COMMON EMITTER AMPLIFIER

VOLTAGE DIVIDER CIRCUIT

LOAD POINT CALCULATIONS

Given:

Quantity	Description	Value
Vcc	Dc Supply voltage	15V
Ic	Capacitor current at Q-point	3mA
B \ Hfe	Current Gain	200 (2N2222)
Vbe	Bias-Emitter Voltage	0.7V

Practical Assumptions:

Quantity	Formula	Substitutions	Value
Vre	10% of Vcc	0.1 * 15	1.5V
Vrc	40% of Vcc	0.4 * 15	6V
Vceq	50% of Vcc	0.5 * 15	7.5V
Vce	Vcc - Vrc	15 - 6	9V

Terminal Resistances:

Quantity	Formula	Substitutions	Value
Ie	~Ic		3mA
Re	Vre / Ie ~ Vre / Ic	1.5 / 3m	0.5kΩ
Rc	Vrc / Ic	6 / 3m	2kΩ

Base Terminal & Divider calculations:

Quantity	Formula	Substitutions	Value
Vb	Vre + Vbe	1.5 + 0.7	2.2V
Ib	Ic / B	3m / 200	15uA

Idiv	10 * Ib	10 * 15u	150uA
Rb1	(Vcc - Vb) / Idiv	(15 - 2.2) / 150u	85.33kΩ
Rb2	Vb / Idiv	2.2 / 150u	14.67kΩ

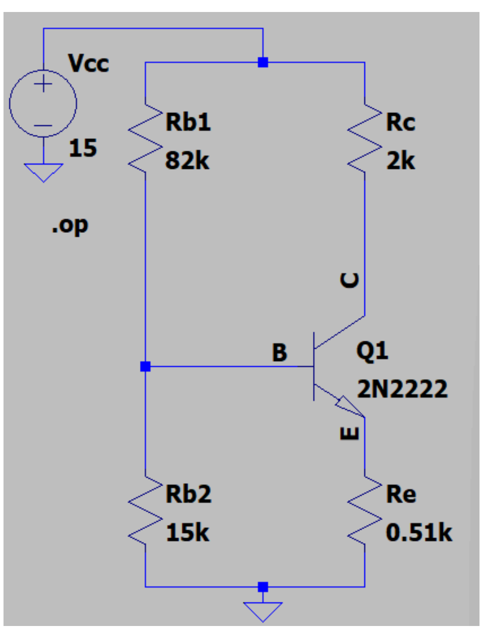
Swapping calculated resistor values to closest E24 series resistors (offers 5% tolerance)

Quantity	Original	Closes Standard value	Change (%)
Re	500	510	2
Rc	2k	2k	0
Rb1	85.33k	82k	3.9
Rb2	14.67k	15k	2.25

Expected Q point shift:

Quantity	Formula	Substitutions	Value
Rb	Rb1 + Rb2	82k + 15k	97kΩ
Vb	Vcc * [Rb2 / (Rb1 + Rb2)]	15 * [15k / (82k + 15k)]	2.32V
Ie ~ Ic	(Vb - Vbe) / Re	(2.32 - 0.7) / 510	3.18mA

Results:

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       --- Operating Point ---

V(b):          2.14862         voltage
V(c):          9.27352         voltage
V(e):          1.46713         voltage
V(n001):       15              voltage
I(Rb1):        0.000156724     device_current
I(Rb2):        0.000143241     device_current
I(Rc):         0.00286324      device_current
I(Re):         0.00287672      device_current
I(Vcc):        -0.00301996     device_current
Ib(Q1):        1.34832e-05     device_current
Ic(Q1):        0.00286324      device_current
Ie(Q1):        -0.00287672     device_current
Is(Q1):        0               device_current
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Based on assumptions made above, an error of 10-15% is permissible.

Quantity	Calculated	Simulated	Absolute Difference	Error %
Vb	2.32	2.14862	0.17138	7.39
Vc	9	9.27352	0.27352	3.04
Ve	1.5	1.46713	0.03287	2.19
Vce	7.5	9.57937-1.36151=7.80639	0.30639	4.01

AC PARAMETERS CALCULATIONS

Quantity	Description	Calculations	Value
Dynamic emitter resistance (re’)	Thermal Voltage / Collector current	Vt / Ic = 25mV / 3.18mA	7.86Ω
AC base resistance [Rin (base)]	Resistance of the emitter circuit "reflected" to the base by the current gain.	B * re’ = 200 * 7.86	1.572kΩ
Input Impedance	The parallel combination of the two base-biasing resistors (Rb1 & Rb2) and the AC resistance looking into the base Rin (base).	Rb1 || Rb2 || Rin (base) = 82k || 15k || 1.572k	1.398kΩ
Output Impedance	~Rc		2kΩ
Ideal Voltage Gain (Av) [emitter resistor bypassed]	Gain produced in output voltage	-Rc / re’ = - 2k / 7.86	-254.45
Coupling Capacitors	High-pass filters, setting the low-frequency cutoff (fL)	C = 1/(2*pi*fc*R)	fc = 20Hz
Input resistance (Rin)		Rs (source series resistance) + Zin = 50 + 1.398	1.448kΩ

Input coupling Capacitor (Cin)		1/(2*pi*Rin*fc) = 1/(2*pi*1.448*20)	22uF
Output coupling Capacitor (Cout)		1/(2*pi*(Rl + Zout)*fc) = 1/(2*pi*(1k+2k)*20)	10.6uF ~ 10uF or 15uF
Emitter Bypass Capacitor (Ce)	Ce is also a high-pass filter that determines a low-frequency cutoff (fce). It must be large enough so that its reactance is much smaller than Re at the lowest operating frequency (fL).	Rseen ≈ re' + (Rb1 + Rb2) / β = 7.86 + 12.86k / 200 = 71.26Ω Ce = 1 / (2*pi*fc*Rseen) = 1/(2π× 5 ×71.26	446uF ~ 470uF

Expected Results:

Quantity	Description	Calculations	Value
AC Collector Resistance (rc)		Rc || Rl = 2k || 1k	0.667kΩ
Actual Loaded Gain [Av (loaded)] (without Ce)	Emitter resistor unbypassed	-rc / (re' + Re) = -667 / (7.86 + 510)	-1.288
Actual Loaded Gain [Av (loaded)] (with Ce)	Emitter resistor bypassed	-rc / re' = 667 / 7.86	-84.86
Maximum Output Swing (ΔVout):	Minimum of distance from cutoff and saturation region	Saturation: Vce - Vce(sat) = 7.5-0.2=7.3V Cutoff: Vcc - Vce = 15-7.5 = 7.5V	7.3V (peak)
Maximum Input Voltage [Vin (peak)]		ΔVout / | Av (loaded) |= 7.3 / 84.86	86mV

NOTE: With given parameters the Vin (peak) which can be amplified without distortion is ~5mV This is due to the non-linear characteristic of the BJT's base-emitter junction (the re' resistance) which becomes very pronounced when the emitter is bypassed.

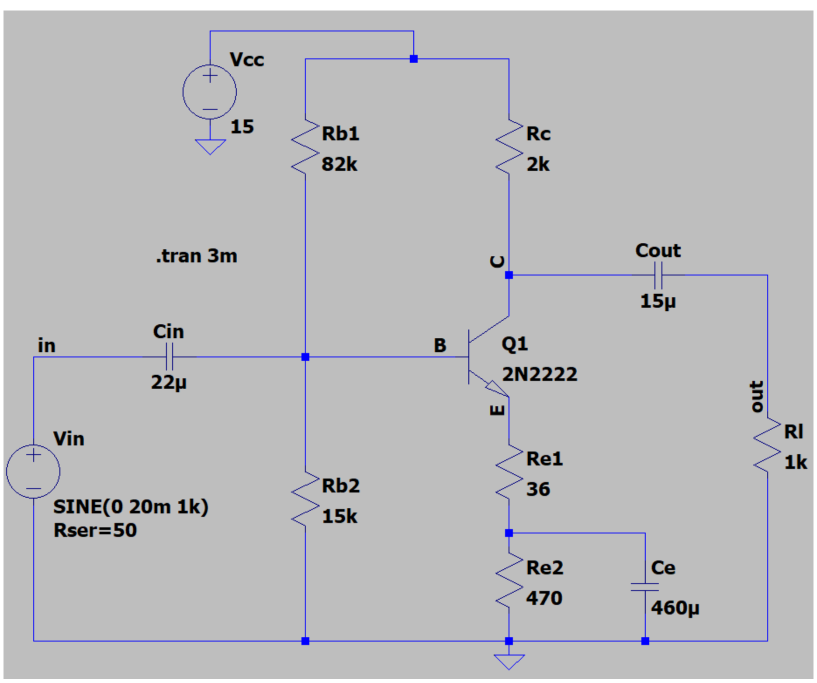
A general rule of thumb for BJT amplifiers to remain in the linear small-signal region is that the AC emitter current ie must be small enough that the AC voltage across re' is much less than the thermal voltage, Vt:
Ve = ie * re' << Vt (25mV)

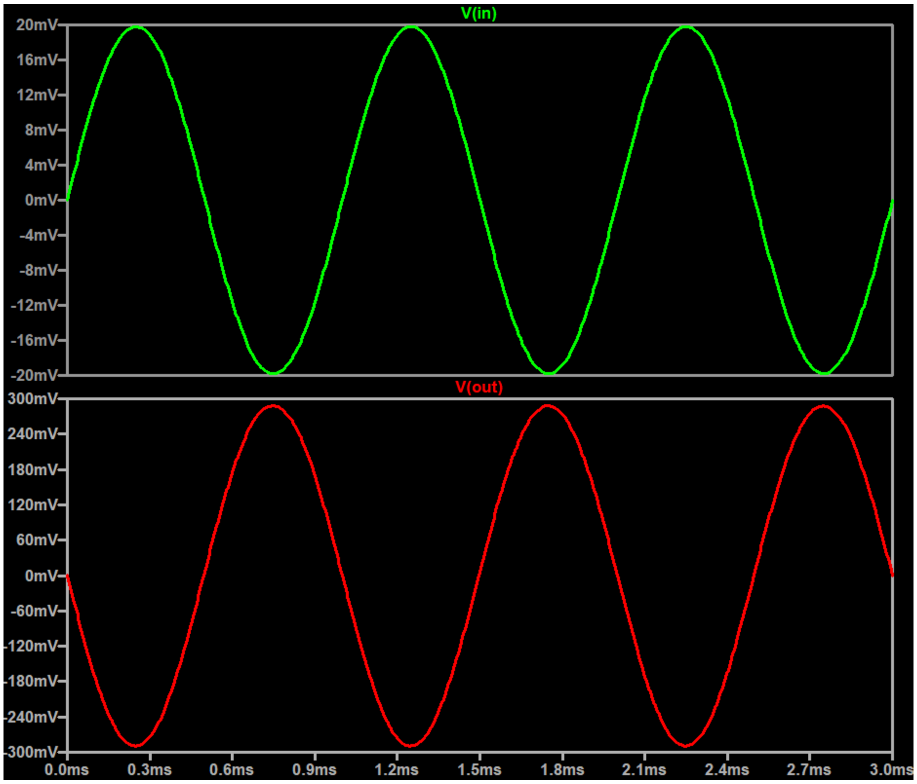
Since vin ~ vbe = ve
Vin(peak) << 25mV

Typically, the limit for acceptable distortion in a fully bypassed CE stage is around 5mV to 10mV peak.

Ac negative feedback:

Quantity	Description	Calculations	Value
Vin(peak)	New permissible input peak voltage		50mV
Av(new)	More realistic gain for better linearity		-15
Re1	unbypassed to provide AC feedback and linearity	Av (new) = -rc / (re' + Re1) => Re1 = -rc/A(new) - re' = 667 / 15 - 7.86	36.6 ~ 36Ω
Re2	Bypassed by Ce for DC stability	Re - Re1 = 510 - 36	474 ~ 470Ω





FREQUENCY RESPONSE ANALYSIS

Low Frequency Analysis

Quantity	Description	Calculations	Value
Transistor's base resistance (Rin(base))		B*(re' + Re1) = 200 * (7.86 + 300)	8.77kΩ
Input Impedance (Zin)		Rb1 || Rb2 || Rin(base) = 82k || 15k || 8.77k	5.18kΩ
fc (in)		1 / (2*pi*Cin*(Zin + Rs)) = 1/(2*pi*22*10^-6*(5180+50))	1.39Hz
fc (out)		1 / (2*pi*Cout*(Zout + Rl)) = 1/(2*pi*15*10^-6*(2k+1k))	3.54Hz
Rseen	The resistance seen by Ce	Re2 || (re' + (Rb1 || Rb2 || Rs) / (B+1)) = 470 || (7.86 + (82k || 15k || 50) (200 + 1))	8Ω

fce		1 / (2*pi*Ce*Rseen) = 1/(2*pi*460*10^-6*8)	*43.3Hz
fL	low-frequency cutoff	*max(fc(in), fc(out))	3.54Hz

*Calculated fce is very high and should be close to fc (in) and fc (out) and therefore ignored

High frequency analysis
High-frequency cutoff is determined by the parasitic capacitances within the transistor and any stray wiring capacitance. These capacitances act as low-pass filters.

Quantity	Description	Calculations	Value
Cbe	Base emitter capacitance, effects the input	2N2222	25pF
Cbc	Base collector capacitance, effects both input and output due to the Miller effect.	2N2222	8pF
Cmiller (Cm)		Cbc*(1-Av) = 8p * (1-(-15))	128pF
Cin (total)		Cbe + Cm = 25p + 128p	153pF
Rth		Rs || Rb1 || Rb2 = 50 || 82k || 15k	50
fH	high-frequency cutoff	1/(2*pi*Rth*Cin(total)) = 1/(2*pi*50*153p)	20.8Mhz

Expected Results:

Quantity	Description	Calculations	Value
Gain (db)		20 * log(15)	23.5dB
Midband Range			3.54Hz - 20.8MHz
Midband Phase	-180° across the midband		
Low-Frequency Phase Shift	In high-pass filters the output voltage leads the input current as the frequency drops		-90°
High-Frequency	In a low-pass filter, the		-270°

Phase Shift	output voltage lags the input voltage.