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Mini Project 2

ELEC 301

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# Introduction

The aim of this project report is to detail the modeling of bipolar junction transistors that are intended for small signal operation using a hybrid-π model. Specifically, two basic single transistor amplifier circuits, namely the common emitter and common base amplifiers, will be examined. It is important to note that the analysis is conducted under the assumption of small signals, as larger signals can cause the transistors to enter saturation or cut-off modes, where the hybrid-π model is no longer applicable. The project employs three different types of transistors, namely 2N2222A, 2N3904, and 2N4401, and their datasheets were sourced from the manufacturers' websites.

# Problems

## PART 1

1. **Small Signal Parameters**

The values of the small signal parameters for VCE = 10V, IC = 1 mA, f = 1kHz and T = 25˚C are,

|  |  |  |
| --- | --- | --- |
| Parameter | Min | Max |
|  | 50 | 300 |
|  | 2 kΩ | 8 kΩ |
|  | 5 µS | 35 µS |

1. **Calculation of hybrid-** **π Model Parameters**

Diagram

Description automatically generated with medium confidenceUsing *CircuitMaker* and the Circuits given below to plat the graphs to obtain the values

Circuit 1

Plot 1: IB v/s VBE



Circuit 2

Plot 2: IC v/s VCE with variable IBN

In Ic vs VCE plot, variable IB = 1µA increments, with top increment IB= 10 µA.

Circuit 3

Plot 3: IC v/s VCE with variable VBE­­­­­



For the calculation of β, rπ, gm, and r0 for VCE = 5 V and Ic = 1mA.

From Plot 2, at given data IB = 6 µA. Since Ic=βIB,

| Given that VT = 25 mV at T = 25 ˚C

Next, for ro we can estimate VA by calculating the slope of active region at IB= 8 µA

, Therefore

Thus

VBE = 0.6 V

|  |  |  |  |
| --- | --- | --- | --- |
|  | β | rπ | gm |
| Measured | 166.7 | 4.167 kΩ | 0.040 |
| Datasheet (Mean Values) | 175 | 4.375 kΩ | 0.040 |



1. **Bias Network**
2. Values of all the currents:

Circuit 4:Bias Network for npn transistor

Mesh Analysis from VCC to ground, (VCE = 4 V)

Hence,

To find RB1 and RB2 , ; , and

Choosing , Since solving Equations is not Linear.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| IC | IB | IE | V­c | VB | VE |
| 1.009 mA | 6.091 | 1.105 mA | 7.61 | 4.315 | 3.714 |

1. Biasing using 1/3 Rule

Diagram, schematic

Description automatically generatedCurrent Values,

Resistance Values

Circuit 5: 1/3 Rule Bias

DC operating point values (Values are measured in *CircuitMaker* ) :

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| IC | IB | IE | V­c | VB | VE |
| 1.024 mA | 6.097 µA | 1.030 mA | 9.889 V | 4.996 V | 4.395 V |

1. **Using standard Resistor Values**

|  |  |  |  |
| --- | --- | --- | --- |
| RB1 | RB2 | RC | RE |
| 130 kΩ | 68 kΩ | 5.1 kΩ | 4.3 kΩ |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| IC | IB | IE | V­c | VB | VE |
| 0.991 mA | 5.927 µA | 0.997 mA | 9.946 V | 4.888 V | 4.1888 V |

1. On comparison, the values of dc operating points are very similar. But the 1/3 rule is most efficient since it is easy to calculate.
2. **DC Operating points for 2N3904 and 2N4401**

Diagram, schematic

Description automatically generated

Circuit 6: Bias Circuit for 2N3904 and 2N4401

Using Similar Method and *CircuitMaker* the following values for 2N3904 and 2N4401 are:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | IC | IB | IE | V­c | VB | VE |
| 2N3904 | 0.986 mA | 8.314 µA | 0.994 mA | 10.07 V | 4.896 V | 4.250 V |
| 2N4401 | 1.003 mA | 6.791 µA | 1.010 mA | 9.995 V | 4.965 V | 4.307 V |
| 2N2222A | 0.991 mA | 5.927 µA | 0.997 mA | 9.946 V | 4.888 V | 4.1888 V |

## PART 2



Circuit 7: Common Emitter Amplifier

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Plot 4:Phase (degrees) Bode Plot

Plot 5:Magnitute Bode Plot

Chart, box and whisker chart

Description automatically generated

Circuit 8: High frequency small-signal model

Chart, line chart

Description automatically generated

Plot 6: Linear Interpolation for Measuring poles and zeros

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |
| Calculated | 0 | 0 | 3.701Hz | 0.384Hz | 1.560Hz | 607.75Hz | 15.79MHz | 34.38MHz |
| Measured | 0 | 0 | 4.502Hz | 0.557Hz | 2.758Hz | 690.78Hz | 11.67MHz | 40.1Mhz |

Next, we repeat this process for a 2N4401 transistor, and obtain the poles and zeroes location.

by plotting and taking the linear approximation, then by calculations. The same methods are.

used as for 2N3904 above.



Plot 7: Phase Bode Plot for 2N4401

Plot 8:Magnitude Bode Plot for 2N4401

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |
| Calculated | 0 | 0 | 5.29Hz | 0.491Hz | 5.81Hz | 3.9kHz | 105.2MHz | 176MHz |
| Measured | 0 | 0 | 6.32Hz | 0.524Hz | 6.69Hz | 4.1kHz | 112.3MHz | 190MHz |

1. **Mid Band Frequency**

Chart, line chart

Description automatically generatedChart, line chart

Description automatically generatedAs we can observe from the Plot 5, the midband frequency ranges from 1kHz to 10Mhz. We choose 20kHz as our midband Frequency to get a non-linear output signal.

Plot 9: Transfer Curve for 2N4401

Plot 10: Transfer Curve for 2N3904

1. **INPUT IMPEDENCE**

**Measured Using *CircuitMaker:***

2N3904:

2N4401:

**Calculated:**

2N3904:

2N4401:

1. **OUTPUT IMPEDENCE**

**Measured Using *CircuitMaker:***

2N3904:

2N4401:

**Calculated:**

2N3904:

2N4401:

1. **Best Performance Transistor**

I believe 2N3904 is better as it can handle high currents and gets a linear output domain at much lower peak amplitude as compared to 2N4401.

## PART 3



Circuit 9:Common Base Amplifier

Plot 11: Phase Bode Plot for CB Amplifier



Plot 12: Magnitude Bode Plot for CB Amplifier

By shorting all the low frequency capacitors,

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |
| Calculated | 0 | 0 | 0.357Hz | 0.3781Hz | 1.560Hz | 535.03Hz | 42.569MHz | 8.065MHz |
| Measured | 0 | 0 | 0.98 Hz | 0.42 Hz | 3.1 Hz | 550.2 Hz | 45.76 MHz | 9.12 MHz |

1. **Midband Frequency**

From the bode plot, midband frequency ranges from 1kHz to 1MHz. I choose 10kHz to get nonlinear transfer function graph. It is observed that near 70 mV, the output domain starts to get non - linear

**Chart, line chart

Description automatically generated**

Plot 13: Transfer Curve for 2N2222A

1. **Input Impedance**

Measured:

Calculated:

1. **Output Impedance**

Measured:

Calculated:

Both values are very close.

# Conclusion

The goal of this project was to model, bias, and test different types of transistor amplifiers, including Common-base and Common-emitter amplifiers. The first step involved analyzing the characteristics of the transistors at specific voltages and currents, and comparing the results to both calculated values and data from the transistor's datasheet. To ensure that the transistors were operating correctly, they were biased to their DC operating point using a variety of methods, including measurement and the use of the ⅓ rule with standard resistors. The Bode plot was then analyzed to identify the locations of poles and zeroes, and any discrepancies between calculated and measured values were noted. The project also included an investigation into the effects of large signals on small signal models, which provided valuable insight into the performance of the approximate transistor models.

# References

1.ELEC 301 Course Notes.

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