Design Analysis: Common-Emitter Amplifier for an RC Phase-Shift Oscillator

Abstract

This report provides a comprehensive, step-by-step analysis of the design of the common-emitter (CE) amplifier stage as detailed in the "RC PHASE SHIFT OSCILLATOR USING BJT" lab experiment[1]. The primary function of this amplifier within the oscillator circuit is twofold: first, to provide a 180° phase inversion to the signal, and second, to supply sufficient voltage gain (greater than 29) to overcome the attenuation of the three-stage RC feedback network[2222]. This ensures the total loop gain is unity and the total phase shift is 360°, satisfying the Barkhausen criterion for sustained oscillations[3].

1.0 DC Operating Point (Q-Point) Design

The first and most critical phase of the amplifier design is establishing a stable DC operating point, also known as the Quiescent Point (Q-Point). This sets the amplifier's default state (with no AC signal) in the middle of its active region, which is essential for achieving maximum undistorted signal swing at the output[4].

1.1 Initial Design Parameters

The design is based on the following specifications and component data:

- **Transistor:** BC107 [5]
- **DC Current Gain (hfe or β):** 110

- **DC Supply Voltage (VCC):** 12 V [7]
- **Target Quiescent Collector Current (IC):** 2 mA [8]

1.2 Setting the Collector-Emitter Voltage (VCE)

To allow the output voltage to swing equally in both the positive and negative directions without being cut off (clipped), the Q-point for VCE is set at the midpoint of the available voltage range.

- **Logic:** Set VCE to 50% of the supply voltage, VCC[9].
- Calculation:

  VCE=0.50×VCC=0.50×12V=6V [10]

1.3 Designing the Emitter Resistor (RE) for Thermal Stability

The emitter resistor (RE) provides DC negative feedback, which stabilizes the Q-point against variations in temperature and transistor gain (β). A common rule of thumb is to set the DC voltage drop across

RE to be about 10% of VCC[11].

- **Logic:** Set VRE to 10% of VCC[12].
- Calculation of VRE:

  VRE=0.10×VCC=0.10×12V=1.2V [13]

- **Calculation of RE:** Assuming the emitter current (IE) is approximately equal to the collector current (IC)[14]:

  RE=ICVRE=2×10−3A1.2V=600Ω [15]

- **Component Selection:** The nearest available standard resistor value is **560 Ω**[16].

1.4 Designing the Collector Resistor (RC)

RC determines the collector voltage and is a primary factor in setting the amplifier's voltage gain. Its value is determined by the remaining voltage drop available in the collector-emitter circuit loop, according to Kirchhoff's Voltage Law.

- **Logic:** The sum of voltage drops across RC, the transistor (VCE), and RE must equal the supply voltage, VCC[17].
- Calculation of Voltage across RC (VRC):

  $$V_{RC} = V_{CC} - V_{CE} - V_{RE} = 12V - 6V - 1.2V = 4.8V$$ [18]

- Calculation of RC:

  $$R_C = \frac{V_{RC}}{I_C} = \frac{4.8V}{2 \times 10^{-3} A} = 2.4k\Omega$$ [19]

- **Component Selection:** The nearest available standard resistor value is **2.2 kΩ**[20].

2.0 Voltage Divider Biasing Network Design

A voltage divider bias, consisting of resistors R1 and R2, is used to provide a stable and predictable DC voltage to the base of the transistor.

2.1 Determining Base Voltage (VB) and Base Current (IB)

The required base voltage is determined by the emitter voltage (VRE) and the transistor's base-emitter forward voltage drop (VBE), which is assumed to be 0.6V for a silicon transistor.

- Base Voltage (VB) Calculation:

  $VB=VRE+VBE=1.2V+0.6V=1.8V$ [21]

- Base Current (IB) Calculation:

  $IB=\beta IC=1102\times10-3A=18.2\mu A$ [22]

2.2 Calculating Biasing Resistors R1 and R2

For the voltage divider to be "stiff" (i.e., stable against changes in base current), the current flowing through it should be significantly larger than the base current itself. The design uses a factor of 10.

- **Logic for R2:** The current flowing through R2 (I2) is set to 10 times the base current[23].
- Calculation of R2:

  $R2=I2VB=10\times IBVB=10\times18.2\times10-6A1.8V=9.9k\Omega$ [24]

- **Component Selection for R2:** The nearest standard value is **10 kΩ**[25].
- **Logic for R1:** The current flowing through R1 (I1) is the sum of the current through R2 and the base current (I1=I2+IB=11IB)[26].
- Calculation of R1:

  $R1=I1VCC-VB=11\times18.2\times10-6A12V-1.8V\approx51k\Omega$ [27]

- **Component Selection for R1:** The nearest standard value is **47 kΩ**[28].

3.0 AC Component Design (Capacitors)

Capacitors are added to control the AC signal path. Coupling capacitors block DC while passing AC, and bypass capacitors are used to increase AC gain. The design aims for a lower cutoff frequency of

200 Hz[29].

3.1 Input Coupling Capacitor (CC1)

CC1 couples the input signal to the base. Its reactance (XC1) should be negligible compared to the amplifier's input impedance (Rin) at the lowest frequency of operation.

- **Design Rule:** $XC1\leq10Rin$[30].
- **Input Impedance (Rin) Calculation:** Rin is the parallel combination of R1, R2, and the transistor's internal AC input impedance ($hfe\times hib$, where hib is assumed as 12.5 Ω)[31]. The document calculates this as 1.17 kΩ[32].
- **Reactance (XC1) Calculation:** $XC1\leq101.17k\Omega=117\Omega$[33].
- Capacitance (CC1) Calculation:

  $CC1=2\pi fXC11=2\pi\times200Hz\times117\Omega1\approx6.8\mu F$ [34]

- **Component Selection:** A standard value of **10 µF** is selected for reliable coupling[35].

3.2 Output Coupling Capacitor (CC2)

CC2 couples the amplified output signal to the load. Its reactance (XC2) must be small compared to the output resistance (Rout≈RC).

- **Design Rule:** XC2≤10Rout[36].
- **Reactance (XC2) Calculation:** XC2≤10RC=102.2kΩ=220Ω[37].
- Capacitance (CC2) Calculation:

  CC2=2πfXC21=2π×200Hz×220Ω1≈3.6μF [38]

- **Component Selection:** A standard value of **3.3 μF** is selected[39].

3.3 Emitter Bypass Capacitor (CE)

CE is placed in parallel with RE to create an AC ground at the emitter. This prevents the gain reduction that RE would otherwise cause for AC signals.

- **Design Rule:** The reactance of CE (XCE) should be much less than RE at the lowest frequency[40]. The rule used is

  XCE≤10RE[41].

- **Reactance (XCE) Calculation:** XCE≤10560Ω=56Ω[42].
- Capacitance (CE) Calculation:

  CE≥2πfXCE1=2π×200Hz×56Ω1≈14.2μF [43]

- **Component Selection:** To ensure effective bypassing, a larger standard value of **22 µF** is chosen[44].

4.0 Conclusion

The common-emitter amplifier has been systematically designed with all component values calculated and justified. A stable DC bias point (IC=2mA, VCE=6V) has been established to ensure maximum signal swing. The biasing resistors (R1, R2), collector resistor (RC), and emitter resistor (RE) set this Q-point. Furthermore, the coupling and bypass capacitors (CC1, CC2, CE) have been selected to provide the desired AC performance with a lower cutoff frequency of 200 Hz. This amplifier is now properly configured to provide the gain and phase shift necessary to function as the active element in the RC phase-shift oscillator circuit.