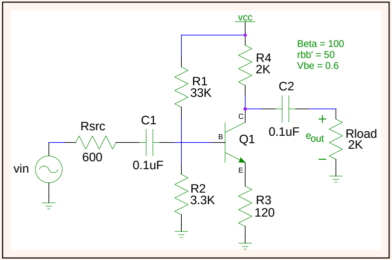
Biasing the BJT

- Finding a starting point for biasing the BJT is confusing initially. Its not as easy or straightforward as you might expect.
- It's important to understand the basics of how the value of one resistor effects the amplifier's characteristics. There are a lot of moving parts and most are connected in some way. Its like a balloon. Poking in one place causes bulging elsewhere.
- There are many parameters to consider:
  - input impedance
  - output impedance
  - gain
  - current consumption/power dissipation
  - temperature stability
- In addition, you usually don't get to choose any resistor value but only standard ones; and preferably not 1% ones.

Biasing the BJT

- Consider the following common emitter amplifier.



- The parallel combination of R1 and R2 effects R_{in}. R3 effects the input impedance, gain and output swing of the amplifier.
- R3's effect on input impedance is modified by transistor β. Its resistance value is effectively multiplied by β.
- R1, R2 and R3 all effect the temperature behavior of the amplifier.
- $R1||R2$ should be at least $10R_{src}$ to lower IR drop across R_{src}.
- Current through R1 and R2 should be at least $10I_b$.
- AHHHHHH!!!!

Biasing the BJT

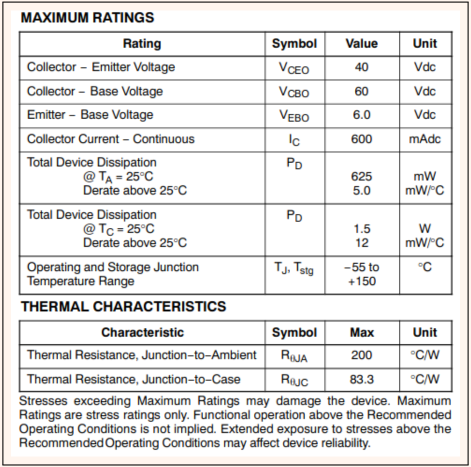
- Here is general procedure for our simple amplifier circuits. It still requires some *fiddling* around. But, fiddling around gives insight.
- This procedure makes some simplifications, maintains stability (DC primarily) and gives pretty accurate results.
- Suppose we want a single-stage BJT amplifier with the following parameters:
  - $V_{cc} = 10V$, Gain= 20, $I_{cc} < 20mA$
- First we choose a suitable transistor:

Biasing the BJT

- There are literally hundreds of transistors that could work.
- The short list would include the 2N2222, 2N3904, 2N4401.
- These are all cheap, easily obtainable transistors. They could be considered the "cockroaches" of the BJT transistor family tree. They will be around when all the others have disappeared.
- For this example we will look at the 2N4401. The important parameters are: V_{ceo}, β, I_c, and V_{be} which is about 0.6V at the current levels we are interested in.

Biasing the BJT

- Let's first take a look at the maximum ratings. These are values you want to stay away from.



MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector – Emitter Voltage	V_{CEO}	40	Vdc
Collector – Base Voltage	V_{CBO}	60	Vdc
Emitter – Base Voltage	V_{EBO}	6.0	Vdc
Collector Current – Continuous	I_C	600	mAdc
Total Device Dissipation @ $T_A = 25°C$ Derate above 25°C	P_D	 625 5.0	 mW mW/°C
Total Device Dissipation @ $T_C = 25°C$ Derate above 25°C	P_D	 1.5 12	 W mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	–55 to +150	°C

THERMAL CHARACTERISTICS

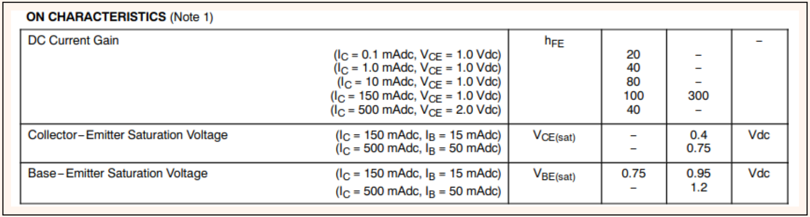
Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction–to–Ambient	$R_{\theta JA}$	200	°C/W
Thermal Resistance, Junction–to–Case	$R_{\theta JC}$	83.3	°C/W

Stresses exceeding Maximum Ratings may damage the device. Maximum Ratings are stress ratings only. Functional operation above the Recommended Operating Conditions is not implied. Extended exposure to stresses above the Recommended Operating Conditions may affect device reliability.

From: https://www.onsemi.com/pdf/datasheet/2n4401-d.pdf

Biasing the BJT

- What's important here? Does this apply to our application?
- You have to carefully read datasheets and think about what they are telling you, what they are not, and what to carefully infer.
- You must pay close attention to the conditions for each specification.



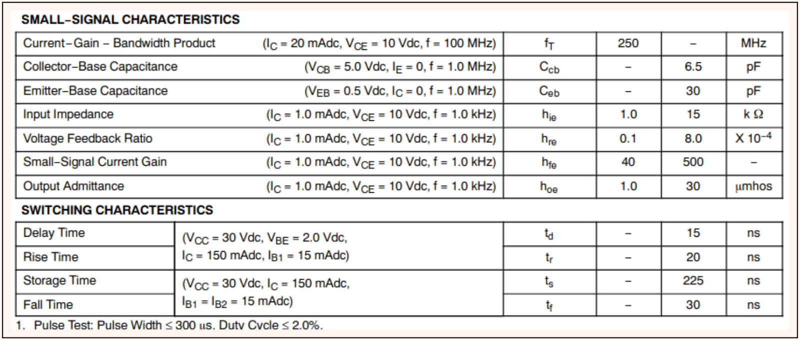
ON CHARACTERISTICS (Note 1)

DC Current Gain		h_{FE}			–
	(I_C = 0.1 mAdc, V_{CE} = 1.0 Vdc)		20	–	
	(I_C = 1.0 mAdc, V_{CE} = 1.0 Vdc)		40	–	
	(I_C = 10 mAdc, V_{CE} = 1.0 Vdc)		80	–	
	(I_C = 150 mAdc, V_{CE} = 1.0 Vdc)		100	300	
	(I_C = 500 mAdc, V_{CE} = 2.0 Vdc)		40	–	
Collector–Emitter Saturation Voltage	(I_C = 150 mAdc, I_B = 15 mAdc) (I_C = 500 mAdc, I_B = 50 mAdc)	$V_{CE(sat)}$	– –	0.4 0.75	Vdc
Base–Emitter Saturation Voltage	(I_C = 150 mAdc, I_B = 15 mAdc) (I_C = 500 mAdc, I_B = 50 mAdc)	$V_{BE(sat)}$	0.75 –	0.95 1.2	Vdc

From: `https://www.onsemi.com/pdf/datasheet/2n4401-d.pdf`

Biasing the BJT

- Now, what's this telling us? What's important, what's not?
- Now we see what *Note 1* tells us. Did you miss that before?



SMALL–SIGNAL CHARACTERISTICS

Current–Gain – Bandwidth Product	(I_C = 20 mAdc, V_{CE} = 10 Vdc, f = 100 MHz)	f_T	250	–	MHz
Collector–Base Capacitance	(V_{CB} = 5.0 Vdc, I_E = 0, f = 1.0 MHz)	C_{cb}	–	6.5	pF
Emitter–Base Capacitance	(V_{EB} = 0.5 Vdc, I_C = 0, f = 1.0 MHz)	C_{eb}	–	30	pF
Input Impedance	(I_C = 1.0 mAdc, V_{CE} = 10 Vdc, f = 1.0 kHz)	h_{ie}	1.0	15	k Ω
Voltage Feedback Ratio	(I_C = 1.0 mAdc, V_{CE} = 10 Vdc, f = 1.0 kHz)	h_{re}	0.1	8.0	X 10^{-4}
Small–Signal Current Gain	(I_C = 1.0 mAdc, V_{CE} = 10 Vdc, f = 1.0 kHz)	h_{fe}	40	500	–
Output Admittance	(I_C = 1.0 mAdc, V_{CE} = 10 Vdc, f = 1.0 kHz)	h_{oe}	1.0	30	μmhos

SWITCHING CHARACTERISTICS

Delay Time	(V_{CC} = 30 Vdc, V_{BE} = 2.0 Vdc, I_C = 150 mAdc, I_{B1} = 15 mAdc)	t_d	–	15	ns
Rise Time		t_r	–	20	ns
Storage Time	(V_{CC} = 30 Vdc, I_C = 150 mAdc, I_{B1} = I_{B2} = 15 mAdc)	t_s	–	225	ns
Fall Time		t_f	–	30	ns

1. Pulse Test: Pulse Width ≤ 300 μs, Duty Cycle ≤ 2.0%.

From: https://www.onsemi.com/pdf/datasheet/2n4401-d.pdf

Biasing the BJT

- Let's look at the small signal current gain, h_{fe}. We can usually call this β.
- This tells us where we should set our transistor I_c.
- We want $\beta > 100$ to make our approximations work.

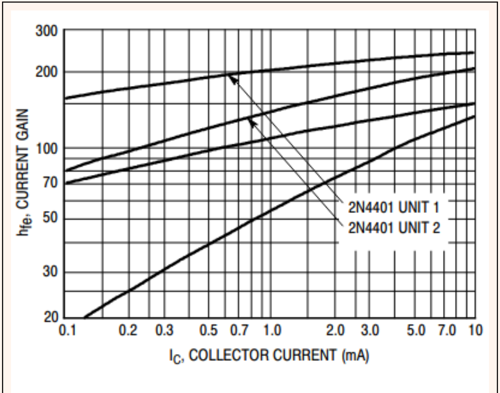


Figure 11. Current Gain

From: https://www.onsemi.com/pdf/datasheet/2n4401-d.pdf

Biasing the BJT

- This graph tells how h_{fe} changes with I_c and temperature.
- Just something to keep in mind.

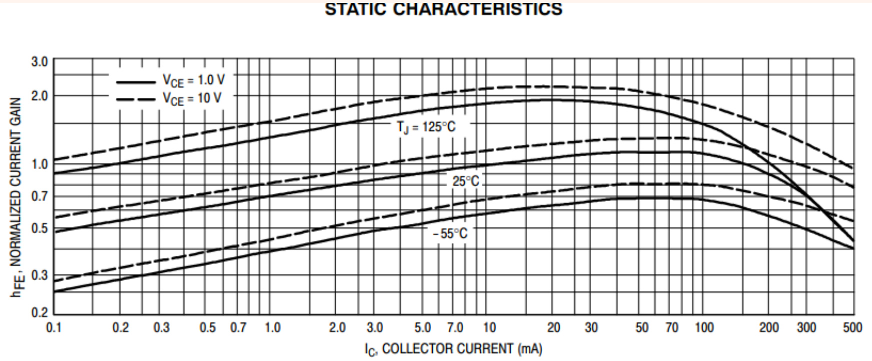
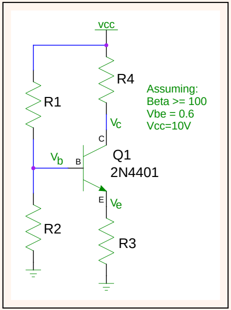


Figure 15. DC Current Gain

From: `https://www.onsemi.com/pdf/datasheet/2n4401-d.pdf`

Biasing the BJT

- From the datasheet, the following can be chosen as starting points:
    - $I_c = 5mA$, as $\beta \geq 100$, power dissipation and I_c is not exceeded.
- We will choose a circuit topology as shown below:



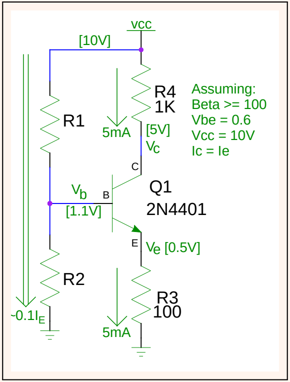
Assuming:
Beta >= 100
Vbe = 0.6
Vcc=10V

Biasing the BJT

- For maximum dynamic range, we choose a quiescent $V_c = 5V$. So, $R4 = \frac{\frac{V_{cc}}{2}}{I_{cc}} = \frac{5}{.005} = 1000$ ohms
- Now, to minimize I_c variations due to temperature changing V_{be} we want $R_e I_e > 10V_t$ where V_t is the thermal voltage or 26mV at 300deg C.
- Let's shoot for a V_e of 0.5V.
- If we make the assumption that β exceeds 100, $I_c \approx I_e$, so: $R3 = \frac{V_e}{I_e} = \frac{0.5}{.005} = 100$ ohms.
- Note the gain is roughly equal to $\frac{R4}{R3} = 10$. We will fix that later, wink, wink.

Biasing the BJT

- Since we know V_e, we also know V_b and can solve for R1 and R2. $V_b = V_e + V_E = 1.1V$
- R1 and R2 can be solved for with Matlab or by hand.
- We want the current through the R1/R2 voltage divider $\approx 0.1 I_e$.
- This ensures that variations in I_b will not alter V_b. The voltage divider also reduces the variation in V_b with changes in V_{cc}.



Biasing the BJT

- Solving for R1, R2. First the voltage divider relation:

$$V_b = V_{cc}\left(\frac{R2}{R1+R2}\right)$$

$$1.1 = 10\left(\frac{R2}{R1+R2}\right)$$

and so,

$$R2 = .11(R1+R2)$$

$$R1 = 8.1R2$$

Biasing the BJT

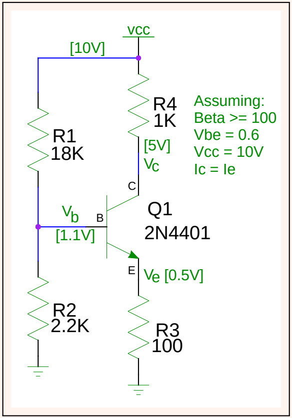
- Now keeping in mind that we want the current through the R1/R2 voltage divider $\approx 0.1 I_e$ we can say:

$$\begin{aligned}
\frac{V_{cc}}{R1 + R2} &= 0.1(I_e) \textit{ (neglicting Ib)} \\
\frac{10}{R1 + R2} &= 0.1(.005) \\
\frac{10}{8.1R2 + R2} &= .0005 \\
10 &= .0005(9.1R2) \\
R2 &= 2197 \text{ ohms, and} \\
R1 &= 17795 \text{ ohms}
\end{aligned}$$

- In the implementation, we would use R1=18K and R2=2.2K ohms.

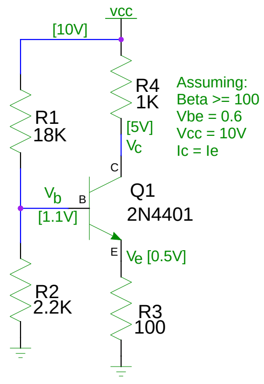
Biasing the BJT

- Our circuit (DC only) looks like this:



- Now, its time to simulate! And not a minute sooner.

Biasing the BJT

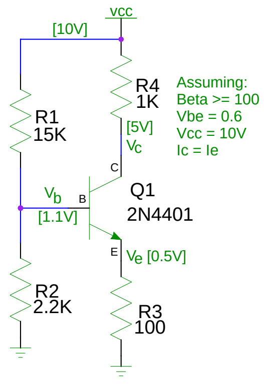


```
.title dcopt1.sp
*determine dc operating point of transistor

.include 2n4401.mod

Vcc   vcc         gnd                 10v
R1    vcc         base                18K
R2    base        gnd                 2.2K
R3    emitter     gnd                 100
R4    vcc         collector           1K
Q1    collector   base       emitter  2n4401

.control
  op
; DC operating point analysis
  print v(base) v(emitter) v(collector) ; print DC voltages
.endc
.end

*results
*Doing analysis at TEMP = 27.000000 and TNOM = 27.000000
*v(base) = 1.041303e+00
*v(emitter) = 3.774958e-01
*v(collector) = 6.249428e+00
```

- Our currents/voltages are a little bit off: V_b low, I_e low, V_c high

Biasing the BJT

- Let's try fiddling a bit. Lowering R1 a bit should help all three parameters.
- We will try 15K instead of 18K. This raises V_b, V_e and lowers V_c.



```
.title dcopt2.sp

*determine dc operating point, fiddle #1

.include 2n4401.mod

Vcc    vcc          gnd                    10v
R1     vcc          base                   15K
R2     base         gnd                    2.2K
R3     emitter      gnd                     100
R4     vcc          collector              1K
Q1     collector    base        emitter   2n4401

.control
  op
; DC operating point analysis
  print v(base) v(emitter) v(collector) ; print DC voltages
.endc
.end

*Doing analysis at TEMP = 27.000000 and TNOM = 27.000000
*v(base) = 1.215030e+00
*v(emitter) = 5.411213e-01
*v(collector) = 4.622165e+00
```

- Are we good or what?!