30 or 17 | | 2.104 |
| | 32 | $C_1$ | $159{,}000/(X_1 f)$ | pF | 13, a1 | | 7.36 |
| | 33 | $C_{bed}$ | $g_m 159{,}000/f_T$ | pF | 2, c3 or 1 | | 6.22 |
| | 34 | $M_M$ | $V_{be}/V_L$ | | 14, 2 | | 5.70 |
| | 35 | $C_{1M}$ | $C_{cb}[1 + 1/M_M]$ | pF | c5, 34 | | 5.75 |

**Algorithm 12.4** (*Continued*)

| Oscillator Performance<br>Crystal and Transistor Characteristics | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Step No. | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
| | 36 | $C_1'$ | $C_1 - C_{bed} - C_{1M} - C_{bet}$ | pF | 32, 33, 35, c4 | | Fig. 5.9b |
| | 37 | | Check whether $N = 1$ | | b2 | | |
| | 27a | | If yes, $s^2 = 0.2$ | | | | 5.82a |
| | 37b | | If no, $s = 1 - 1.5/N$ | | | | 5.82b |
| | 38 | $X_{CN}$ | $(1 - s^2)X_2$ | Ω | 37, 5 | | 5.83 |
| | 39 | $C_N$ | $159{,}000/(X_{CN}f)$ | pF | 38, a1 | | 5.84 |
| ⊕ | 40 | $C_N'$ | $C_N - C_{cb}(1 + M_M) - C_{ce}$ | pF | 39, c5, 34, c6 | | 5.73 |
| | | | | | | | Fig. 5.9b |
| | 41 | $X_{LN}$ | $X_{CN}/s^2$ | Ω | 38, 37 | | 5.85 |
| ⊕ | 42 | $L_N$ | $X_{LN}/(6.28f)$ | μH | 41, a1 | | 5.85a |
| | | | | | | | |
| | | | | | | | |
| | 43 | | Check if the crystal cut | | b1 | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | is SC | | | | |
| | | | If no, | | | | |
| ⊕ | 44a | $C_b$ | $C_1'$ | pF | 36 | | SE |
| | 44b | $L_b$ | 0 | | | Continue at Step 46 | SE |
| | | | If yes, | | | | |
| ⊕ | 45a | $C_b$ | $0.156C_1'$ | pF | 36 | | 5.86 |
| ⊕ | 45b | $L_b$ | $10^6/[C_b(6.84f)^2]$ | $\mu$H | 45a, a1 | | 5.87 |
| | 46 | $X_{cr_2}$ | $\leqq 0.02X_{LN}$ | Ω | 41 | | 9.10 |
| ⊕ | 47 | $C_{r_2}$ | $159{,}000/(X_{cr_2}f)$ | pF | 46, a1 | | 7.35 |
| | 48 | $X_{C_L'}$ | $[159{,}000/C_{L_{df}}f)] - (X_1 + X_2)$ | Ω | b14, a1, 13, 5 | | 7.39 |
| ⊕ | 49 | $C_L'$ | $159{,}000/(X_{C_L'}f)$ | pF | 48, a1 | | 7.40 |
| | 50 | $Q_{op}$ | $< Q_xR_{df}/R_T$ | | b12, 20, b9 | | 5.77a |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

## Algorithm Figure 12.5 Colpitts Oscillator, *be* Cutoff Limiting




All units in . . .

℧ MHz Ω mW pF μH
mA, mV dc or rms

| | Item | Value |
|---|---|---|
| Oscillator Performance | $f$ | |
| | $P_L$ | |
| | $P_x$ | |
| | $V_{BB}$ | |
| | | |
| Principal Crystal Data | $R_{df}$ | |
| | $I_x$ | |
| | Cut | |
| | $N$ | |
| | | |
| Transistor Data | $\beta_o$ | |
| | $f_T$ | |
| | $BV_{CE}$ | |
| | $C_{cb}$ | |
| | $C_{bet}$ | |
| | $C_{ce}$ | |
| | $P_{dis}$ | |
| | Type | |
| Circuit Parameters | $\alpha$ | 0.3 |
| | $\gamma_1$ | 1.4 |
| | $V_{be}$ | 113 |
| | $\eta$ | |
| Calculated Data | $I_{BB}$ | |
| | $g_m$ | |
| | $V_E$ | |
| | | |
| | | |

**Algorithm 12.5 Colpitts Oscillator, *be* Cutoff Limiting**

| Oscillator Performance<br>Crystal and Transistor Characteristics | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Step No. | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
| | a1 | $f$ | Specified | MHz | | | |
| | a2 | $P_L$ | | mW | | **Oscillator** | |
| | a3 | $P_x$ | | mW | | | |
| | a4 | $V_{BB}$ | | mV | | **Performance** | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | b1 | Cut | Specified | | | | |
| | b2 | $N$ | | | | **Crystal** | |
| | b3 | $dt$ | | Hz | | | |
| | b4 | $R_L$ | | Ω | | **Characteristics** | |
| | b5 | $C_L$ | | pF | | Notes: | |

**Algorithm 12.5** (*Continued*)

| | Oscillator Performance<br>Crystal and Transistor Characteristics | | | | | | |
|---|---|---|---|---|---|---|---|
| | Step No. | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
| | b6 | $C_1$ | ↓ | pF | | 1. For production runs | |
| | b7 | $C_0$ | | pF | | $R_{df}$ = max | |
| | b8 | $C_0'$ | | pF | | 2. $P_x$ will increase | |
| | | | | | | as $R_{df}$ decreases | |
| | b9 | $Q_x$ | $10^6/(2\pi C_1 f R_1)$ | | b6, b11, a1 | 3. $P_L$ will | 3.29a |
| | b10 | $\Delta X/(\Delta f/f)$ | $10^6/(\pi C_1 f)$ | Ω | b6, a1 | increase | 3.20a |
| | | | | | | as $R_{df}$ decreases | |
| | b11 | $R_1$ | $[(C_L/(C_L + C_0)]^2 R_L$ | Ω | b5, b7, b4 | | 3.19 |
| | b12 | $R_{df}$ | $R_1/[1C_0'/(C_L + C_0) -$ | Ω | b11, b6, b7 | | 3.26a |
| | | | $2C_0' df/(C_1 f \times 10^6)]^2$ | | a1, b5, b8 | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | b13 | $I_x$ | $(1000 P_x/R_{df})^{1/2}$ | mA | a3, b12 | | 3.27a |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | b14 | $C_{L_{df}}$ | $\left[\frac{1}{C_L + C_0} + \frac{2 \times 10^{-6}\, df}{C_1 f}\right]^{-1} - C_0'$ | pF | b5, b7, b3<br>b6, a1, b8 | | 3.24a |
| | | | | | | | |
| | c1 | Type No. | Specified | | | | |
| | c2 | $\beta_o$ | | | | $\beta_o > 1200 g_m$ | 5.116 |
| | c3 | $f_T$ | | MHz | | $f_T > 600 f g_m$ | 5.113 |
| | c4 | $C_{bet}$ | | pF | | | |
| | c5 | $C_{cb}$ | | pF | | **Transistor** | |
| | c6 | $C_{ce}$ | | pF | | | |
| | c7 | $BV_{CB}$ | | mV | | **Characteristics** | |
| | c8 | $BV_{CE}$ | | mV | | | |
| | c9 | $BV_{BE}$ | | mV | | | |
| | c10 | $P_{\text{dis}}$ | | mW | | **at maximum temperature** | |
| | c11 | $r_{bb}$ | | Ω | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

**Algorithm 12.5** (*Continued*)

| | Oscillator Performance Crystal and Transistor Characteristics | | | | | | |
|---|---|---|---|---|---|---|---|
| | Step No. | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
| | | | **Circuit Parameters** | | | | |
| | d1 | $\alpha$ | 0.3 | | | See Section 7.6.1 | |
| | d2 | $\gamma_1$ | 1.4 | | | | |
| | d3 | $V_{be}$ | 113 | mV | | | |
| | | | *Calculation of Component Values* | | | | |
| | | | *Note: ⊕ signifies physical component* | | | | |
| | 1 | $\eta$ | $P_L/P_x$ | | a2, a3 | See discussion | 7.10 |
| | | | | | | on $\eta$ | |
| | 2 | $V_L$ | The smaller of | mV | | See discussion of | |
| | 2a | | $0.22 BV_{CE}$ or | | c8 | $R_L$ and $V_L$ | 9.6 |
| | 2b | | $\sqrt{10^7 P_L/\sqrt{f}}$ | | a2, a1 | | 7.30 |
| ⊕ | 3 | $R_L$ | $V_L^2/(1000 P_L)$ | Ω | 2, a2 | | 7.9 |
| | 4 | $V_E$ | $V_{BB} - [> 2.1(V_L + V_{be}] - 1700$ | mV | a4, 2, d3 | > 2000, See Note A | 9.8 |
| | 5 | $R_2$ | $\eta R_{df} - R_{df}^2/R_L$ | Ω | 1, b12, 3 | See Section 7.2.3.1 | 7.16 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 6 | $X_2$ | $\sqrt{R_2 R_L}$ | Ω | 5, 3 | | 7.4 |
| | 7 | $R'_T$ | $R_{df} + R_2$ | Ω | b12, 5 | | 5.40 |
| | 8 | $X_1$ | $V_{be}/I_x$ | Ω | d3, b13 | | 5.52 |
| | 9 | $g'_m$ | $R'_T/[X_1(X_2 - X_1/\beta_o)]$ | ℧ | 7, 8, 6, c2 | | 7.34 |
| | 10 | $I'_e$ | $g'_m V_{be}$ | mA | 9, d3 | | 7.7 |
| | 11 | $I'_E$ | $I'_e/\gamma_1$ | mA | 10, d2 | | 2.69 |
| | 12 | $r'_2$ | $V_E/I'_E$ | Ω | 4, 11 | | 2.99 |
| | 13 | $r'_b$ | $\beta_0 r'_2/5$ | Ω | c2, 12 | | 2.100 |
| | 14 | $R'_{in}$ | $g'_m X_1^2/\beta_0$ | Ω | 9, 8, c2 | | 7.2 |
| | 15 | $R'_b$ | $(X_1 + X'_2)^2/r'_b$ | Ω | 8, 6, 13 | | 5.57 |
| | 16 | $R_T$ | $R'_T + R'_{in} + R'_b$ | Ω | 7, 14, 15 | | 5.40 |
| | 17 | | Check that $R_T \leqq 1.1R'_T$ | | 16, 7 | | 7.46 |
| | 17a | | If yes, go to Step 24 | | | | |
| | 17b | | If no, go to Step 18 | | | | |
| | | | Note A: If $V_E$ calculates > $V_{BB}/2$, make $V_E = V_{BB}/2$. | | | | |
| | 18 | $I_e$ | $I_x R_T/X_2$ | mA | b13, 16, 6 | | 5.58a |

**Algorithm 12.5** (*Continued*)

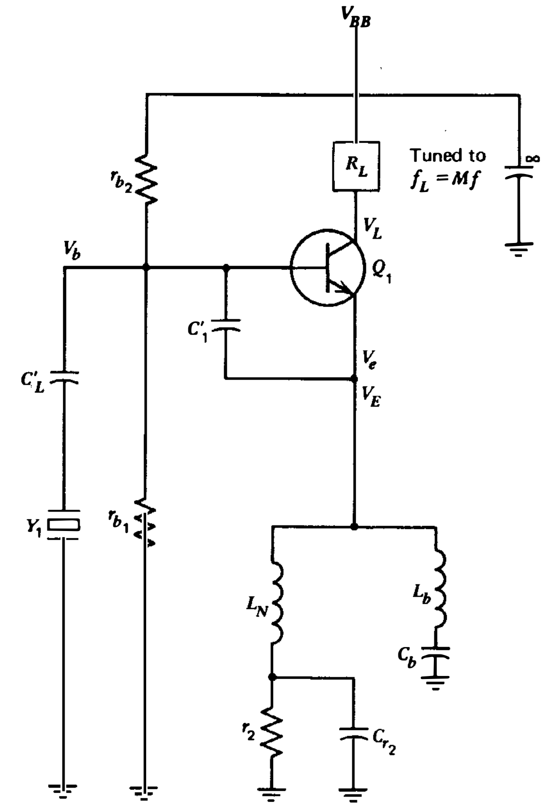
| | Oscillator Performance<br>Crystal and Transistor Characteristics | | | | | | |
|---|---|---|---|---|---|---|---|
| | Step No. | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
| | 19 | $I_E$ | $I_e/\gamma_1$ | mA | 18, d2 | | 2.69 |
| | 20 | $g_m$ | $R_T/(X_1 X_2)$ | ℧ | 16, 8, 6 | | 5.40 |
| ⊕ | 21 | $r_2$ | $V_E/I_E$ | Ω | 4, 19 | | 2.99 |
| | 22 | $r_b$ | $\beta_0 r_2/5$ | Ω | c2, 21 | | 2.100 |
| | 23 | Note: In the following steps, substitute $(r_b')^0$ for $(r_b)$ when Step 17 is yes. | | | | | |
| ⊕ | 24 | $r_{b_2}$ | $0.83 r_b V_{BB}/(V_E + 700)$ | Ω | 22 or 13, a4, 4 | | 2.103 |
| ⊕ | 25 | $r_{b_1}$ | $1/(1/r_b - 1/r_{b_2})$ | Ω | 22 or 13, 24 | | 2.104 |
| | 26 | $C_1$ | $159{,}000/(X_1 f)$ | pF | 8, a1 | | 7.35 |
| | 27 | $C_{bed}$ | $g_m 159{,}000/f_T$ | pF | 9 or 20, a1 | | 2.75 |
| | 28 | $M_M$ | $V_{be}/V_L$ | | d3, 2 | | 5.70 |
| | 29 | $C_{1M}$ | $C_{cb}(1 + 1/M_M)$ | pF | c5, 28 | | 5.71 |
| | 30 | $C_1'$ | $C_1 - C_{bed} - C_{1M} - C_{bet}$ | pF | 26, 27, 29, c4 | | Fig. 5.9b |
| | 31 | | Check whether $N = 1$ | | b2 | | |
| | 31a | $s$ | If yes, $s^2 = 0.2$ | | | | 5.82a |
| | 31b | $s$ | If no, $s = 1 - 1.5/N$ | | | | 5.82b |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 32 | $X_{CN}$ | $(1 - s^2)X_2$ | Ω | 31, 6 | | 5.83 |
| | 33 | $C_N$ | $159{,}000/(X_{CN}f)$ | pF | 32, a1 | | 5.84 |
| ⊕ | 34 | $C'_N$ | $C_N - C_{cb}(1 + M_M) - C_{ce}$ | pF | 33, c5, 28, c6 | | 5.73 |
| | | | | | | | Fig. 5.9b |
| | 35 | $X_{LN}$ | $X_{CN}/s^2$ | Ω | 32, 31 | | 5.85 |
| ⊕ | 36 | $L_N$ | $X_{LN}/(6.28f)$ | μH | 35, a1 | | 5.85a |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | 37 | | Check if the crystal cut | | | | |
| | | | is SC | | | | |
| | | | If no, | | | | |
| ⊕ | 38a | $C_b$ | $C'_1$ | pF | 30 | | SE |
| | 38b | $L_b$ | 0 | | | Continue at Step 40 | SE |
| | | | If yes, | | | | |
| ⊕ | 39a | $C_b$ | $0.156C'_1$ | pF | 30 | | 5.86 |

**Algorithm 12.5** (***Continued***)

| | Step No. | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
|---|---|---|---|---|---|---|---|
| Oscillator Performance Crystal and Transistor Characteristics | | | | | | | |
| ⊕ | 39b | $L_b$ | $10^6/[C_b(6.84f)^2]$ | $\mu$H | 39a, a1 | | 5.87 |
| | 40 | $X_{cr_2}$ | $0.02\,X_{LN}$ | | 35 | | 9.10 |
| ⊕ | 41 | $C_{r_2}$ | $159{,}000/(X_{cr_2}f)$ | pF | 40, a1 | | 7.35 |
| | 42 | $X_{C'_L}$ | $[159{,}000/(C_{Ldf}f)] - (X_1 + X_2)$ | Ω | b14, a1, 8, 6 | | 7.39 |
| ⊕ | 43 | $C'_L$ | $159{,}000/(X_{C'_L}f)$ | pF | 42, a1 | | 7.40 |
| | 44 | $Q_{op}$ | $Q_x R_{df}/R_T$ | | b9, b12, b16 | | 5.77a |
| | | | | | | | |

**Algorithm Figure 12.6.1 Semi-isolated Colpitts Oscillator, Form 1 Mode Selector.** ***Note*****: For $N = 1$, $L_N = C_{r_2} = 0$**

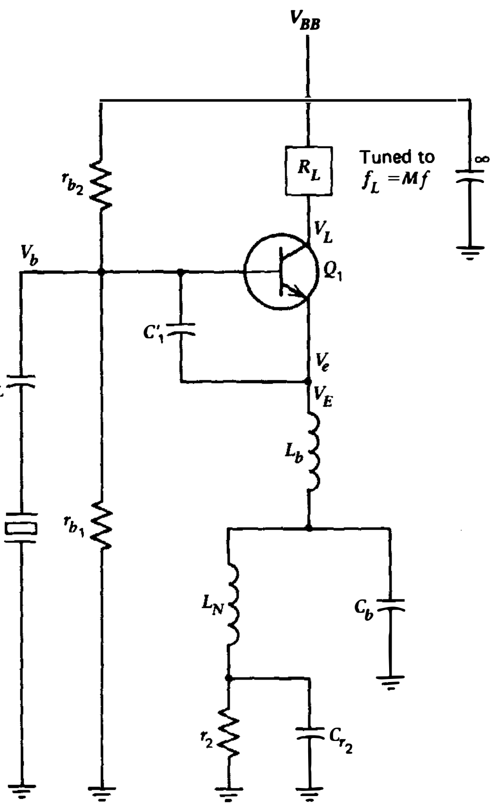



All units in . . .

℧ MHz Ω mW pF μH
mA, mV dc or rms

| | Item | Value |
|---|---|---|
| Oscillator Performance | $f$ | |
| | $P_L$ | |
| | $P_x$ | |
| | $V_{BB}$ | |
| | $M$ | |
| Principal Crystal Data | $R_{df}$ | |
| | $I_x$ | |
| | Cut | |
| | $N$ | |
| | | |
| Transistor Data | $\beta_o$ | |
| | $f_T$ | |
| | $BV_{CE}$ | |
| | $C_{cb}$ | |
| | $C_{bet}$ | |
| | $C_{ce}$ | |
| | $P_{dis}$ | |
| | Type | |
| Circuit Parameters | $\alpha$ | |
| | $\gamma_1$ | |
| | $\gamma_M$ | |
| | $V_{be}$ | |
| Calculated Data | $I_{BB}$ | |
| | $g_m$ | |
| | $V_E$ | |
| | | |
| | | |

**Algorithm Figure 12.6.2 Semi-isolated Colpitts Oscillator Form 2 Mode Selector**




All units in . . .

℧ MHz Ω mW pF μH
mA, mV dc or rms

| | Item | Value |
|---|---|---|
| Oscillator Performance | $f$ | |
| | $P_L$ | |
| | $P_x$ | |
| | $V_{BB}$ | |
| | $M$ | |
| Principal Crystal Data | $R_{df}$ | |
| | $I_x$ | |
| | Cut | |
| | $N$ | |
| | | |
| Transistor Data | $\beta_o$ | |
| | $f_T$ | |
| | $BV_{CE}$ | |
| | $C_{cb}$ | |
| | $C_{bei}$ | |
| | $C_{ce}$ | |
| | $P_{dis}$ | |
| | Type | |
| Circuit Parameters | $\alpha$ | |
| | $\gamma_1$ | |
| | $\gamma_M$ | |
| | $V_{be}$ | |
| Calculated Data | $I_{BB}$ | |
| | $g_m$ | |
| | $V_E$ | |
| | | |
| | | |

**Algorithm 12.6 Semi-Isolated Colpitts Oscillator, be Cutoff Limiting**

| Oscillator Performance<br>Crystal and Transistor Characteristics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Step | Item | Formula or Quantity | | Units | Refer to Step Nos. | Comments | Text Equation No. |
| | a1 | $f$ | Specified | | MHz | | | |
| | a2 | $P_L$ | | | mW | | **Oscillator** | |
| | a3 | $P_x$ | | | mW | | | |
| | a4 | $V_{BB}$ | | | mV | | **Performance** | |
| | a5 | $M$ | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | b1 | Cut | Specified | | | | | |
| | b2 | $N$ | | | | | **Crystal** | |
| | b3 | $df$ | | | Hz | | | |
| | b4 | $R_L$ | | | Ω | | **Characteristics** | |
| | b5 | $C_L$ | | | pF | | Notes: | |

**Algorithm 12.6 (*Continued*)**

Oscillator Performance
Crystal and Transistor Characteristics

| Step | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
|---|---|---|---|---|---|---|
| b6 | $C_1$ | | pF | | 1. For production runs | |
| b7 | $C_0$ | | pF | | $R_{df}$ = max | |
| b8 | $C_0'$ | | pF | | 2. $P_x$ will increase | |
| | | | | | as $R_{df}$ decrease | |
| b9 | $Q_x$ | $10^6/(2\pi C_1 f R_1)$ | | b6, b11, a1 | 3. $P_l$ will | 3.29a |
| b10 | $\Delta X/(\Delta f/f)$ | $10^6/(\pi C_1 f)$ | Ω | b6, a1 | remain constant | 3.20a |
| | | | | | as $R_{df}$ decreases | |
| b11 | $R_1$ | $[(C_L/(C_L + C_0)]^2 R_L$ | Ω | b5, b7, b4 | | 3.19 |
| b12 | $R_{df}$ | $R_1/[1 - C_0'/(C_L + C_0) -$ | Ω | b11, b6, b7 | | 3.26a |
| | | $2C_0' \, df/(C_1 f \times 10^6)]^2$ | | a1, b5, b8 | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| b13 | $I_x$ | $(1000 P_x/R_{df})^{1/2}$ | mA | a3, b12 | | 3.27a |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | b14 | $C_{L_{df}}$ | $\left[\dfrac{1}{C_L + C_0} + \dfrac{2 \times 10^{-6}\, df}{C_1 f}\right]^{-1} - C_0'$ | pF | b5, b7, b3<br>b6, a1, b8 | | 3.24a |
| | | | | | | | |
| | c1 | Type No. | Specified | | | | |
| | c2 | $\beta_o$ | | | | $\beta_o > 1200 g_m$ | 5.116 |
| | c3 | $f_T$ | | MHz | | $f_T > 600 f g_m$ | 5.113 |
| | c4 | $C_{bet}$ | | pF | | | |
| | c5 | $C_{cb}$ | | pF | | **Transistor** | |
| | c6 | $C_{ce}$ | | pF | | | |
| | c7 | $BV_{CB}$ | | mV | | **Characteristics** | |
| | c8 | $BV_{CE}$ | | mV | | | |
| | c9 | $BV_{BE}$ | | mV | | | |
| | c10 | $P_{dis}$ | | mW | | **at maximum temperature** | |
| | c11 | $r_{bb}$ | | Ω | | | |
| | | | | | | | |
| | | | | | | | |
| | | | **Circuit Parameters** | | | | |
| | d1 | $\alpha$ | $0.3/M$ | | a5 | | 10.8 |

**Algorithm 12.6** (*Continued*)

| | Oscillator Performance<br>Crystal and Transistor Characteristics | | | | | | |
|---|---|---|---|---|---|---|---|
| | Step | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
| | d2 | $\gamma_1$ | 1.4 | | | | 10.9a |
| | d3 | $\gamma_M$ | $1.6–0.2M$ | | a5 | | 10.9 |
| | d4 | $V_{be}$ | $36/\alpha$ | mV | d1 | | 10.10 |
| | | | *Calculation of Component Values* | | | | |
| | 1 | $V_L$ | The smaller of | mV | | See discussion of | |
| | 1a | | $0.27BV_{CE}$ or | | c8 | $R_L$ and $V_L$ | 10.11 |
| | 1b | | $\sqrt{10^7P_L/\sqrt{fM}}$ | | a2, a1 | | 10.13 |
| | | | | | | | |
| ⊕ | 2 | $R_L$ | $V_L^2/(1000P_L)$ | Ω | 1, a2, | | 7.9 |
| | 3 | $I_M$ | $V_L/R_L$ | mA | 1, 2 | | SE |
| | 4 | $I_E$ | $I_M/\gamma_M$ | mA | 3, d3 | | 2.69 |
| | 5 | $V_E$ | $V_{BB} - [1.7V_L] - 1700$ | mV | a4, 1 | > 2000 | 10.11a |
| | | | | | | If $V_E$ calculates | 10.11b |
| ⊕ | 6 | $r_2$ | $V_E/I_E$ | Ω | 5, 4 | $> V_{BB}/2$, | 2.99 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 7 | $r_b$ | $\beta_o(r_2)/5$ | Ω | c2, 6 | make $V_E = V_{BB}/2$ | 2.100 |
| ⊕ | 8 | $r_{b_2}$ | $0.83 r_b V_{BB}/(V_E + 700)$ | Ω | 7, a4, 5 | | 2.103 |
| ⊕ | 9 | $r_{b_1}$ | $1/(1/r_b - 1/r_{b_2})$ | Ω | 7, 8 | | 2.104 |
| | 10 | | Check whether $M = 1$ | | a5 | | |
| | 10a | $R_{L_1}$ | If yes, $R_{L_1} = R_L$ | Ω | 2 | | 10.15 |
| | 10b | $R_{L_1}$ | If no, $R_{L_1} = 0$ | Ω | | | 10.14 |
| | 11 | | Check whether $N = 1$ | | b2 | | |
| | 11a | | If yes, $r_{2ac} = r_2$ | Ω | 6 | | 10.16 |
| | 11b | | If no, $r_{2ac} \to \infty$ | Ω | | | 10.17 |
| | 12 | $I_{e_1}$ | $I_E \gamma_1$ | mA | 4, d2 | | 2.69 |
| | 13 | $X_1$ | $V_{be}/I_x$ | Ω | d4, b13 | | 5.52 |
| | 14 | $g_m$ | $\alpha/(26/I_E)$ | ℧ | d1, 4 | | 2.70 |
| | | | | | | | 2.72 |
| | 15 | $R_{\text{in}}$ | $X_1^2 g_m/\beta_o$ | Ω | 13, 14, c2 | | 7.2 |
| | 16 | $R_{\text{bp}}$ | $X_1^2/r_b$ | Ω | 13, 7 | | 5.60 |
| | 17 | $R_p$ | $R_{df} + R_{\text{in}} + R_{\text{bp}}$ | Ω | b12, 15, 16 | | 5.60 |
| | | | | | | | |
| | | | | | | | |
| | 18 | $a_i$ | $I_x/I_{e_1}$ | | b13, 12 | | 5.58a |

**Algorithm 12.6** (***Continued***)

| | Oscillator Performance<br>Crystal and Transistor Characteristics | | | | | | |
|---|---|---|---|---|---|---|---|
| | Step | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
| | 19 | $X_2$ | $a_i R_p(1 + 2a_i X_1/r_b)$ | Ω | 18, 17, 13, 7 | | 5.63 |
| | 20 | $V_e$ | $I_x\sqrt{\left[R_{df} + R_{in} + \frac{(X_1 + X_2)}{r_b}(X_1)\right]^2 + X_2^2}$ | mV | b13, b12, 15, | | 5.66 |
| | | | | | 19, 13, 7 | | |
| | 21 | $V_b$ | $I_x\left\{\sqrt{\left[(X_1 + X_2)^2 + R_{df}^2\right]}\right\}$ | mV | b13, 13, 19, b12 | | 5.50a |
| | 22 | $V_{L_1}$ | $I_{e_1} R_{L_1}$ | mV | 12, 10 | | SE |
| | 23 | $C_1$ | $159000/(X_{1f})$ | pF | 13, a1 | | 7.35 |
| | 24 | $C_{bed}$ | $g_{mi}159000/f_T$ | pF | 14, c3 | | 2.75 |
| | 25 | $M_{cb}$ | $1 + V_{L_1}/V_b$ | | 22, 21 | | 10.4 |
| | 26 | $C_M$ | $M_{cb}C_{cb}$ | pF | 25, c5 | | 10.3 |
| | 27 | $M_M$ | $V_{be}/V_e$ | | d4, 20 | | 10.6 |
| | 28 | $C_{1M}$ | $C_M(1 + 1/M_M)$ | pF | 26, 27 | | 10.5 |
| ⊕ | 29 | $C_1'$ | $C_1 - C_{bed} - C_{1M} - C_{bet}$ | pF | 23, 24, 28, c4 | | Fig. 5.91 |
| | 30 | $C_{2M}$ | $C_M(1 + M_M)$ | pF | 26, 27 | | 10.7 |

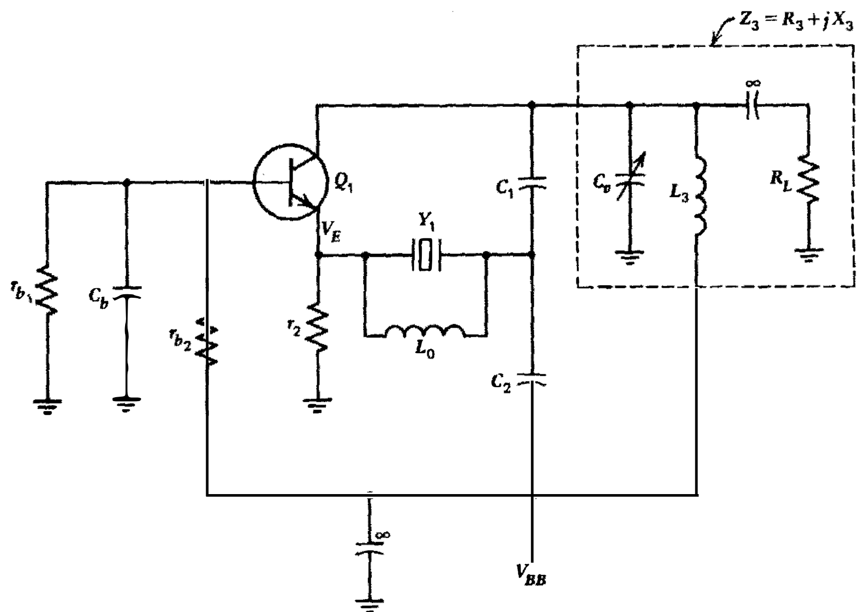
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 31 | $M_{ce}$ | $1 + V_{L_1}/V_e$ | | 22, 20 | | 10.2 |
| | 32 | $C_{cem}$ | $C_{ce}M_{ce}$ | pF | c6, 34 | | 10.1 |
| | 33 | | For nondoubly rotated cuts | | b1 | | |
| | 33a | | for $N = 1, L_N = 0$ <br> $X_{CN} = X_2$ | | b2 | See the note in the legend of Algorithm Figure 12.6.1. Go to step 35 | |
| | | | | | | | |
| | 33b | $s$ | for $N \neq 1, s = 1 - 1.5/N$ | | b2 | | 5.82b |
| | 34 | $X_{CN}$ | $(1 - s^2)X_2$ | Ω | 30, 19 | or as per 33a | 5.83 |
| | 35 | $C_N$ | $159{,}000/(X_{CN}f)$ | pF | 31, a1 | ↓ ↓ | 5.84 |
| | 36 | $C'_N$ | $C_N - C_{2M} - C_{cem}$ | pF | 35, 30, 32 | | SE |
| | 37 | $X_{LN}$ | $X_{C_N}/s^2$ | Ω | 34, 33 | For $N = 1$ see note in the legend of Algorithm Figure 12.6.1 | 5.85 |
| ⊕ | 38 | $L_N$ | $X_{L_N}/(6.28f)$ | μH | 37, a1 | | 5.85a |
| | | | | | | | |
| | | | | | | | |
| ⊕ | 39a | $C_b$ | $C'_N$ | pF | 36 | | SE |

Algorithm 12.6 (*Continued*)

| | Oscillator Performance<br>Crystal and Transistor Characteristics | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Step** | **Item** | **Formula or Quantity** | **Units** | **Refer to Step Nos.** | **Comments** | **Text Equation No.** |
| | 39b | $L_b$ | 0 | | | Continue at Step 45 | SE |
| | 40 | | For SC-cut | | b1 | | |
| | 40a | $X_2'$ | $1/\left(\frac{1}{X_2} - \frac{f(C_{2M} + C_{cem})}{159{,}000}\right)$ | Ω | 19, a1, 30, 32 | See Fig. 59b | SE |
| | 41 | | For SC-cut, $N = 1$ | | b1, b2 | | |
| ⊕ | 41a | $C_b$ | $0.156\frac{159{,}000}{X_2^1 f}$ | pF | 40a, a1 | | 5.86 |
| ⊕ | 41b | $L_b$ | $10^6/[C_b(6.84f)^2]$ | μH | 41a, a1 | Continue at Step 46. | 5.87 |
| | 42 | | For SC-cut, $N = 3$ or 5 | | b1, b2 | See Section 5.6.5.4 | |
| ⊕ | 43a | $C_b$ | $159{,}000/(5.37fX_2')$ | pF | a1, 40a | Form 1 network | 5.92a |
| | | | | | | | 5.93 |
| ⊕ | 43b | $L_N$ | $5.01X_2'/(2\pi f)$ | μH | 40a, a1 | Algorithm Figure 12.6.1 | 5.88a |
| | | | | | | | 5.99 |
| ⊕ | 43c | $L_b$ | $0.905L_N$ | μH | 43b | Continue at Step 46. | 5.91a |
| ⊕ | 44a | $C_b$ | $159{,}000/(1.48fX_2')$ | pF | a1, 40a | Form 2 network | 5.97a |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | 5.98 |
| ⊕ | 44b | $L_N$ | $2.62X_2'/(2\pi f)$ | μH | 40a, a1 | Algorithm Figure 12.6.2 | 5.94a |
| | | | | | | | 5.95 |
| ⊕ | 44c | $L_b$ | $0.905L_N$ | μH | 44b | Continue at Step 46 | 5.96a |
| | 45 | | Not used | | | | |
| | | | | | | | |
| | 46 | $X_{C_{r2}}$ | $0.02X_{LN}$ | Ω | 37 or $X_{LN}$ of | | 9.9 |
| | | | | | 43 b or 44b | | |
| ⊕ | 47 | $C_{r_2}$ | $159{,}000/(X_{c_{r2}}f)$ | pF | 46, a1 | for $N = 1$ $C_{r_2} = 0$ | 9.10 |
| | 48 | $X_{C_L'}$ | $159{,}000/(C_{L_{df}}f) - (X_1 + X_2)$ | Ω | b14, a1, 13, 19 | | 7.39 |
| ⊕ | 49 | $C_L'$ | $159{,}000/(X_{C_L'}f)$ | pF | 48, a1 | | 7.40 |
| | 50 | $Q_{op}$ | $Q_xR_{df}/$ | | b9, b12, 15, 13, 19 | | 5.77a |
| | | | $\left(R_{df} + R_{in} + \frac{X_2^2}{r_{2ac}} + \frac{(X_1 + X_2)^2}{r_b}\right)$ | | 11, 7 | | |
| | | | | | | | |
| | | | | | | | |

**Algorithm Figure 12.7 Butler Oscillator, $X_A = 0$ Design.**




All units in . . .

℧ MHz Ω mW pF μH
mA, mV dc or rms

| | Item | Value |
|---|---|---|
| Oscillator Performance | $f$ | |
| | $P_L$ | |
| | $P_x$ | |
| | $V_{BB}$ | |
| | | |
| Principal Crystal Data | $R_{df}$ | |
| | $I_x$ | |
| | Cut | |
| | $N$ | |
| | | |
| Transistor Data | $\beta_o$ | |
| | $f_T$ | |
| | $BV_{CE}$ | |
| | $C_{cb}$ | |
| | $C_{bet}$ | |
| | $C_{ce}$ | |
| | $P_{dis}$ | |
| | Type | |
| Circuit Parameters | $A_{L_0}$ | |
| | $Q_{L_3}$ | |
| | $R_A/X_2$ | |
| | | |
| Calculated Data | $I_{BB}$ | |
| | $\lvert Z_c \rvert$ | |
| | $R_N$ | |
| | $X_A$ | |
| | $X_L$ | |

**Algoritlun 12.7 $X_A$ = 0 Butler Oscillator, $R_{IN}$ Limiting**

Oscillator Performance
Crystal and Transistor Characteristics

| | Step No. | Item | Formula or Quantity | | Units | Refer to Step No. | Comments | Text Equation No. |
|---|---|---|---|---|---|---|---|---|
| | a1 | $f$ | Specified | | MHz | | | |
| | a2 | $P_L$ | | | mW | | **Oscillator** | |
| | a3 | $P_x$ | | | mW | | | |
| | a4 | $V_{BB}$ | | | mV | | **Performance** | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | b1 | Cut | Specified | | | | | |
| | b2 | $N$ | | | | | **Crystal** | |
| | b3 | $df$ | | | Hz | | | |
| | b4 | $R_L$ | | | Ω | | **Characteristics** | |
| | b5 | $C_L$ | | | pF | | Notes: | |

**Algorithm 12.7** (***Continued***)

| Oscillator Performance<br>Crystal and Transistor Characteristics | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Step No. | Item | Formula or Quantity | Units | Refer to Step No. | Comments | Text Equation No. |
| | b6 | $C_1$ | | pF | | 1. For production runs | |
| | b7 | $C_0$ | | pF | | $R_{df}$ = max | |
| | b8 | $C_0'$ | | pF | | 2. $P_x$ will decrease | |
| | | | | | | as $R_{df}$ decreases. | |
| | b9 | $Q_x$ | $10^6/(2\pi C_1 f R_1)$ | | b6, b11, a1 | 3. $P_L$ will | 3.29a |
| | b10 | $\Delta X/(\Delta f/f)$ | $10^6/(\pi C_1 f)$ | Ω | b6, a1 | remain constant | 3.20a |
| | | | | | | as $R_{df}$ decreases. | |
| | b11 | $R_1$ | $[1C_L/(C_L + C_0)]^2 R_L$ | Ω | b5, b7, b4 | | 3.19 |
| | | | | | | | |
| | b12 | $R_{df}$ | $R_1/[1 - C_0'/(C_L + C_0) -$ | Ω | b11, b6, b7 | | 3.26a |
| | | | $2C_0' \, df/(C_1 f \times 10^6)]^2$ | | a1, b5, b8 | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | b13 | $I_x$ | $(1000 P_x/R_{df})^{1/2}$ | mA | a3, b12 | | 3.27a |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | b14 | $C_{L_{df}}$ | $\left[\frac{1}{C_L + C_0} + \frac{2 \times 10^{-6} df}{C_1 f}\right]^{-1} - C_0'$ | pF | b5, b7, b3<br>b6, a1, b8 | | 3.24a |
| | | | | | | | |
| | c1 | Type No. | Specified | | | | |
| | c2 | $\beta_o$ | | | | $\beta_o > 120[illegible]/R_{IN}$ | 5.116 |
| | c3 | $f_T$ | | MHz | | $f_T > 4fI_E$ | 11.1a |
| | c4 | $C_{ber}$ | | pF | | | |
| | c5 | $C_{cb}$ | | pF | | **Transistor** | |
| | c6 | $C_{ce}$ | | pF | | | |
| | c7 | $BV_{CB}$ | | mV | | **Characteristics** | |
| | c8 | $BV_{CE}$ | | mV | | | |
| | c9 | $BV_{BE}$ | | mV | | | |
| | c10 | $P_{dis}$ | | mW | | **at maximum temperature** | |
| | c11 | $r_{bb}$ | | Ω | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | **Circuit Parameters** | | | | |
| | d1 | $A_{L_0}$ | Specified | | | Recommend $A_{L_0} = 2$ | 11.45 |

**Algorithm 12.7** (***Continued***)

| | Step No. | Item | Formula or Quantity | Units | Refer to Step No. | Comments | Text Equation No. |
|---|---|---|---|---|---|---|---|
| | | | Oscillator Performance<br>Crystal and Transistor Characteristics | | | | |
| | d2 | $Q_{L_3}$ | Specified | | | | |
| | | | | | | | |
| | | | *Calculation of Component Values* | | | | |
| | | | *Note:* ⊕ *signifies physical component* | | | | |
| | 1 | $I_E$ | $1.4I_x$ | mA | b13 | | 6.23 |
| | 2 | $R_{IN_0}$ | $26/I_E$ | Ω | 1 | | 2.87 |
| | 3 | $R_A$ | $A_L(R_{IN_0} + R_{df})$ | Ω | d1, b12, 2 | | 11.45a |
| | 4 | $P_A$ | $I_x^2 R_A/1000$ | mW | b13, 3 | | 11.25 |
| | 5 | $n$ | $P_L/P_A$ | | a2, 4 | | 11.40 |
| ⊕ | 6 | $R_L$ | $[(n + 1)I_x R_A]^2/(10^3 P_L)$ | Ω | 5, b13, 3 | $< 10{,}000/\sqrt{f}$ | 11.42 |
| | 7 | $X_2$ | $R_A/5$ | Ω | 3 | | 11.35 |
| | 8 | $X_1 + X_2$ | $(n + 1)X_2$ | Ω | 5, 7 | | 11.37 |
| | 9 | $X_1$ | $nX_2$ | Ω | 5, 7 | | 11.37 |
| | 10 | $X_L$ | $(X_1 + X_2)\left(1 + \left(\frac{X_1 + X_2}{R_L}\right)^2\right)$ | Ω | 8, 6 | | 11.27 |

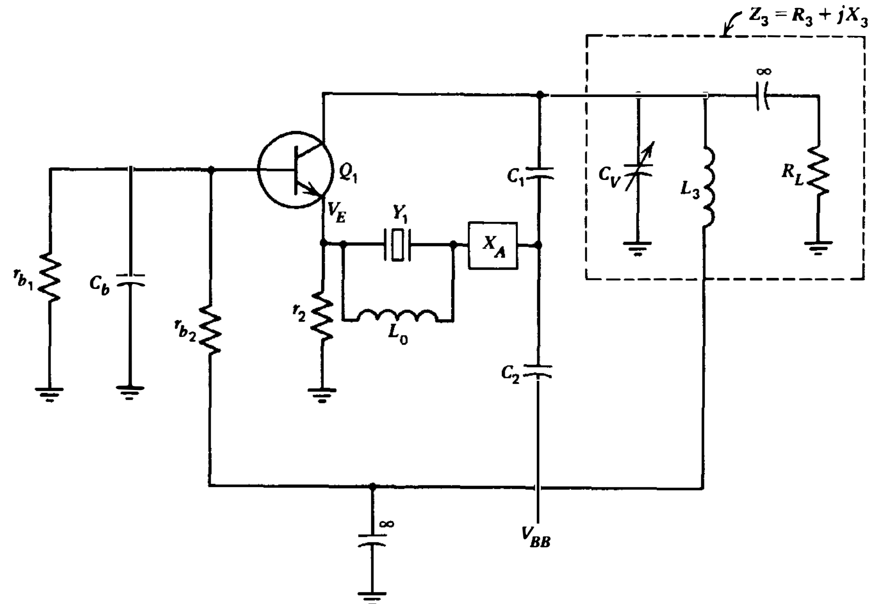
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ⊕ | 11 | $C_2$ | $159{,}000/(X_2 f)$ | pF | 7, a1 | | 5.84 |
| ⊕ | 12 | $C_1$ | $159{,}000/(X_1 f)$ | pF | 9, a1 | | 5.84 |
| ⊕ | 13 | $C_V$ | 0 to $C_1/2$ | pF | 12 | | SE |
| | 14 | $X_{L_3}$ | $1/(1/X_L + C_{V_{mean}} f/159{,}000)$ | Ω | 10, a1, 13 | | 11.16 |
| ⊕ | 15 | $L_3$ | $X_{L_3}/(6.28f)$ | μH | 14, a1 | | 5.85a |
| ⊕ | 16 | $C_b$ | $> 1.59 \times 10^6/(f(R_A - R_{df}))$ | pF | a1, 3, b12 | | 11.48 |
| | 17 | $P_L'$ | $P_L[1 + R_L/(Q_{L_3} X_{L_3})]$ | mW | a2, 6, d2, 14 | See Note A | 11.52 |
| | 18 | | Check that $P_L' < 1.1P_L$ | | | If not, see Note A | |
| | 19 | $V_L$ | $\sqrt{1000 P_L R_L}$ | mV | a2, 6 | $< 0.25BV_{CE}$ | 7.9 |
| | 20 | | Not used | | | | |
| | 21 | $V_E$ | $V_{BB} - 1.7V_L - 1700$ | mV | a4, 19 | $> 2000$ | 11.46 |
| | | | | | | If $V_E$ calculates | 11.46a |
| ⊕ | 22 | $r_2$ | $V_E/I_E$ | Ω | 21, 1 | $> V_{BB}/2$, | 2.99 |
| | | | | | | make $V_E = V_{BB}/2$ | |
| | | | | | | | |
| | 23 | $r_b$ | $\beta_o r_2/5$ | Ω | c2, 22 | | 2.100 |

**Algorithm 12.7 (*Continued*)**

Oscillator Performance
Crystal and Transistor Characteristics

| | Step No. | Item | Formula or Quantity | Units | Refer to Step No. | Comments | Text Equation No. |
|---|---|---|---|---|---|---|---|
| ⊕ | 24 | $r_{b_2}$ | $0.83 r_b V_{BB}/(V_E + 700)$ | Ω | 23, a4, 21 | | 2.103 |
| ⊕ | 25 | $r_{b_1}$ | $1/(1/r_b - 1/r_{b_2})$ | Ω | 23.24 | | 2.104 |
| ⊕ | 26 | $L_0$ | $10^6/[C_0'(6.28f)^2]$ | μH | b8, a1 | Omit for $f < 50$ MHz | 11.49 |
| | 27 | $Q_{op}$ | $< Q_x R_{df}/R_A$ | | b9, b12, 3 | | 11.55 |
| | | | | | | | |
| | | | Note A: If necessary and desirable, redo Steps 5 to 27 substituting $P_L'$ for $P_L$ in Step 5. | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

## Algoritlım Figure 12.8 Stable Butler Oscillator




All units in . . .

℧ MHz Ω mW pF μH
mA, mV dc or rms

| | Item | Value |
|---|---|---|
| Oscillator Performance | $f$ | |
| | $P_L$ | |
| | $P_x$ | |
| | $V_{BB}$ | |
| | | |
| Principal Crystal Data | $R_{df}$ | |
| | $I_x$ | |
| | Cut | |
| | $N$ | |
| | | |
| Transistor Data | $\beta_o$ | |
| | $f_T$ | |
| | $BV_{CE}$ | |
| | $C_{cb}$ | |
| | $C_{bet}$ | |
| | $C_{ce}$ | |
| | $P_{dis}$ | |
| | Type | |
| Circuit Parameters | $A_{L_0}$ | |
| | $Q_{L_3}$ | |
| | $R_A/X_2$ | |
| | | |
| Calculated Data | $I_{BB}$ | |
| | $\lvert Z_c \rvert$ | |
| | $R_N$ | |
| | $X_A$ | |
| | $X_L$ | |

**Algorithm 12.8 Stable Butler Oscillator, $R_{IN}$ Limiting**

| Oscillator Performance<br>Crystal and Transistor Characteristics | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Step No. | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
| | a1 | $f$ | Specified | MHz | | | |
| | a2 | $P_L$ | | mW | | **Oscillator** | |
| | a3 | $P_x$ | | mW | | | |
| | a4 | $V_{BB}$ | | mV | | **Performance** | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | b1 | Cut | Specified | | | | |
| | b2 | $N$ | | | | **Crystal** | |
| | b3 | $df$ | | Hz | | | |
| | b4 | $R_L$ | | Ω | | **Characteristics** | |
| | b5 | $C_L$ | | pF | | Notes: | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | b6 | $C_1$ | │ | pF | | 1. For production runs | |
| | b7 | $C_0$ | │ | pF | | $R_{Df}$ = max | |
| | b8 | $C_0'$ | ↓ | pF | | 2. $P_x$ will decrease | |
| | | | | | | as $R_{df}$ decreases | |
| | b9 | $Q_x$ | $10^6/(2\pi C_1 f R_1)$ | | b6, b11, a1 | 3. $P_L$ will | 3.29a |
| | b10 | $\Delta X/(\Delta f/f)$ | $10^6/(\pi C_1 f)$ | Ω | b6, a1 | remain constant | 3.20a |
| | | | | | | as $R_{df}$ decreases | |
| | b11 | $R_1$ | $[(C_L/(C_L + C_0)]^2 R_L$ | Ω | b5, b7, b4 | | 3.19 |
| | b12 | $R_{df}$ | $R_1/[1 - C_0'/(C_L + C_0) -$ | Ω | b11, b6, b7 | | 3.26a |
| | | | $2C_0' df/(C_1 f \times 10^6)]^2$ | a1, b5, b8 | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | b13 | $I_x$ | $(1000 P_x/R_{df})^{1/2}$ | mA | a3, b12 | | 3.27a |
| | b14 | $C_{L_{df}}$ | $\left[\frac{1}{C_L + C_0} + \frac{2 \times 10^{-6} df}{C_L f}\right]^{-1} - C_0'$ | | b6, a1, b8 | | 3.24a |
| | c1 | Type No. | Specified | | | | |

**Algorithm 12.8** (***Continued***)

Oscillator Performance
Crystal and Transistor Characteristics

| | Step No. | Item | Formula or Quantity | | Units | Refer to Step Nos. | Comments | Text Equation No. |
|---|---|---|---|---|---|---|---|---|
| | c2 | $\beta_o$ | | | | | $\beta_o > 1200/R_{IN}$ | 5.116 |
| | c3 | $f_T$ | | | MHz | | $f_T > 4fI_E$ | 11.1a |
| | c4 | $C_{bet}$ | | | pF | | | |
| | c5 | $C_{cb}$ | | | pF | | **Transistor** | |
| | c6 | $C_{ce}$ | | | pF | | | |
| | c7 | $BV_{CB}$ | | | mV | | **Characteristics** | |
| | c8 | $BV_{CE}$ | | | mV | | | |
| | c9 | $BV_{BE}$ | | | mV | | | |
| | c10 | $P_{dis}$ | | | mV | | **at maximum temperature** | |
| | c11 | $r_{bb}$ | | | Ω | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

| | | | Circuit Parameters | | | | |
|---|---|---|---|---|---|---|---|
| | d1 | $A_{L_0}$ | Specified | | | Recommend $A_{L_0} = 2$ | 11.45 |
| | d2 | $Q_{L_3}$ | ↓ | | | | |
| | | | | | | | |
| | | | *Calculation of Component Values* | | | | |
| | | | *Note:* ⊕ *signifies physical component* | | | | |
| | 1 | $I_E$ | $1.4I_x$ | mA | b13 | | 6.23 |
| | 2 | $R_{\text{IN}_0}$ | $26/I_E$ | Ω | 1 | | 2.87 |
| | 3 | $R_{A_0}$ | $R_{\text{IN}_0} + R_{df}$ | Ω | 2, b12 | | 11.43 |
| | 4 | $R_A$ | $A_{L_0}R_{A_0}$ | Ω | d1, 3 | | 11.45 |
| ⊕ | 5 | $R_L$ | $2000P_L/I_x^2$ | Ω | a2, b13 | $< 10{,}000/\sqrt{f}$ | 11.65 |
| | 6 | $n$ | $0.5R_L/R_A - 1$ | | 5, 4 | | 11.73 |
| | 7 | $R_A/X_2$ | Choose a value | | | Recommend 2.5 to 5 | |
| | 8 | $X_{L+}$ | $R_L/(2R_A/X_2 + 1)$ | | 5, 7 | See Section 11.4.6. | 11.74 |
| | 9 | $X_2$ | $R_A/(R_A/X_2)$ | Ω | 4, 7 | | SE |
| | 10 | $X_1$ | $nX_2$ | Ω | 6, 9 | | 11.71 |
| | 11 | $X_1 + X_2$ | $(n + 1)X_2$ | Ω | 6, 9 | | 11.37 |

**Algorithm 12.8** (***Continued***)

| Oscillator Performance<br>Crystal and Transistor Characteristics | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Step No. | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
| | 12 | $-R_N$ | $X_1 X_2 \dfrac{R_L}{1 + (R_L/X_{L+})^2}$ (numerator, over Denominator) | Ω | 10, 9, 5 | | 11.56 |
| | | | | | 8 | | |
| | | | $\left(\dfrac{R_L}{1 + (R_L/X_{L+})^2}\right)^2 + \left(\dfrac{X_{L+}}{1 + (X_{L+}/R_L)^2} - (X_1 + X_2)\right)^2$ } Denominator | | | | |
| | | | $\dfrac{-X_1 X_2 \left(\dfrac{X_{L+}}{1 + (X_{L+}/R_L)^2} - (X_1 + X_2)\right)}{\text{Denominator}}$ | | | | |
| | 13 | $X_A$ | | Ω | 10, 9, 5 | | 11.57 |
| | | | | | 8 | | |
| | 14 | | Check that $-R_N \approx R_A$ | | 12, 4 | | |
| ⊕ | 15 | $C_2$ | $159{,}000/(X_2 f)$ | pF | 9, a1 | | 5.84 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ⊕ | 16 | $C_1$ | $C_2/n$ | pF | 15, 6 | | 11.37 |
| ⊕ | 17 | $C_v$ | $C_1/2$ | pF | 16 | | SE |
| | 18 | $X_{L_3}$ | $1/(1/X_{L+} + fC_{v_{mean}}/159{,}000)$ | Ω | 8, a1, 17 | | 11.16 |
| ⊕ | 19 | $L_3$ | $X_{L_3}/(6.28f)$ | μH | 18, a1 | | 5.85a |
| ⊕ | 20 | $C_b$ | $1.59 \times 10^6/(f(R_A - R_{df}))$ | pF | a1, 3, b12 | | 11.48 |
| ⊕ | 21 | $L_A$ | $X_A/(6.28f)$ | μH | 13, a1 | | 5.85a |
| | 22 | $P'_L$ | $P_L(1 + R_L/(Q_{L_3}X_{L_3}))$ | mW | a2, 5, d2, 18 | Note A | 11.52 |
| | 23 | | Check that $P'_L < 1.1P_L$ | | a2, 22 | | |
| | 24 | $V_L$ | $\sqrt{1000P_LR_L}$ | mV | a2, 5 | | 7.9 |
| | 25 | $V_E$ | $V_{BB} - 1.7V_L - 1700$ | mV | a4, 24 | > 2000 | 11.46 |
| | | | | | | If $V_E$ calculates | 11.46a |
| ⊕ | 26 | $r_2$ | $V_E/I_E$ | Ω | 25, 1 | $> V_{BB}/2$ | 2.99 |
| | | | | | | make $V_E = V_{BB}/2$ | |
| | 27 | $r_b$ | $\beta_o r_2/5$ | Ω | c2, 26 | | 2.100 |
| ⊕ | 28 | $r_{b_0}$ | $0.83r_bV_{BB}/(V_E + 700)$ | Ω | 27, a4, 25 | | 2.103 |
| ⊕ | 29 | $r_{b_1}$ | $1/(1/r_b - 1/r_{b_2})$ | Ω | 27, 28 | | 2.104 |
| ⊕ | 30 | $L_0$ | $10^6/[C'_0(6.28f)^2]$ | μH | b8, a1 | omit for $f < 50$ | 11.49 |

**Algorithm 12.8** (*Continued*)

Oscillator Performance
Crystal and Transistor Characteristics

| | Step No. | Item | Formula or Quantity | Units | Refer to Step Nos. | Comments | Text Equation No. |
|---|---|---|---|---|---|---|---|
| | 31 | $Q_{op}$ | $< Q_x R_{df}/ - R_N$ | | b9, b12, 12 | | 11.81 |
| | | | | | | | |
| | | | Note A: If necessary and desirable, redo Steps 5 to 31 substituting $P_L'$ for $P_L$ in Step 5. | | | | |
| | | | For the $X_{L-}$ design. | | | | |
| | | $X_{L-}$ | $R_L/(2R_A/X_2 - 1)$ | Ω | 5, 7 | | 11.75 |
| | | | Continue with Steps 9 to 31. Note that $L_A$, in Step 21, 11.75 is a capacitor. | | | | |
| | | | | | | | |
| | | | | | | | |