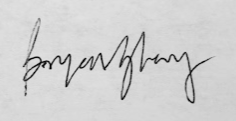
|  |
| --- |
| The University of British Columbia |
| Mini Project 2 |
| ELEC 301 – Electronic Circuits |

|  |
| --- |
| Bryan Zhang  69238335  10-24-2022 |



Contents

[Part 1 2](#_Toc117893472)

[a) 2N3904 datasheet lookup 2](#_Toc117893473)

[b) 2N3904 characteristics 2](#_Toc117893474)

[Comparing Measured value to datasheet values 5](#_Toc117893475)

[c) Biasing 5](#_Toc117893476)

[Biassing from measured plot (i) 5](#_Toc117893477)

[Biassing using the 1/3 rule (ii) 6](#_Toc117893478)

[Using standard resistors (iii) 7](#_Toc117893479)

[d) *2N2222A* and *2N4401* d.c operating points (iv) 7](#_Toc117893480)

[Part 2 8](#_Toc117893481)

[a) *2N3904 & 2N4401* Common Emitter Amplifier 8](#_Toc117893482)

[b) Midband Voltage Transfer Curve 11](#_Toc117893483)

[c) Input Impedance at midband 12](#_Toc117893484)

[d) Output Impedance at midband 12](#_Toc117893485)

[e) Transistor selection 13](#_Toc117893486)

[Part 3 13](#_Toc117893487)

[a) 2N2222A Common Base Amplifier poles & zeros 13](#_Toc117893488)

[b) Voltage Transfer Curve 16](#_Toc117893489)

[c) Midband Input Impedance 16](#_Toc117893490)

[d) Midband Output Impedance 16](#_Toc117893491)

[References 17](#_Toc117893492)

[Appendix 18](#_Toc117893493)

# Part 1

## 2N3904 datasheet lookup

The datasheet values for the 2N3904 transistor at and are shown below.

|  |  |  |  |
| --- | --- | --- | --- |
| Symbol | Description | Minimum | Maximum |
|  | DC Current Gain | 100 | 400 |
|  | Input Impedance | 1.0 kΩ | 10 kΩ |
|  | Output Admittance | 1.0 µmhos | 40 µmhos |

## 2N3904 characteristics

Here is the circuit used to obtain the graph of . I set and then sweep from 0 to 0.7V in 0.01V increments.





Figure 1: IB vs VBE graph

To find with as the varying parameter the circuit below is simulated. VCE is swept from 0-6V in 20mV increments and IB is swept from 1-10µA in 0.5µA increments.





Figure 2: IC vs VCE with varying IB

Each line represents a different characteristic, with the bottom line being when IB is 1 µA and the top line when IB is 10 µA. The ‘a’ cursor is set to the value of VCE=5V and the ‘c’ cursor is set to the value of IC = 1mA. The intersection of the 2 cursors falls on the 3rd line from the top, so therefore

.

Finally, we can find IC vs VCE with varying VBE by simulating the below circuit. VCE is the primary and is swept from 0-6V in 20mV increments, and VBE ­is the secondary swept from 0.55-0.70V in 0.01V increments.





Figure 3: IC vs VCE with varying VBE

Observe that at IC=1mA at the intersected curve corresponds to VBE = 0.65V. The slope of the top curve can be calculated as where a, b, c, d are the cursor positions.

An equation of the line can be found using point-slope form . The Xb, Yd point is selected but any of the two points may be used.

Now the early voltage can be found at the x-intercept when IC=0:

### Comparing Measured value to datasheet values

The measured values of β, rπ, and 1/r0 all fall in between the minimum and maximum value found in the data sheet for the *2N3904* transistor.

## Biasing

### Biassing from measured plot (i)

The measured parameters from the curves are and VBE = 0.65V.

In addition, VCC = 15V, IC = 1mA, VCE < 4V, RE=RC/2. The other currents may be determined as follows:

Next RC and RE can be determined by doing KVL from VCC to ground across the collector-emitter junction. VCE can be set to 3V since it is less than 4V.

Now the voltage of the emitter, collector, and base can be calculated.

The following 2 equations can be used to determine the values of RB1 and RB2.

These equations do not provide a unique solution, so I arbitrarily chose RB1=10kΩ which gives

RB2=4.55 kΩ.

|  |  |  |  |
| --- | --- | --- | --- |
| RC | RE | RB1 | RB2 |
| 7978Ω | 3989Ω | 10kΩ | 4.55kΩ |

Here are the results of the simulation for the d.c operating point for the *2N3904*.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| IC | IB | IE | VB | VC | VE |
| 998.6µA | 8.590 µA | 1.007mA | 4.664V | 7.034V | 4.017V |

### Biassing using the 1/3 rule (ii)

I will use the first version of the 1/3 rule which states that:

Using and VBE = 0.65V we find that

Subsequently the currents are calculated

Finally, the resistances are calculated

The d.c operating point values of the biased circuit using the 1/3 rule is shown below.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| IC | IB | IE | VB | VC | VE |
| 1.001mA | 8.431µA | 1.010mA | 5.002V | 9.994V | 4.356V |

### Using standard resistors (iii)

Replace the resistances calculated using the 1/3 rule with standard resistors.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| IC | IB | IE | VB | VC | VE |
| 1.020mA | 8.575µA | 1.028mA | 5.067V | 9.801V | 4.420V |

Every method biases the circuit correctly however using the 1/3 rule is much faster and still provides accurate results while allowing versatility when selecting the resistances.

## *2N2222A* and *2N4401* d.c operating points (iv)

Using the same standard resistance values, we replace the *2N3904* with the *2N2222A* and *2N4401* and measure their d.c operating points.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | IC | IB | IE | VB | VC | VE |
| *2N3904* | 1.020mA | 8.575µA | 1.028mA | 5.067V | 9.801V | 4.420V |
| *2N222A* | 1.055mA | 6.285µA | 1.061mA | 5.158V | 9.629V | 4.556V |
| *2N4401* | 1.035mA | 6.971µA | 1.042mA | 5.131V | 9.731V | 4.472V |

The BJTs are still biased properly in the active region. Therefore the 1/3 rule is a valid method of biasing BJTs even with different β values.

# Part 2

## *2N3904 & 2N4401* Common Emitter Amplifier

Here is the biased common emitter amplifier using the *2N3904*.



The magnitude and phase(degrees) bode plots are included in the appendix simulated from 1mHz to 100GHz. Calculate Cπ and Cµ using the d.c operating point gm=0.04S and VCB = 5V and the SPICE model parameters of the *2N3904*.

The complete small-signal model is created for the *2N3904*. Recall rπ = 2950Ω and β=118 from part 1.



Applying Miller’s theorem and Thevenin equivalent for the CE amplifier like in the course notes can yield the zeros and poles. There are two coupling capacitors so it is known that there will be 2 low frequency zeros at zero. This is the Low Frequency Small-Signal Model. Diagram, schematic

Description automatically generated

This is the High Frequency Small-Signal Model.

A picture containing logo

Description automatically generated

Here are the locations of the poles and zeros estimated using linear approximation.

Chart

Description automatically generated with medium confidence

This table summarizes the calculated and graphically measured locations of the poles and zeros in Hz.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *2N3904* | fLz1 | fLz2 | fLp1 | fLp2 | fLz3 | fLp3 | fHp1 | fHp2 | fHz1 |
| Calculated | 0 | 0 | 0.432 | 1.56 | 3.70 | 635 | 15.5M | 34.9M | ∞ |
| Measured | 0 | 0 | 0.400 | 2.2 | 4 | 600 | 10M | 600M | 5G |
| % error | 0 | 0 | 8% | 29.1% | 7.5% | 5.83% | 55% | 94.1% |  |

The graphically measured values are quite like the calculated values other than the high frequency poles. There was also a high frequency zero in the simulated result.

Now replace the *2N3904* with the *2N4401*. The magnitude and phase bode plots simulated from 1mHz to 100GHz for the *2N4401* are included in the appendix. Recalculate the location of the poles and zeros the same way as done before*,* except with new parameters for the parasitic capacitances of the *2N4401*, and then recalculate β and rπ. β = 148, rπ = 3586Ω. Cπ=67.28pF, Cµ=5.2pF.

Then, graphically measure the poles/zeros with linear approximation and compare with the calculated.

Chart

Description automatically generated with low confidence

Here are the calculated and graphically measured frequencies in Hz for the 2N4401.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *2N4401* | fLz1 | fLz2 | fLp1 | fLp2 | fLz3 | fLp3 | fHp1 | fHp2 | fHz1 | fHz2 |
| Calculated | 0 | 0 | 0.426 | 1.56 | 3.70 | 655 | 5.19M | 11.9M | ∞ | ∞ |
| Measured | 0 | 0 | 0.390 | 2 | 3.40 | 600 | 4M | 190M | 1G | 10G |
| % error | 0 | 0 | 9.23% | 22% | 8.82% | 9.17% | 29.8% | 93.7% |  |  |

Again, the graphically measured values are quite like the calculated values other then the high frequency poles. There are also two a high frequency zero in the simulated result.

## Midband Voltage Transfer Curve

A midband frequency of 100kHz is selected for this test. The input voltage source amplitude is varied from 0-0.3V.

The non-linear behavior starts to happen around 0.1V for both transistors.

## Midband Input Impedance

Here is the circuit at midband. CE will be shorted, and so the emitter will be grounded.

Diagram, schematic

Description automatically generated

The input impedance for the *2N3904* can be calculated as

The input impedance for the *2N4401* is

To measure the input impedance set the AC source to 100kHz with 1V amplitude and then use the AC multimeter to measure the input current and base voltage.

## Midband Output Impedance

At the midband the impedance seen at the output impedance is simply RC. A 10mV, 10kHz source is used.

The output impedance is measured by

## Transistor selection

The *2N3904* has a larger bandwidth than the *2N4401* with other characteristics remaining similar. For an amplifier a wider bandwidth gives the best performance, so the *2N3904* should be selected.

# Part 3

## 2N2222A Common Base Amplifier poles & zeros



Calculate cπ=75.7pFand cµ=7.76pF with the new circuit parameters. The d.c operating point calculated in part 1 for the *2N2222A* can be used to calculate β = 168, gm = 0.0422, and rπ = 3981Ω. There are 2 zeros at zero due to the coupling capacitors. We find the locations of the remaining poles/zeros using formulas taught in the class.





Approximate the locations using linear approximation. There must be a low frequency pole and zero that occur in the same location (as shown in the calculations), these are marked in the table by \*.

Chart

Description automatically generated

Here are the calculated and approximated values for the locations of the poles in Hz. The cusp at ~1GHz may be caused by multiple zeros or a complex pole.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *2N2222A* | fLz1 | fLz2 | fLz3 | fLp1 | fLp2 | fLp3 | fHp1 | fHp2 |
| Calculated | 0 | 0 | 0.401 | 0.423 | 1.56 | 217 | 8.04M | 132M |
| Measured | 0 | 0 | 0.401\* | 0.423\* | 1.80 | 220 | 8M | 130M |
| % error | 0 | 0 | 0 | 0 | 13.3% | 1.36% | 0.5% | 1.54% |

## Voltage Transfer Curve

Use a 1kHz source and vary the amplitude. It starts to become non-linear at around Vs = 0.1V.

## Midband Input Impedance

Calculate the input impedance as

To measure the input impedance, short the source resistance and apply a source with 10mV amplitude and 100kHz frequency. Use the AC RMS multimeter to measure the emitter voltage and input current.

## Midband Output Impedance

The output impedance is simply

# References

1. ELEC 301 Course Notes
2. A. Sedra and K. Smith, "Microelectronic Circuits,"5 th (or higher) Ed., Oxford University Press, New York
3. CircuitMaker™ User’s Manual
4. 2N3904 datasheet [https://datasheetspdf.com/pdf-file/1114626/Motorola/2N3904/1]
5. Standard Resistor and Capacitor Values

# Appendix

Part 2a:

2N3904 magnitude/phase bode plot:



2N4401 magnitude/phase bode plot:



