9

The Normal Colpitts Oscillator

9.1 INTRODUCTION

This chapter develops the additional and/or modified relations of Chapters 5 and 7 required to design this type of oscillator. It also contains comments about the practical aspects of the design. Finally, it formulates two design algorithms—one for each of the major types of limiting of Section 6.2. The algorithms are specifically applicable to the self-limiting types of crystal oscillator but they are also useful for non-self-limiting types and for other types of two-terminal resonators.

By the normal Colpitts oscillator is meant the oscillator whose circuit is shown in Fig. 5.1*b* and repeated in a modified form in Fig. 5.8. All the components in that figure are physical; that is, they are all installed components.

The theory of the oscillator is fully covered in Chapter 5, except for the limiting considerations. It is therefore recommended that Chapter 5 be read in its entirety, beginning with Section 5.3.4, before proceeding with this chapter.

Many of the equations developed in Chapter 7 for the Pierce oscillator will also be used for formulating the design algorithms and will be referenced therein in the "Text Equation" column. In using these equations, V_{be} or $V_{be'}$, as appropriate, must be substituted for V_b in the equations of Chapter 7.

9.2 OSCILLATOR CIRCUIT ANALYSIS

9.2.1 Introduction

Most of the circuit analysis is already presented in Chapter 5. Additional material developed in Section 7.2.3 is also applicable. The reader is referred to Chapter 5 and Section 7.2.3, as the material is not being repeated.

9.2.2 Discussion of $V_{L_{max}}$ and R_L

Section 7.2.4 presents the discussion of V_L and R_L for the normal Pierce oscillator. The discussion for the Colpitts oscillator is almost identical, and for that reason the reader is urged to read Section 7.2.4, as the identical material will not be repeated here.

9.2.2.1 Calculation of $V_{L_{max}}$ for the Collector Base Limiting Oscillator

The results are identical to those for the Pierce oscillator but that fact is not self-evident and the results will therefore be derived.

Figure 9.1 shows the voltage relationships in this type of limiting. By inspection it is seen to be

$$v_{CE_{max}} = V_{BB} - v_{E_{min}} \tag{9.1}$$

$$\approx 2.8V_L + 1.4V_{be'}$$

But

$$v_{CE_{max}} \leqq BV_{CE} \tag{9.2}$$

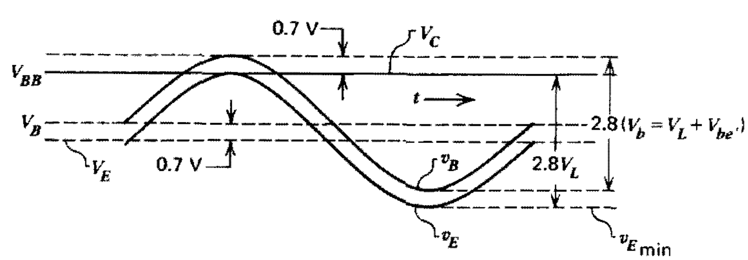


Figure 9.1 Voltage relationships for collector base voltage limiting in the Colpitts oscillator.

therefore,

$$V_L \leqq \frac{BV_{CE} - 1.4V_{be'}}{2.8}$$
$$\leqq 0.357BV_{CE} - 0.5V_{be'}$$
$$\approx 0.33BV_{CE} \qquad (9.3)$$

to compensate for the $V_{be'}$ term.

9.2.2.2 *Calculation of $V_{L_{max}}$ for the be Cutoff Limiting Oscillator*

Figure 9.2 shows the voltage relationship for this type of limiting. In this oscillator $v_{B_{max}}$ must be less than $v_C = V_{BB}$ for Z_3 having the minimum R_3. Since the oscillator is designed for $R_{3_{max}}$, when V_L is minimum, provision must be made for the increase of V_L as R_3 decreases. Let

$$\frac{R_{3_{max}}}{R_{3_{min}}} = 2 \qquad (9.4)$$

then

$$\frac{V_{L_{max}}}{V_{L_{min}}} \approx 1.5 \qquad (9.5)$$

and from Eq. (9.3)

$$V_L = \frac{0.33}{1.5} BV_{CE} = 0.22BV_{CE} \qquad (9.6)$$

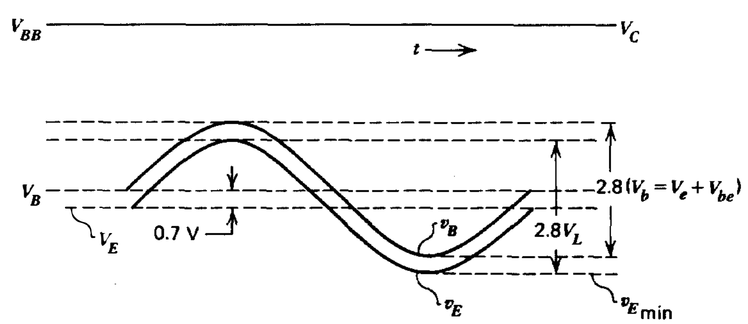


Figure 9.2 Voltage relationships for the base emitter cutoff limiting in the Colpitts oscillator.

9.2.2.3 Calculation of V_E, Which Should Be Greater Than 2 V

It is evident from Fig. 9.1 that, for collector limiting,

$$V_E = V_{BB} - [1.4(V_L + V_{be'}) - 700] - 700$$

$$= V_{BB} - 1.4(V_L + V_{be'}) \qquad (9.7)$$

Similarly, from Fig. 9.2, for the *be* cutoff limiting oscillator

$$V_E = V_{BB} - 2.1(V_L + V_{be}) - 1700 \qquad (9.8)$$

or, when

$$V_{E_1} > \frac{V_{BB}}{2}, \qquad V_E = \frac{V_{BB}}{2} \qquad (9.8a)$$

which is derived in the same manner as that described in Section 7.2.4.3.2, to which the reader is referred.

9.2.3 Calculation of C_{r_2}

It is desirable that

$$X_{C_{r_2}} \leqq 0.02 X_{L_N} \qquad (9.9)$$

in order not to affect the stability of X_{L_N} and

$$C_{r_2} = \frac{159{,}000}{X_{C_{r_2}} f} \qquad (9.10)$$

9.3 FREQUENCY VARIATIONS DUE TO EXTERNAL FACTORS

The material in Section 7.3 is completely applicable.

9.4 THE DESIGN PROCEDURE

The design procedure outlined in Section 7.4 is applicable except that there are two levels of approximation. It is therefore seen that the design for the Colpitts oscillator is more difficult than that for the Pierce oscillator.

9.5 THE COLPITTS OSCILLATOR, COLLECTOR BASE LIMITING

9.5.1 The Design Algorithm for This Oscillator (Algorithm 12.4)

See Section 7.5.1 for pertinent remarks which are also applicable to this algorithm.

It will be noted that Steps 6 to 20 constitute the first level of approximation, and Steps 22 to 28, the second level. The remaining steps constitute the translation of the calculated quantities into the physical components which make up the oscillator.

9.5.2 Design Examples for Algorithm 12.4

Design Examples 9.1 and 9.2 are design examples for this algorithm. The results are quite similar to those for the design examples for Algorithm 12.1 discussed in Section 7.5.2. The major differences are that I_{BB} is larger because of the greater losses, and the operating Q is somewhat smaller.

9.5.3 Trimming for Algorithm 12.4

See Fig. 5.8.

9.5.3.1 Introduction

See Section 7.5.3.1.

9.5.3.2 Basis of the Trimming Procedure

The trimming is based upon the following approximate relations:

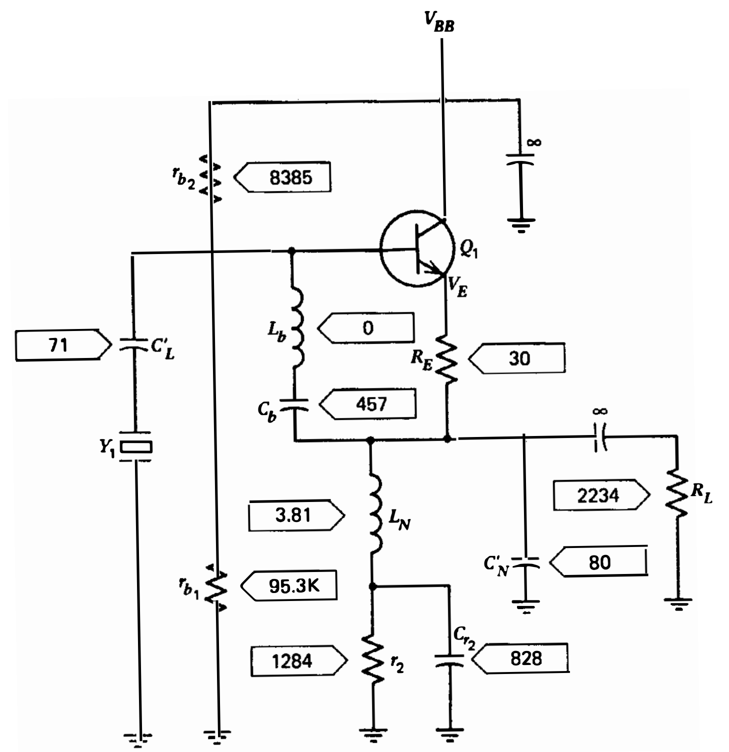
1
$$V_L \propto V_{CE} \tag{9.11}$$
from Eq. (9.3).

2
$$|I_3| \approx \frac{V_L}{\sqrt{R_3^2 + X_2^2}} \tag{9.12}$$
from Eq. (5.65).

3
$$V_{be} \approx |I_3||X_1| \tag{9.13}$$
from Eq. (5.52a).

4
$$P_L \propto \frac{V_L^2}{R_L} \tag{9.14}$$

5 $|V_{be'}|$ and I_E must be maintained so that the proper type of limiting is in effect. This is a rather broad requirement and will permit large ranges of $|V_{be'}|$ and I_E, the values of which must be optimized for lowest X_1 and

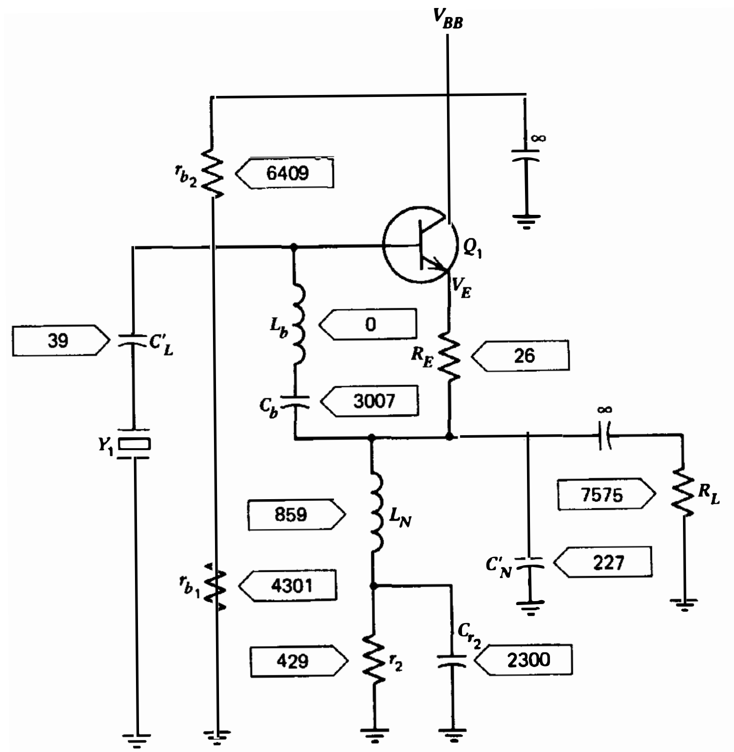


Design Example 9.1 Colpitts oscillator, collector base voltage limiting.

All units in

℧ MHz Ω mW pF μH
mA, mV dc or rms

	Item	Value
Oscillator Performance	f	20
	P_L	1.66
	P_x	5.0
	V_{BB}	10,000
Principal Crystal Data	R_{df}	20
	I_x	15.8
	Cut	AT
	N	1
Transistor Data	β_o	30
	f_T	700
	BV_{CE}	15,000
	C_{cb}	1
	C_{bet}	2
	C_{ce}	2
	P_{dis}	
	Type	2N918
Circuit Parameters	A_{L_0}	2
	η	33
Calculated Data	I_{BB}	5.5
	V_E	6929
	g_m	0.14



Design Example 9.2 Colpitts oscillator, collector base voltage limiting.

All units in

℧ MHz ℧ mW pF μH
mA, mV dc or rms

	Item	Value
Oscillator Performance	f	0.8
	P_L	3.3
	P_x	10
	V_{BB}	10.000
Principal Crystal Data	R_{df}	625
	I_x	4
	Cut	AT
	N	1
Transistor Data	β_o	30
	f_T	700
	BV_{CE}	15000
	C_{cb}	1
	C_{bet}	2
	C_{ce}	2
	P_{dis}	
	Type	2N918
Circuit Parameters	$A_{I\text{-}0}$	2
	η	0.33
Calculated Data	I_{BB}	6.8
	V_E	2633
	g_m	0.016

highest conversion efficiency, consistent with the variations in transistor properties. This may involve adjustments in the values of r_2, r_{b_1}, and r_{b_2}.

Note: For a crystal resonator, $I_3 \equiv I_x$.

9.5.3.3 Typical Trimming Steps

Section 7.5.3.3 is applicable, taking into account the number changes of the equivalent equations.

9.5.4 Frequency Instability Due to Variations in Components, Other Than Z_3

Section 7.5.4 is applicable.

9.6 THE COLPITTS OSCILLATOR, *be* CUTOFF LIMITING

9.6.1 The design algorithm for the oscillator is Algorithm 12.5. The comments in Section 7.6.1 are applicable here.

9.6.2 Design Examples for Algorithm 12.5

Design Examples 9.3 and 9.4 pertain to Algorithm 12.5. The results are quite similar to those for the design examples for Algorithm 12.2 discussed in Section 7.6.2. The major differences are that I_{BB} is larger because of the greater losses, and the operating Q is somewhat smaller.

9.6.3 Trimming for Algorithm 12.5

See Fig. 5.8.

9.6.3.1 Introduction

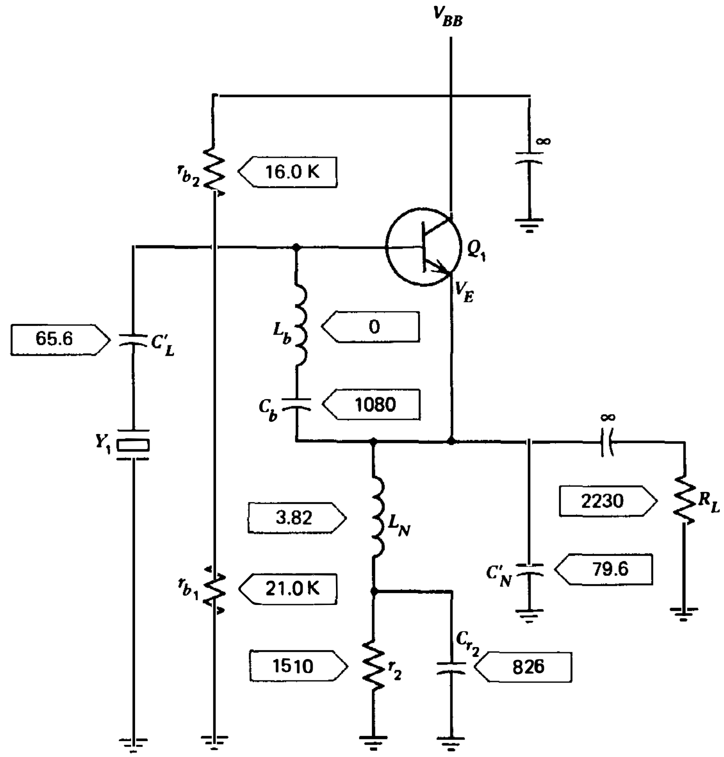
Same as Section 7.5.3.1.

9.6.3.2 Basis of the Trimming Procedure

The trimming is based upon the following relations:

1
$$I_3 = 1.4 I_e \tag{9.15}$$
from Fig. 2.12*b*.

2
$$|V_L| = |I_3|\sqrt{R_T^2 + X_2^2} \tag{9.16}$$
from Eq. (5.66).
$$= |I_e|\frac{|X_2|}{R_T}\sqrt{R_T^2 + X_2^2} \tag{9.17}$$
from Eq. (5.59a).

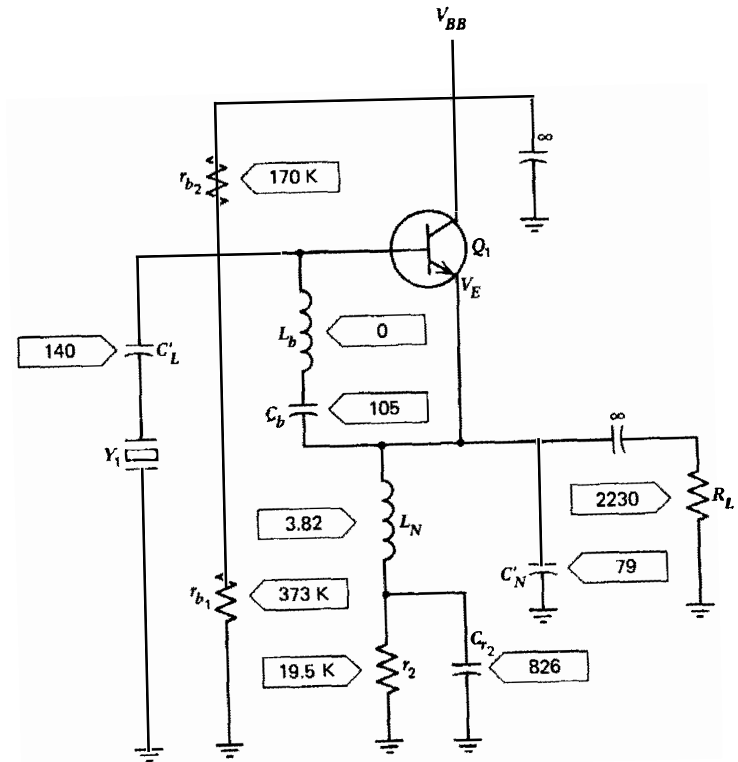


Design Example 9.3 Colpitts oscillator, base emitter cutoff limiting.

All units in

℧ MHz Ω mW pF μH
mA, mV dc or rms

	Item	Value
Oscillator Performance	f	20
	P_L	1.66
	P_x	5.0
	V_{BB}	10,000
Principal Crystal Data	R_{df}	20
	I_x	15.8
	Cut	AT
	N	1
	C_L	32
Transistor Data	β_o	30
	f_T	700
	BV_{CE}	15,000
	C_{cb}	1
	C_{bet}	2
	C_{ce}	2
	P_{dis}	
	Type	2N918
Circuit Parameters	α	0.30
	γ_1	1.4
	V_{be}	113
	η	0.33
Calculated Data	I_{BB}	2.97
	V_E	4010
	g_m	0.033

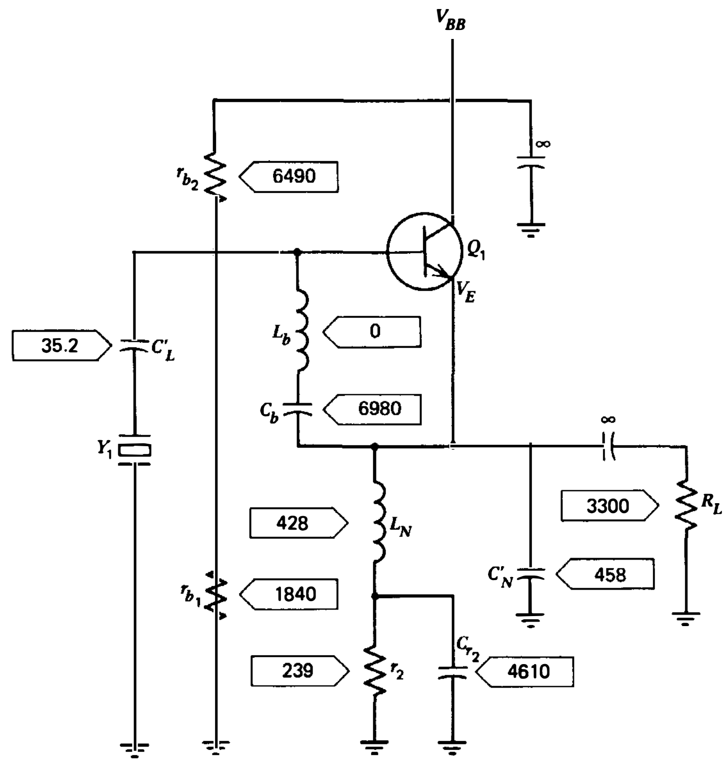


Design Example 9.4 Colpitts oscillator, base emitter cutoff limiting.

All units in

℧ MHz Ω mW pF μH
mA, mV dc or rms

	Item	Value
Oscillator Performance	f	20
	P_L	0.0166
	P_x	0.05
	V_{BB}	10,000
Principal Crystal Data	R_{df}	20
	I_x	1.58
	Cut	AT
	N	1
Transistor Data	β_o	30
	f_T	700
	BV_{CE}	15,000
	C_{cb}	1
	C_{bet}	2
	C_{ce}	2
	P_{dis}	
	Type	2N918
Circuit Parameters	α	0.3
	γ_1	1.4
	V_{be}	113
	η	0.33
Calculated Data	I_{BB}	0.28
	V_E	5000
	g_m	0.0032

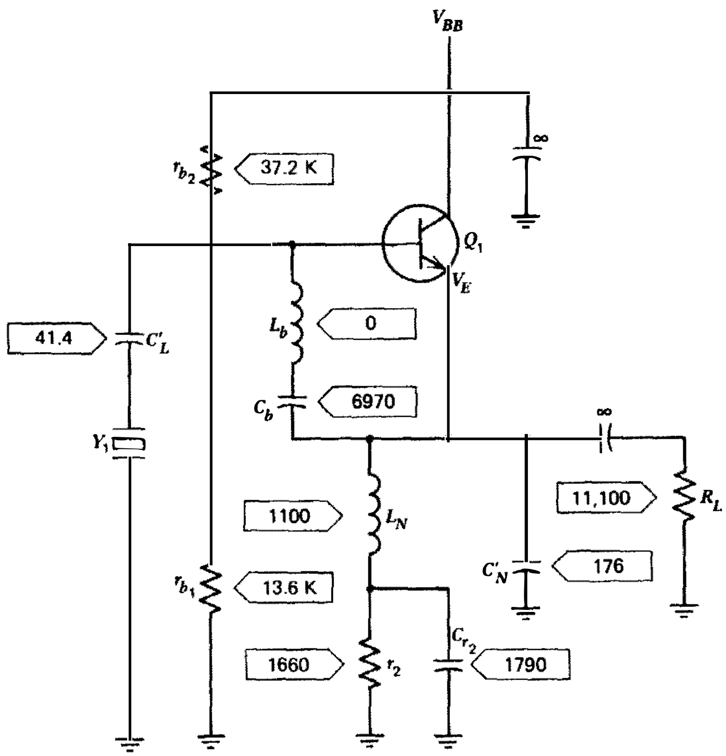


Design Example 9.5 Colpitts oscillator, base emitter cutoff limiting.

All units in

℧ MHz Ω mW pF μH
mA, mV dc or rms

	Item	Value
Oscillator Performance	f	0.8
	P_L	3.3
	P_x	10.0
	V_{BB}	10,000
Principal Crystal Data	R_{df}	625
	I_x	4.0
	Cut	AT
	N	1
	C_L	32
Transistor Data	β_o	30
	f_T	700
	BV_{CE}	15,000
	C_{cb}	1
	C_{bet}	2
	C_{ce}	2
	P_{dis}	
	Type	2N918
Circuit Parameters	α	0.3
	γ_1	1.4
	V_{be}	113
	η	0.33
Calculated Data	I_{BB}	5.98
	V_E	1130
	g_m	0.057



Design Example 9.6 Colpitts oscillator, base emitter cutoff limiting.

All units in

℧ MHz Ω mW pF μH
mA, mV dc or rms

	Item	Value
Oscillator Performance	f	0.8
	P_L	3.3
	P_x	10
	V_{BB}	18,000
Principal Crystal Data	R_{df}	625
	f_x	4.0
	Cut	AT
	N	1
	C_L	32
Transistor Data	β_o	30
	f_T	700
	BV_{CE}	18,000
	C_{cb}	1
	C_{bei}	2
	C_{ce}	2
	P_{dis}	
	Type	2N2221
Circuit Parameters	α	0.3
	γ_1	1.4
	V_{be}	113
	η	0.33
Calculated Data	I_{BB}	2.35
	V_E	3300
	g_m	0.025

3
$$|I_3| = |I_e|\frac{|X_2|}{R_T} \tag{9.18}$$
from Eq. (5.59a).

4
$$|V_{be}| = |I_3||X_1| \tag{9.19}$$
from Eq. (5.52a).

5
$$P_L \propto \frac{V_L^2}{R_L} \tag{9.20}$$

6 Section 7.5.3.2(5) is applicable here.

9.6.3.3 Typical Trimming Steps

Section 7.6.3.3 is applicable, taking into account the number changes of the equivalent equations.

9.6.4 Frequency Instability Due to Variations in Components Other Than Z_3

See Section 7.5.4.