ECE 363 SAMPLE EXAM #1 (F19) NAME:______________________

4 problems for 100 pts

Problem #1: LED Constant Current Driver (25 pts)

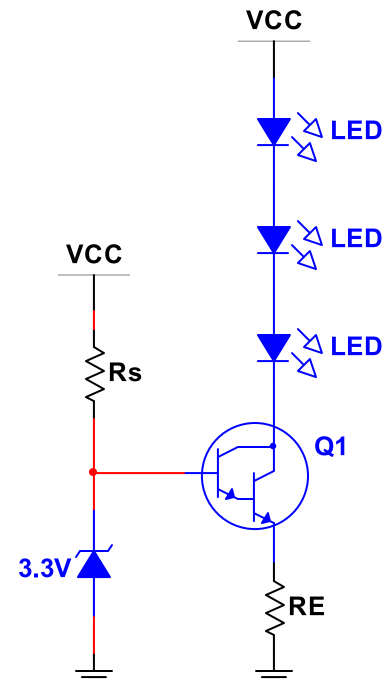
You are asked to design a current source to operate three power LEDs. You decide to use a zener diode with a Darlington transistor. The design specs are:

- LED current = 0.75 A (+/- 5% is OK)
- LED forward voltage = 3.1V - 3.4V
- Darlington is either a BC517 or MJE800
- V_{CC} is either 12, 15, 18, or 21V
- All resistors are standard 5% values.

(a) Perform a "quick" analysis to choose V_{CC}. Show all work.

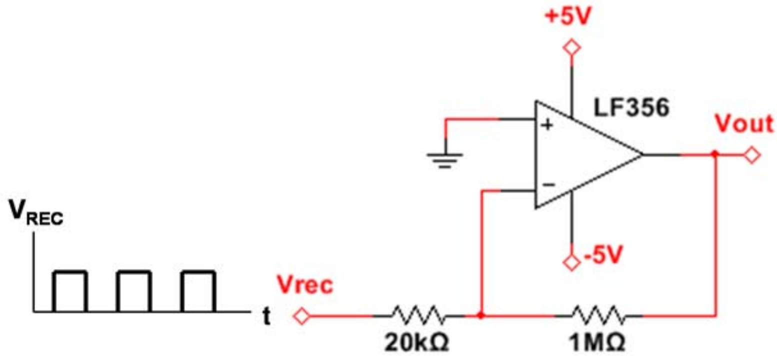
(b) Perform a "quick" analysis to choose Q1. You must explain why you chose one transistor and not the other one. If Q1 needs a heat sink, you must compute the max θ_{SA} (assume θ_{CS} = 0.5°C/W).

(c) Choose R_E and R_S based on "typical" Q1 parameters.



(extra sheet for work)

Problem #2: Amplifier Output Error (25 pts)



Consider an optical communication link for an infrared remote control. A transmitter sends a train of infrared pulses. The receiver converts the optical pulses into voltage pulses.

Suppose the receiver output V_{REC} consists of 50% duty cycle pulses with a 20 mV amplitude and 40 kHz frequency. These tiny pulses are sent to an inverting amplifier built with an LF356 op amp.

a) Is the amplifier output limited by small-signal bandwidth or slew rate? Show all work!

b) Compute the worst-case output error voltage (assume T_A = 25°C). Show all work!

c) Assuming worst-case output error voltage, sketch both V_{REC} and V_{OUT} over a 50 us interval. Label important features!

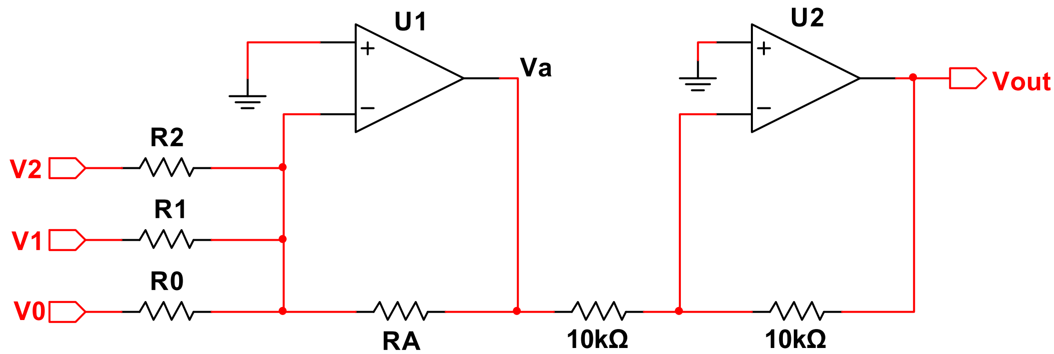
(extra sheet for work)

Problem #3: Digital-to-Analog Converter (25 pts)

Recall binary numbers from ECE 118. A 3-bit binary number ($B_2\,B_1\,B_0$) is equal to $B_2*2^2 + B_1*2^1 + B_0*2^0$. For example, (110) is equal to 1·4 + 1·2 + 0·1 = 6. As another example, (011) is equal to 0·4 + 1·2 + 1·1 = 3.

How do we use hardware to convert a binary number into decimal? The digital outputs from a microcontroller are typically 5V logic. Therefore, a binary "1" is really +5V, while a binary "0" is really 0V.

A simple 3-bit digital-to-analog converter (DAC) is shown below. The input voltages V_2, V_1, V_0 come from a microcontroller. The output V_{OUT} is an "integer" from 0 to 7V. For example, the binary number (110) should produce Vout = 6V, while the binary number (011) should produce Vout= 3V.



(a) Use the Golden Rules to derive an expression for V_{OUT} in terms of V_2, V_1, and V_0. Show all work!

Hint: Think about V_{OUT} in terms of Va, and then Va in terms of the inputs.

(b) Suppose R_A = 40 kohm. Determine the ideal values for R_2, R_1, and R_0. Show all work!

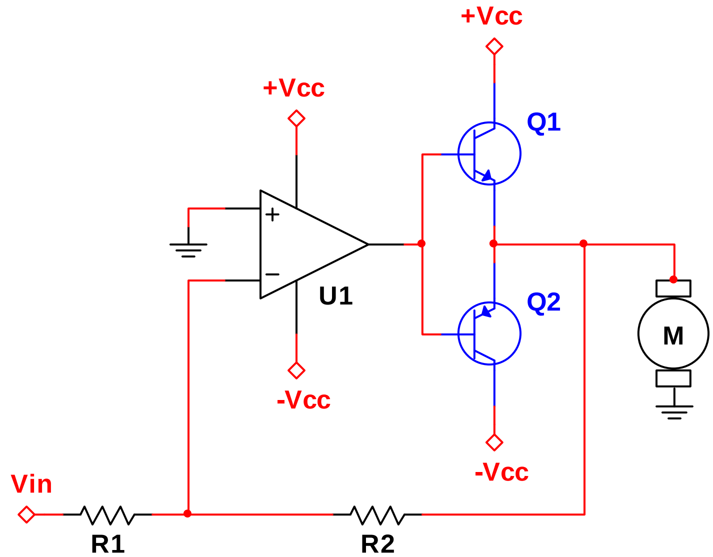
(c) Suppose you are using LF356 op amps, and assume the final output is connected to a load $R_L \geq 10$ kohm. Would you use Vcc = 8V for this circuit? How about Vcc = 9V? Show all work!

(extra sheet for work)

Problem #4: Push-Pull Current Booster (25 pts)

Design a voltage amplifier to drive a 6V DC motor with a max power consumption of 1.2W. The motor voltage must not exceed 6V by more than 5%. The input signal can swing between -0.2V and 0.2V. The design constraints are the following:

- Use an LF356 op amp.
- Q1 is either a 2N4401 or TIP31.
  NOTE: The pnp versions are the 2N4403 and TIP32.
- V_{CC} is either 4.5, 6, 9, or 12V
- Input impedance $Z_{IN} \geq 10$ kohm
- All resistors are 5% standard values.



(a) Perform a "quick" analysis to choose V_{CC}. Show all calculations!

(b) Perform a "quick" analysis to choose Q1. You must explain why you chose one transistor and not the other one. If Q1 needs a heat sink, you must compute the max θ_{SA} (assume θ_{CS} = 0.5°C/W).

(c) Show that the op amp can provide the required output voltage and current, even under worst-case transistor conditions.

(d) Choose R1 and R2. Show all work!

(extra sheet for work)

(extra sheet for work)

Standard Resistor Values (±5%)						
1.0	10	100	1.0K	10K	100K	1.0M
1.1	11	110	1.1K	11K	110K	1.1M
1.2	12	120	1.2K	12K	120K	1.2M
1.3	13	130	1.3K	13K	130K	1.3M
1.5	15	150	1.5K	15K	150K	1.5M
1.6	16	160	1.6K	16K	160K	1.6M
1.8	18	180	1.8K	18K	180K	1.8M
2.0	20	200	2.0K	20K	200K	2.0M
2.2	22	220	2.2K	22K	220K	2.2M
2.4	24	240	2.4K	24K	240K	2.4M
2.7	27	270	2.7K	27K	270K	2.7M
3.0	30	300	3.0K	30K	300K	3.0M
3.3	33	330	3.3K	33K	330K	3.3M
3.6	36	360	3.6K	36K	360K	3.6M
3.9	39	390	3.9K	39K	390K	3.9M
4.3	43	430	4.3K	43K	430K	4.3M
4.7	47	470	4.7K	47K	470K	4.7M
5.1	51	510	5.1K	51K	510K	5.1M
5.6	56	560	5.6K	56K	560K	5.6M
6.2	62	620	6.2K	62K	620K	6.2M
6.8	68	680	6.8K	68K	680K	6.8M
7.5	75	750	7.5K	75K	750K	7.5M
8.2	82	820	8.2K	82K	820K	8.2M
9.1	91	910	9.1K	91K	910K	9.1M

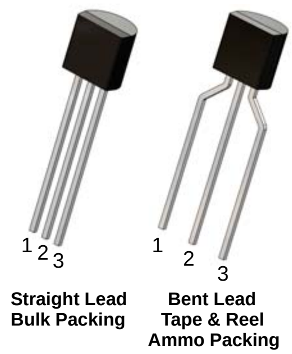
Standard Capacitor Values (±10%)							
10pF	100pF	1000pF	.010µF	.10µF	1.0µF	10µF	**100 µF**
12pF	120pF	1200pF	.012µF	.12µF	1.2µF		
15pF	150pF	1500pF	.015µF	.15µF	1.5µF	**15 µF**	**150 µF**
18pF	180pF	1800pF	.018µF	.18µF	1.8µF		
22pF	220pF	2200pF	.022µF	.22µF	2.2µF	22µF	**220 µF**
27pF	270pF	2700pF	.027µF	.27µF	2.7µF		
33pF	330pF	3300pF	.033µF	.33µF	3.3µF	33µF	**330 µF**
39pF	390pF	3900pF	.039µF	.39µF	3.9µF		
47pF	470pF	4700pF	.047µF	.47µF	4.7µF	47uF	**470 µF**
56pF	560pF	5600pF	.056µF	.56µF	5.6µF		
68pF	680pF	6800pF	.068µF	.68µF	6.8µF	**68 µF**	**680 µF**
82pF	820pF	8200pF	.082µF	.82µF	8.2µF		

ON Semiconductor®

BC517
NPN Darlington Transistor

Features

- This device is designed for applications requiring extremely high current gain at currents to 1.0 A.
- Sourced from process 05.



TO-92
1. Collector
2. Base
3. Emitter

Ordering Information

Part Number	Top Mark	Package	Packing Method
BC517-D74Z	BC517	TO-92 3L (Bent Lead)	Ammo

Absolute Maximum Ratings(1), (2)

Stresses exceeding the absolute maximum ratings may damage the device. The device may not function or be operable above the recommended operating conditions and stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress ratings only. Values are at T_A = 25°C unless otherwise noted.

Symbol	Parameter	Value	Unit
V_{CEO}	Collector-Emitter Voltage	30	V
V_{CBO}	Collector-Base Voltage	40	V
V_{EBO}	Emitter-Base Voltage	10	V
I_C	Collector Current - Continuous	1.2	A
T_J, T_{STG}	Operating and Storage Junction Temperature Range	-55 to +150	°C

Notes:
1. These ratings are based on a maximum junction temperature of 150°C.
2. These are steady-state limits. ON Semiconductor should be consulted on applications involving pulsed or low-duty-cycle operations.

Thermal Characteristics[3]

Values are at T_A = 25°C unless otherwise noted.

Symbol	Parameter	Value	Unit
P_D	Total Device Dissipation, T_A = 25°C	625	mW
	Derate Above 25°C	5.0	mW/°C
$R_{\theta JC}$	Thermal Resistance, Junction-to-Case	83.3	°C/W
$R_{\theta JA}$	Thermal Resistance, Junction-to-Ambient	200	°C/W

Note:

3. PCB size: FR-4, 76 mm x 114 mm x 1.57 mm (3.0 inch x 4.5 inch x 0.062 inch) with minimum land pattern size.

Electrical Characteristics

Values are at T_A = 25°C unless otherwise noted.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
V_{CEO}	Collector-Emitter Breakdown Voltage	I_C = 2.0 mA, I_B = 0	30			V
V_{CBO}	Collector-Base Breakdown Voltage	I_C = 10 μA, I_E = 0	40			V
V_{EBO}	Emitter-Base Breakdown Voltage	I_E = 100 nA, I_C = 0	10			V
I_{CBO}	Collector Cut-Off Current	V_{CB} = 30 V, I_E = 0			100	nA
h_{FE}	DC Current Gain	V_{CE} = 2 V, I_C = 20 mA	30,000			
$V_{CE}(sat)$	Collector-Emitter Saturation Voltage	I_C = 100 mA, I_B = 0.1 mA			1	V
$V_{BE}(on)$	Base-Emitter On Voltage	I_C = 10 mA, V_{CE} = 5.0 V			1.4	V

Typical Performance Characteristics

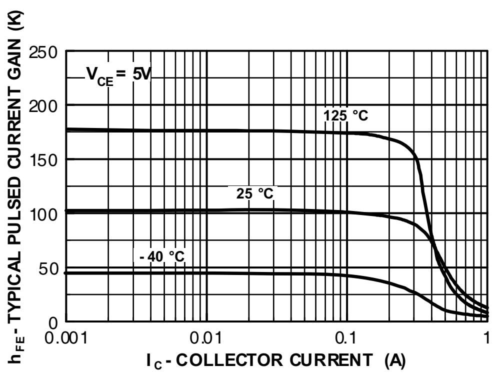


Figure 1. Typical Pulsed Current Gain vs. Collector Current

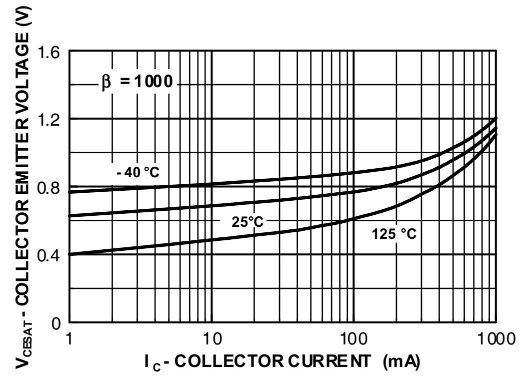


Figure 2. Collector-Emitter Saturation Voltage vs. Collector Current

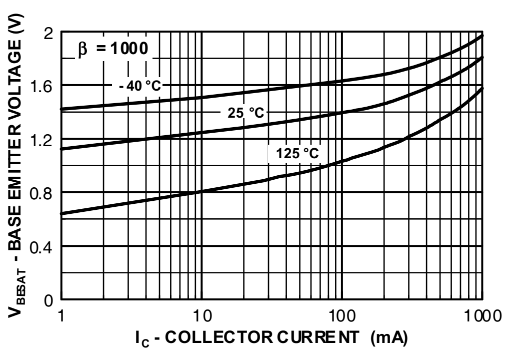


Figure 3. Base-Emitter Saturation Voltage vs. Collector Current

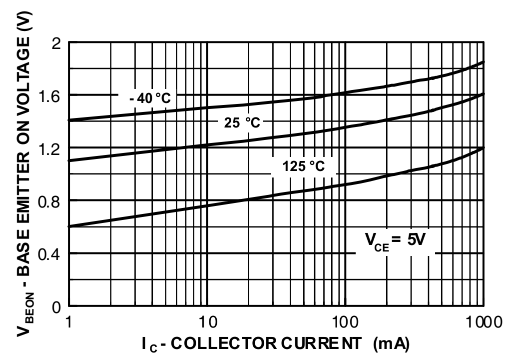


Figure 4. Base Emitter On Voltage vs. Collector Current

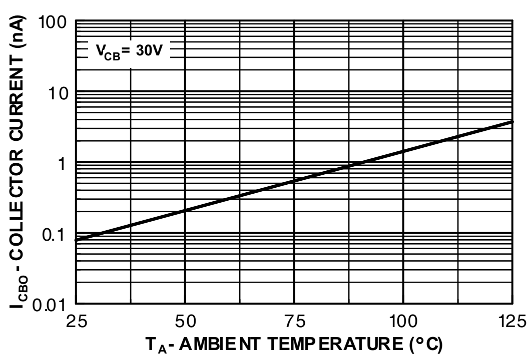


Figure 5. Collector Cut-Off Current vs. Ambient Temperature

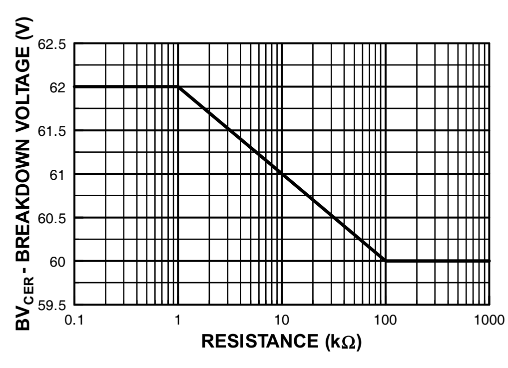


Figure 6. Collector-Emitter Breakdown Voltage with Resistance Between Emitter-Base

MJE700G, MJE702G, MJE703G (PNP), MJE800G, MJE802G, MJE803G (NPN)

Plastic Darlington Complementary Silicon Power Transistors

These devices are designed for general−purpose amplifier and low−speed switching applications.

Features

- High DC Current Gain − h_{FE} = 2000 (Typ) @ I_C = 2.0 Adc
- Monolithic Construction with Built−in Base−Emitter Resistors to Limit Leakage − Multiplication
- Choice of Packages − MJE700 and MJE800 Series
- These Devices are Pb−Free and are RoHS Compliant*

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector−Emitter Voltage MJE700G, MJE800G MJE702G, MJE703G, MJE802G, MJE803G	V_{CEO}	 60 80	Vdc
Collector−Base Voltage MJE700G, MJE800G MJE702G, MJE703G, MJE802G, MJE803G	V_{CB}	 60 80	Vdc
Emitter−Base Voltage	V_{EB}	5.0	Vdc
Collector Current	I_C	4.0	Adc
Base Current	I_B	0.1	Adc
Total Power Dissipation @ T_C = 25°C Derate above 25°C	P_D	 40 0.32	 W mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	–55 to +150	°C

Stresses exceeding those listed in the Maximum Ratings table may damage the device. If any of these limits are exceeded, device functionality should not be assumed, damage may occur and reliability may be affected.

THERMAL CHARACTERISTICS

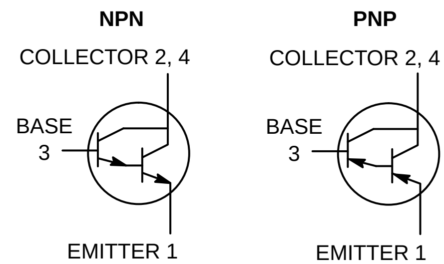
Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction−to−Case	$R_{\theta JC}$	3.12	°C/W
Thermal Resistance, Junction−to−Ambient	$R_{\theta JA}$	83.3	°C/W

*For additional information on our Pb−Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

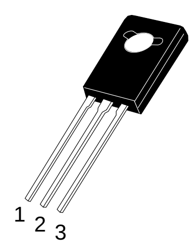
ON Semiconductor®

http://onsemi.com

4.0 AMPERE DARLINGTON POWER TRANSISTORS COMPLEMENTARY SILICON 40 WATT

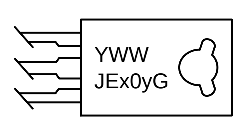


NPN	PNP
MJE800 **MJE802** **MJE803**	**MJE700** **MJE702** **MJE703**



TO−225
CASE 77−09
STYLE 1

MARKING DIAGRAM



Y	=	Year
WW	=	Work Week
JEx0y	=	Device Code x = 7 or 8 y = 0, 2, or 3
G	=	Pb−Free Package

ORDERING INFORMATION

See detailed ordering and shipping information in the package dimensions section on page 5 of this data sheet.

ELECTRICAL CHARACTERISTICS (T_C = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Max	Unit
OFF CHARACTERISTICS				
Collector−Emitter Breakdown Voltage (Note 1) (I_C = 50 mAdc, I_B = 0) MJE700G, MJE800G MJE702G, MJE703G, MJE802G, MJE803G	$V_{(BR)CEO}$	 60 80	 − −	Vdc
Collector Cutoff Current (V_{CE} = 60 Vdc, I_B = 0) MJE700G, MJE800G (V_{CE} = 80 Vdc, I_B = 0) MJE702G, MJE703G, MJE802G, MJE803G	I_{CEO}	 − −	 100 100	μAdc
Collector Cutoff Current (V_{CB} = Rated BV_{CEO}, I_E = 0) (V_{CB} = Rated BV_{CEO}, I_E = 0, T_C = 100°C)	I_{CBO}	 − −	 100 500	μAdc
Emitter Cutoff Current (V_{BE} = 5.0 Vdc, I_C = 0)	I_{EBO}	 −	 2.0	mAdc
ON CHARACTERISTICS				
DC Current Gain (Note 1) (I_C = 1.5 Adc, V_{CE} = 3.0 Vdc) MJE700G, MJE702G, MJE800G, MJE802G (I_C = 2.0 Adc, V_{CE} = 3.0 Vdc) MJE703G, MJE803G (I_C = 4.0 Adc, V_{CE} = 3.0 Vdc) All devices	h_{FE}	 750 750 100	 − − −	−
Collector−Emitter Saturation Voltage (Note 1) (I_C = 1.5 Adc, I_B = 30 mAdc) MJE700G, MJE702G, MJE800G, MJE802G (I_C = 2.0 Adc, I_B = 40 mAdc) MJE703G, MJE803G (I_C = 4.0 Adc, I_B = 40 mAdc) All devices	$V_{CE(sat)}$	 − − −	 2.5 2.8 3.0	Vdc
Base−Emitter On Voltage (Note 1) (I_C = 1.5 Adc, V_{CE} = 3.0 Vdc) MJE700G, MJE702G, MJE800G, MJE802G (I_C = 2.0 Adc, V_{CE} = 3.0 Vdc) MJE703G, MJE803G (I_C = 4.0 Adc, V_{CE} = 3.0 Vdc) All devices	$V_{BE(on)}$	 − − −	 2.5 2.5 3.0	Vdc
DYNAMIC CHARACTERISTICS				
Small−Signal Current Gain (I_C = 1.5 Adc, V_{CE} = 3.0 Vdc, f = 1.0 MHz)	h_{fe}	 1.0	 −	−

Product parametric performance is indicated in the Electrical Characteristics for the listed test conditions, unless otherwise noted. Product performance may not be indicated by the Electrical Characteristics if operated under different conditions.

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

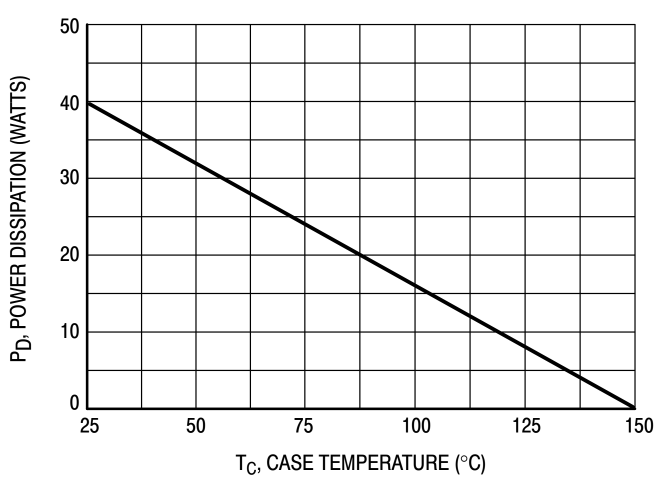


Figure 1. Power Derating

PNP
MJE700 Series

NPN
MJE800 Series

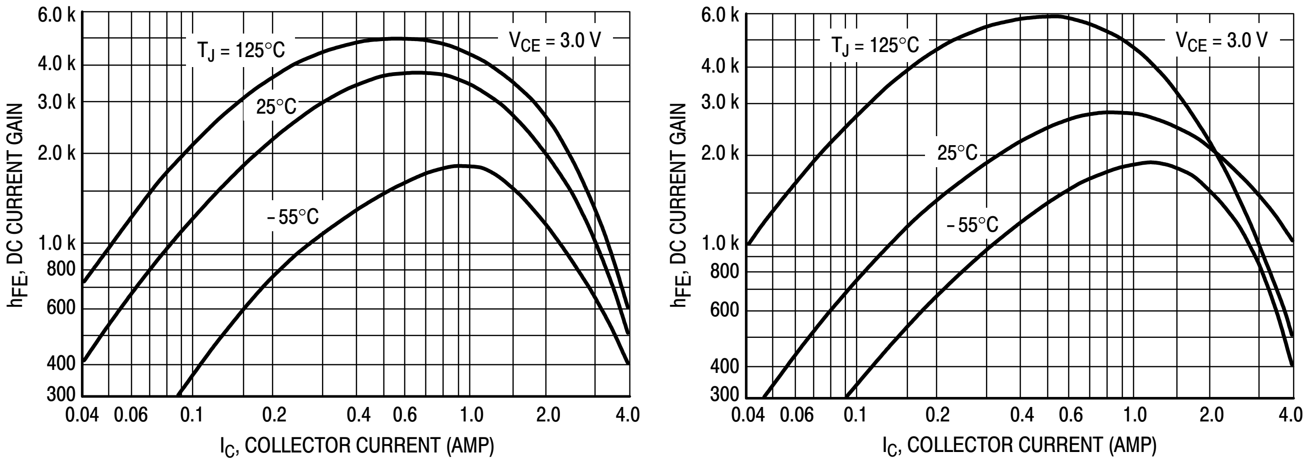


Figure 7. DC Current Gain

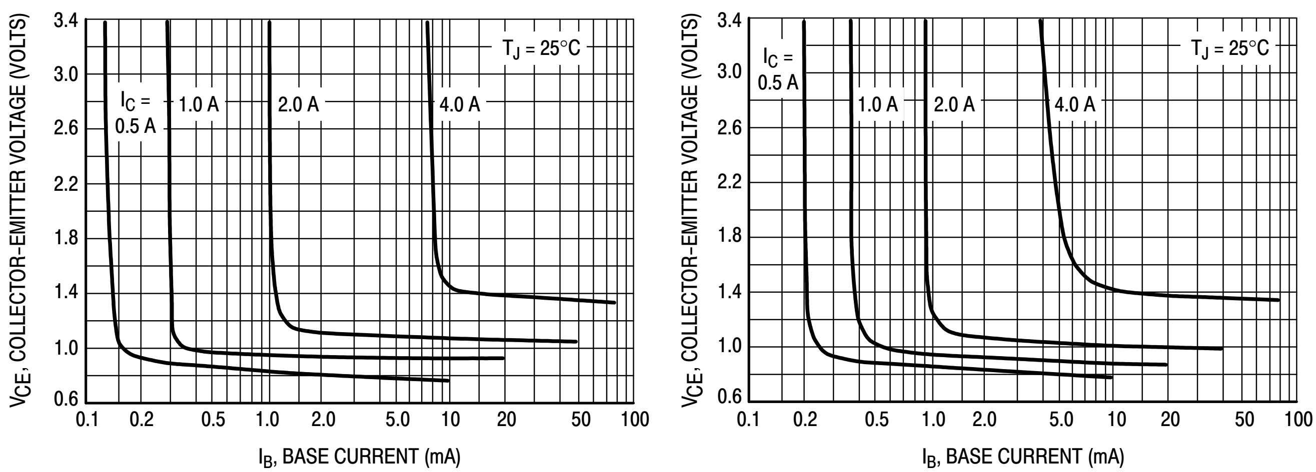


Figure 8. Collector Saturation Region

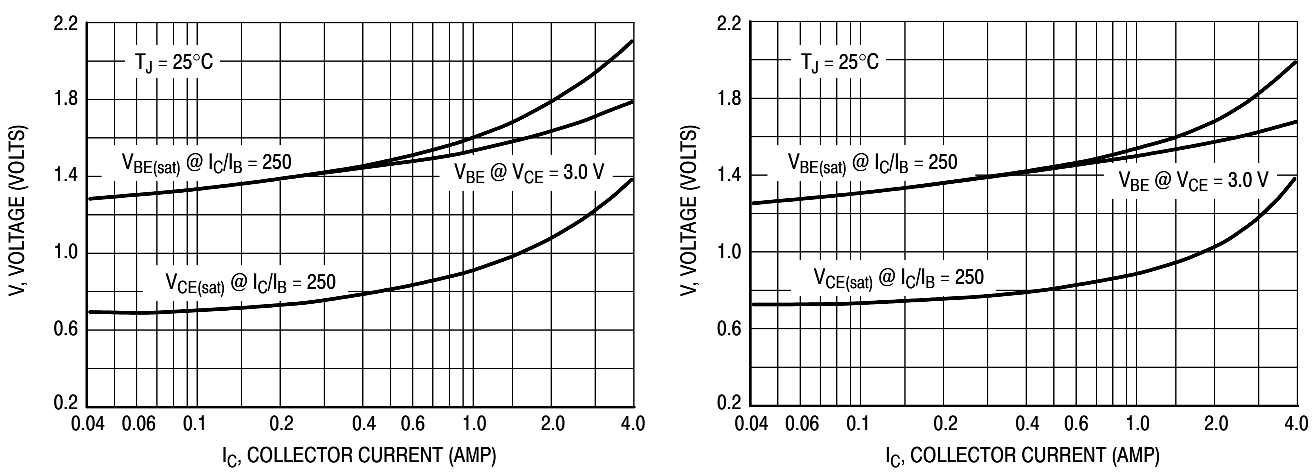


Figure 9. "On" Voltages

DC Electrical Characteristics

Symbol	Parameter	Conditions	LF155/6			LF256/7 LF356B			LF355/6/7			Units
			Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
V_{OS}	Input Offset Voltage	R_S=50Ω, T_A=25°C		3	5		3	5		3	10	mV
		Over Temperature			7			6.5			13	mV
$\Delta V_{OS}/\Delta T$	Average TC of Input Offset Voltage	R_S=50Ω		5			5			5		μV/°C
$\Delta TC/\Delta V_{OS}$	Change in Average TC with V_{OS} Adjust	R_S=50Ω, (2)		0.5			0.5			0.5		μV/°C per mV
I_{OS}	Input Offset Current	T_J=25°C, (1) (3)		3	20		3	20		3	50	pA
		$T_J \le T_{HIGH}$			20			1			2	nA
I_B	Input Bias Current	T_J=25°C, (1) (3)		30	100		30	100		30	200	pA
		$T_J \le T_{HIGH}$			50			5			8	nA
R_{IN}	Input Resistance	T_J=25°C		10^{12}			10^{12}			10^{12}		Ω
A_{VOL}	Large Signal Voltage Gain	V_S=±15V, T_A=25°C	50	200		50	200		25	200		V/mV
		V_O=±10V, R_L=2k										
		Over Temperature	25			25			15			V/mV
V_O	Output Voltage Swing	V_S=±15V, R_L=10k	±12	±13		±12	±13		±12	±13		V
		V_S=±15V, R_L=2k	±10	±12		±10	±12		±10	±12		V
V_{CM}	Input Common-Mode Voltage Range	V_S=±15V	±11	+15.1		±11	±15.1		+10	+15.1		V
				−12			−12			−12		V
CMRR	Common-Mode Rejection Ratio		85	100		85	100		80	100		dB
PSRR	Supply Voltage Rejection Ratio	(4)	85	100		85	100		80	100		dB

(1) Unless otherwise stated, these test conditions apply:

	LF155/156	LF256/257	LF356B	LF355/6/7
Supply Voltage, V_S	±15V ≤ V_S ≤ ±20V	±15V ≤ V_S ≤ ±20V	±15V ≤ V_S ±20V	V_S= ±15V
T_A	−55°C ≤ T_A ≤ +125°C	−25°C ≤ T_A ≤ +85°C	0°C ≤ T_A ≤ +70°C	0°C ≤ T_A ≤ +70°C
T_{HIGH}	+125°C	+85°C	+70°C	+70°C

and V_{OS}, I_B and I_{OS} are measured at V_{CM} = 0.

(2) The Temperature Coefficient of the adjusted input offset voltage changes only a small amount (0.5μV/°C typically) for each mV of adjustment from its original unadjusted value. Common-mode rejection and open loop voltage gain are also unaffected by offset adjustment.

(3) The input bias currents are junction leakage currents which approximately double for every 10°C increase in the junction temperature, T_J. Due to limited production test time, the input bias currents measured are correlated to junction temperature. In normal operation the junction temperature rises above the ambient temperature as a result of internal power dissipation, Pd. $T_J = T_A + \theta_{JA}$ Pd where θ_{JA} is the thermal resistance from junction to ambient. Use of a heat sink is recommended if input bias current is to be kept to a minimum.

(4) Supply Voltage Rejection is measured for both supply magnitudes increasing or decreasing simultaneously, in accordance with common practice.

DC Electrical Characteristics

$T_A = T_J$ = 25°C, V_S = ±15V

Parameter	LF155		LF355		LF156/256/257/356B		LF356		LF357		Units
	Typ	Max	Typ	Max	Typ	Max	Typ	Max	Typ	Max	
Supply Current	2	4	2	4	5	7	5	10	5	10	mA

AC Electrical Characteristics

$T_A = T_J = 25°C$, $V_S = ±15V$

Symbol	Parameter	Conditions	LF155/355	LF156/256/356B	LF156/256/356/LF356B	LF257/357	Units
			Typ	Min	Typ	Typ	
SR	Slew Rate	LF155/6: A_V=1,	5	7.5	12		V/µs
		LF357: A_V=5				50	V/µs
GBW	Gain Bandwidth Product		2.5		5	20	MHz
t_s	Settling Time to 0.01%	(1)	4		1.5	1.5	µs
e_n	Equivalent Input Noise Voltage	R_S=100Ω					
		f=100 Hz	25		15	15	nV/√Hz
		f=1000 Hz	20		12	12	nV/√Hz
i_n	Equivalent Input Current Noise	f=100 Hz	0.01		0.01	0.01	pA/√Hz
		f=1000 Hz	0.01		0.01	0.01	pA/√Hz
C_{IN}	Input Capacitance		3		3	3	pF

(1) Settling time is defined here, for a unity gain inverter connection using 2 kΩ resistors for the LF155/6. It is the time required for the error voltage (the voltage at the inverting input pin on the amplifier) to settle to within 0.01% of its final value from the time a 10V step input is applied to the inverter. For the LF357, A_V = −5, the feedback resistor from output to input is 2kΩ and the output step is 10V (See Settling Time Test Circuit).

Typical DC Performance Characteristics (continued)

Curves are for LF155 and LF156 unless otherwise specified.

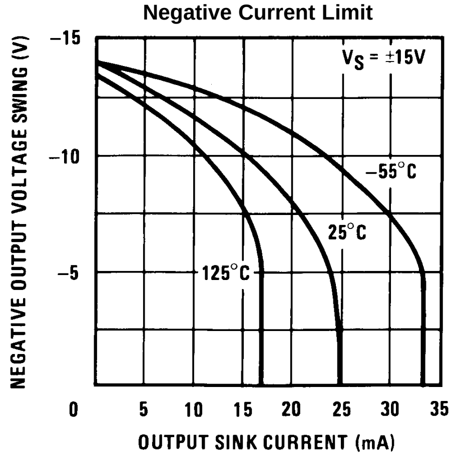


Figure 7.

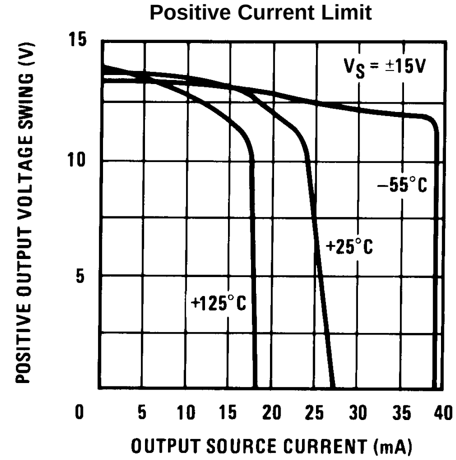


Figure 8.

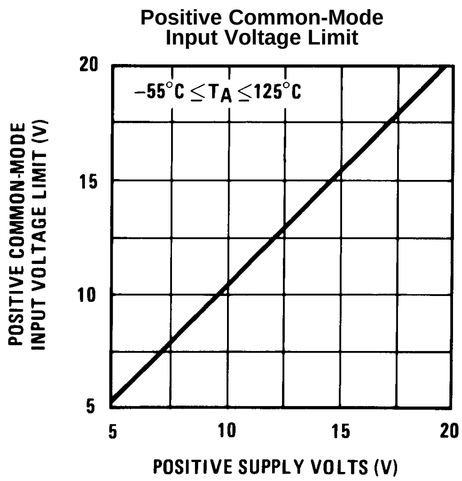


Figure 9.

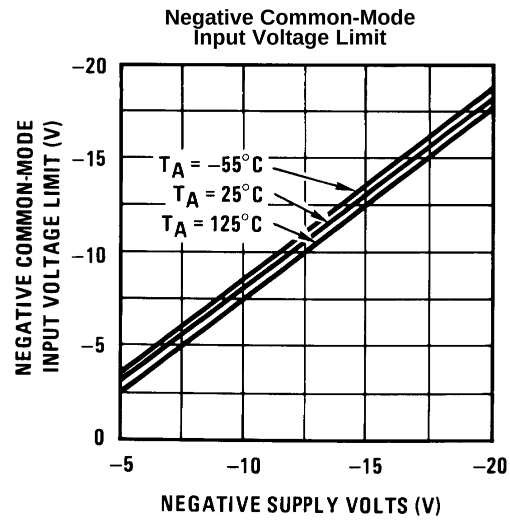


Figure 10.

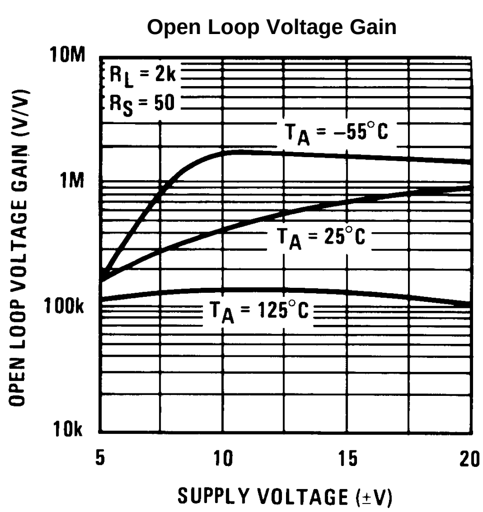


Figure 11.

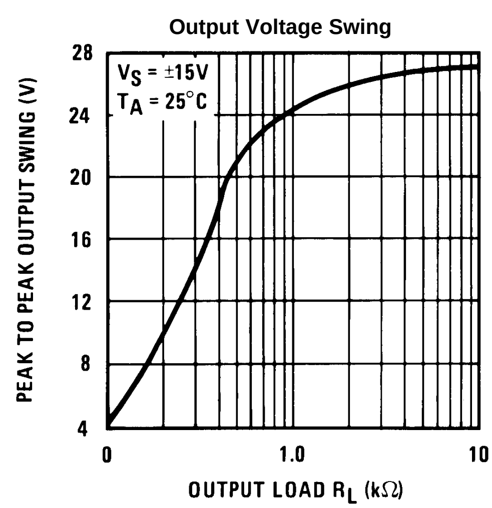


Figure 12.

2N4401

General Purpose Transistors

NPN Silicon

Features

- Pb−Free Packages are Available*

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.

*For additional information on our Pb−Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

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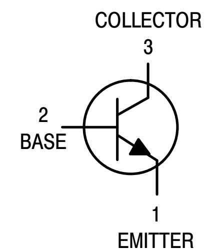
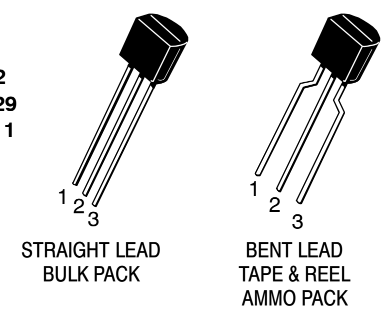
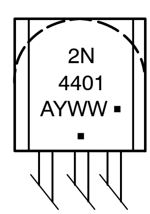


TO−92
CASE 29
STYLE 1



MARKING DIAGRAM



2N4401	= Device Code
A	= Assembly Location
Y	= Year
WW	= Work Week
▪	= Pb−Free Package

(Note: Microdot may be in either location)

ORDERING INFORMATION

See detailed ordering and shipping information in the package dimensions section on page 2 of this data sheet.

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic		Symbol	Min	Max	Unit
OFF CHARACTERISTICS					
Collector–Emitter Breakdown Voltage (Note 1)	(I_C = 1.0 mAdc, I_B = 0)	$V_{(BR)CEO}$	40	–	Vdc
Collector–Base Breakdown Voltage	(I_C = 0.1 mAdc, I_E = 0)	$V_{(BR)CBO}$	60	–	Vdc
Emitter–Base Breakdown Voltage	(I_E = 0.1 mAdc, I_C = 0)	$V_{(BR)EBO}$	6.0	–	Vdc
Base Cutoff Current	(V_{CE} = 35 Vdc, V_{EB} = 0.4 Vdc)	I_{BEV}	–	0.1	μAdc
Collector Cutoff Current	(V_{CE} = 35 Vdc, V_{EB} = 0.4 Vdc)	I_{CEX}	–	0.1	μAdc
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)	$V_{CE(sat)}$	–	0.4	Vdc
	(I_C = 500 mAdc, I_B = 50 mAdc)		–	0.75	
Base–Emitter Saturation Voltage	(I_C = 150 mAdc, I_B = 15 mAdc)	$V_{BE(sat)}$	0.75	0.95	Vdc
	(I_C = 500 mAdc, I_B = 50 mAdc)		–	1.2	
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%.

ORDERING INFORMATION

Device	Package	Shipping†
2N4401	TO–92	5000 Units / Bulk
2N4401G	TO–92 (Pb–Free)	5000 Units / Bulk
2N4401RLRA	TO–92	2000 / Tape & Reel
2N4401RLRAG	TO–92 (Pb–Free)	2000 / Tape & Reel
2N4401RLRMG	TO–92 (Pb–Free)	2000 / Tape & Ammo Box
2N4401RLRP	TO–92	2000 / Tape & Ammo Box
2N4401RLRPG	TO–92 (Pb–Free)	2000 / Tape & Ammo Box

†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specifications Brochure, BRD8011/D.

STATIC CHARACTERISTICS

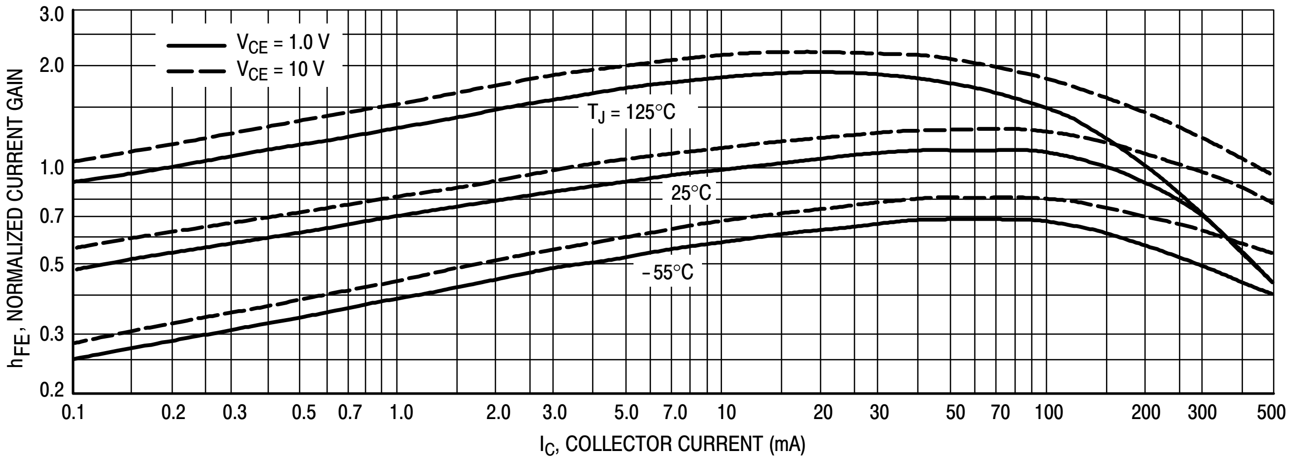


Figure 15. DC Current Gain

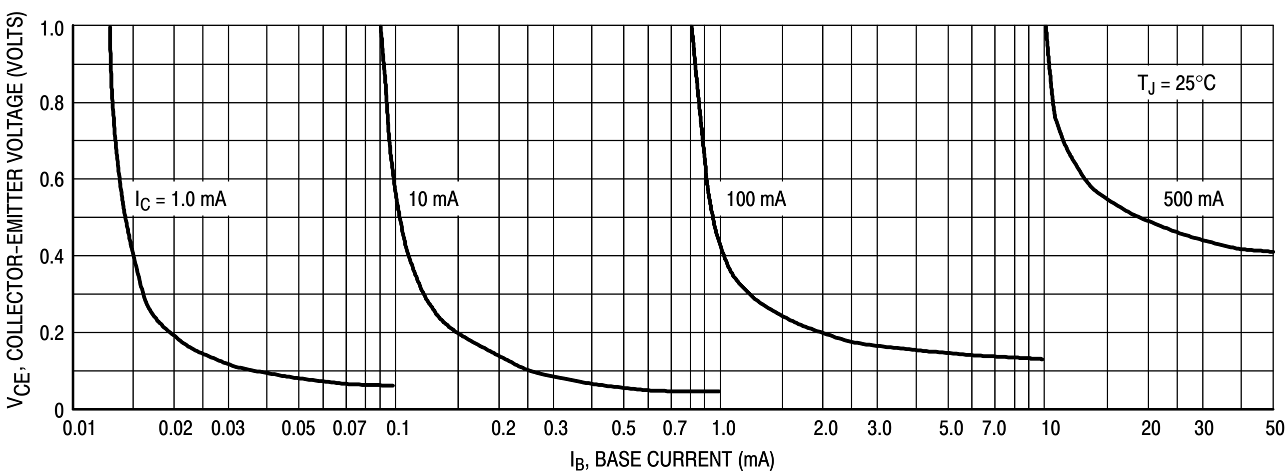


Figure 16. Collector Saturation Region

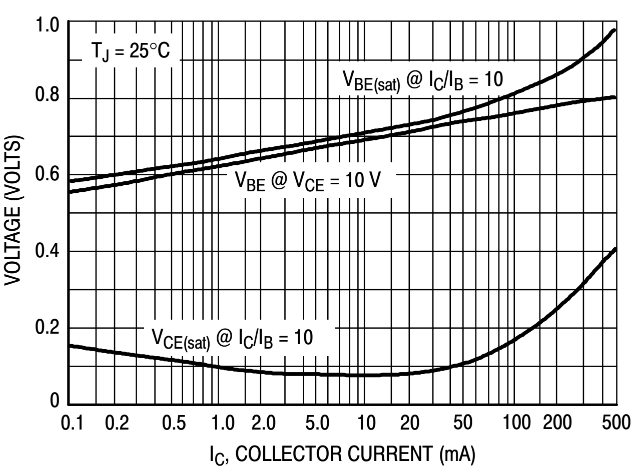


Figure 17. "On" Voltages

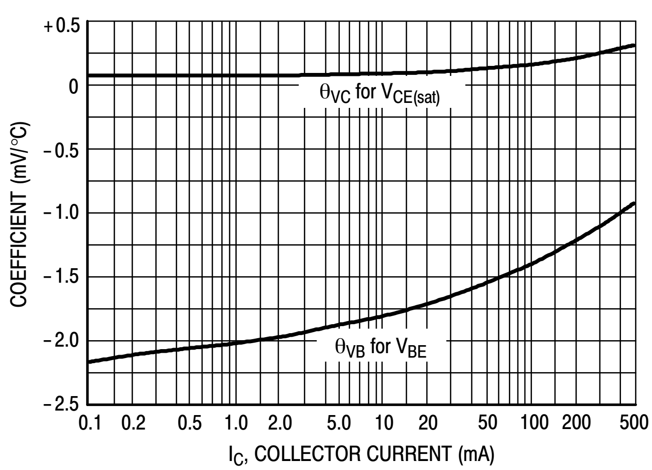


Figure 18. Temperature Coefficients

TIP31, TIP31A, TIP31B, TIP31C, (NPN), TIP32, TIP32A, TIP32B, TIP32C, (PNP)

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Complementary Silicon Plastic Power Transistors

Designed for use in general purpose amplifier and switching applications.

Features

- Collector−Emitter Saturation Voltage −
  $V_{CE(sat)}$ = 1.2 Vdc (Max) @ I_C = 3.0 Adc
- Collector−Emitter Sustaining Voltage −
  $V_{CEO(sus)}$ = 40 Vdc (Min) − TIP31, TIP32
  = 60 Vdc (Min) − TIP31A, TIP32A
  = 80 Vdc (Min) − TIP31B, TIP32B
  = 100 Vdc (Min) − TIP31C, TIP32C
- High Current Gain − Bandwidth Product
  f_T = 3.0 MHz (Min) @ I_C = 500 mAdc
- Compact TO−220 AB Package
- Pb−Free Packages are Available*

MAXIMUM RATINGS

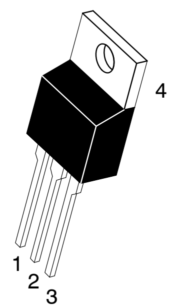
Rating		Symbol	Value	Unit
Collector − Emitter Voltage	TIP31, TIP32 TIP31A, TIP32A TIP31B, TIP32B TIP31C, TIP32C	V_{CEO}	40 60 80 100	Vdc
Collector−Base Voltage	TIP31, TIP32 TIP31A, TIP32A TIP31B, TIP32B TIP31C, TIP32C	V_{CB}	40 60 80 100	Vdc
Emitter−Base Voltage		V_{EB}	5.0	Vdc
Collector Current	Continuous Peak	I_C	3.0 5.0	Adc
Base Current		I_B	1.0	Adc
Total Power Dissipation @ T_C = 25°C Derate above 25°C		P_D	 40 0.32	 W W/°C
Total Power Dissipation @ T_A = 25°C Derate above 25°C		P_D	 2.0 0.016	 W W/°C
Unclamped Inductive Load Energy (Note 1)		E	32	mJ
Operating and Storage Junction Temperature Range		T_J, T_{stg}	−65 to +150	°C

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.

1. I_C = 1.8 A, L = 20 mH, P.R.F. = 10 Hz, V_{CC} = 10 V, R_{BE} = 100 Ω

*For additional information on our Pb−Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

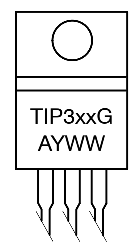
3 AMPERE POWER TRANSISTORS COMPLEMENTARY SILICON 40−60−80−100 VOLTS, 40 WATTS



TO−220AB CASE 221A STYLE 1

PIN 1. BASE
2. COLLECTOR
3. EMITTER
4. COLLECTOR

MARKING DIAGRAM



TIP3xx	= Device Code	
xx	= 1, 1A, 1B, 1C, 2, 2A, 2B, 2C,	
A	= Assembly Location	
Y	= Year	
WW	= Work Week	
G	Pb−Free Package	

ORDERING INFORMATION

See detailed ordering and shipping information in the package dimensions section on page 3 of this data sheet.

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction−to−Ambient	$R_{\theta JA}$	62.5	°C/W
Thermal Resistance, Junction−to−Case	$R_{\theta JC}$	3.125	°C/W

ELECTRICAL CHARACTERISTICS (T_C = 25°C unless otherwise noted)

Characteristic		Symbol	Min	Max	Unit
OFF CHARACTERISTICS					
Collector−Emitter Sustaining Voltage (Note 2) (I_C = 30 mAdc, I_B = 0)	TIP31, TIP32	$V_{CEO(sus)}$	40	–	Vdc
	TIP31A, TIP32A		60	–	
	TIP31B, TIP32B		80	–	
	TIP31C, TIP32C		100	–	
Collector Cutoff Current (V_{CE} = 30 Vdc, I_B = 0)	TIP31, TIP32, TIP31A, TIP32A	I_{CEO}	–	0.3	mAdc
(V_{CE} = 60 Vdc, I_B = 0)	TIP31B, TIP31C, TIP32B, TIP32C		–	0.3	
Collector Cutoff Current		I_{CES}			μAdc
(V_{CE} = 40 Vdc, V_{EB} = 0)	TIP31, TIP32		–	200	
(V_{CE} = 60 Vdc, V_{EB} = 0)	TIP31A, TIP32A		–	200	
(V_{CE} = 80 Vdc, V_{EB} = 0)	TIP31B, TIP32B		–	200	
(V_{CE} = 100 Vdc, V_{EB} = 0)	TIP31C, TIP32C		–	200	
Emitter Cutoff Current (V_{BE} = 5.0 Vdc, I_C = 0)		I_{EBO}	–	1.0	mAdc
ON CHARACTERISTICS (Note 2)					
DC Current Gain (I_C = 1.0 Adc, V_{CE} = 4.0 Vdc)		h_{FE}	25	–	–
(I_C = 3.0 Adc, V_{CE} = 4.0 Vdc)			10	50	
Collector−Emitter Saturation Voltage (I_C = 3.0 Adc, I_B = 375 mAdc)		$V_{CE(sat)}$	–	1.2	Vdc
Base−Emitter On Voltage (I_C = 3.0 Adc, V_{CE} = 4.0 Vdc)		$V_{BE(on)}$	–	1.8	Vdc
DYNAMIC CHARACTERISTICS					
Current−Gain − Bandwidth Product (I_C = 500 mAdc, V_{CE} = 10 Vdc, f_{test} = 1.0 MHz)		f_T	3.0	–	MHz
Small−Signal Current Gain (I_C = 0.5 Adc, V_{CE} = 10 Vdc, f = 1.0 kHz)		h_{fe}	20	–	–

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

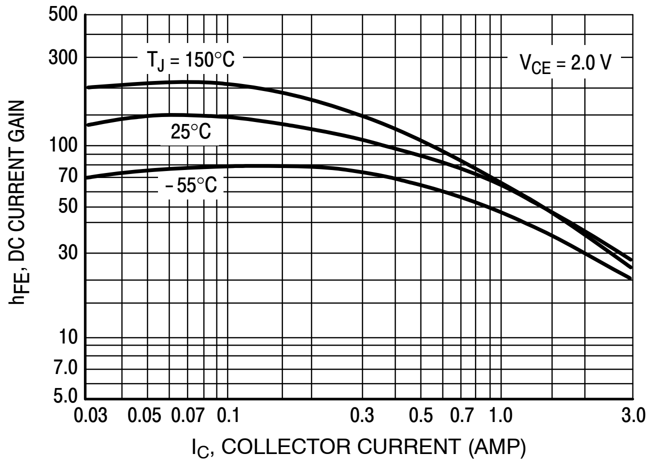


Figure 9. DC Current Gain

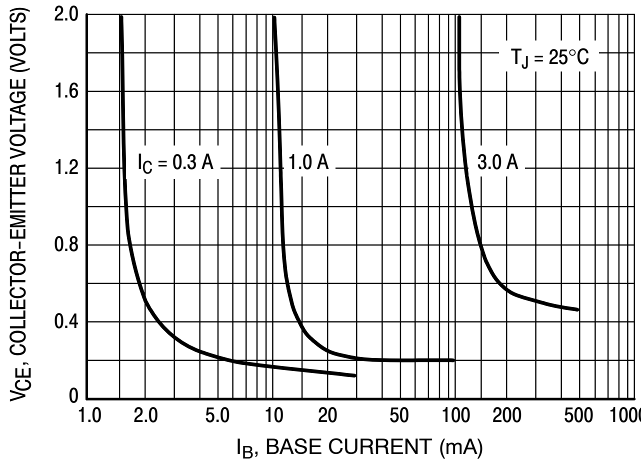


Figure 10. Collector Saturation Region

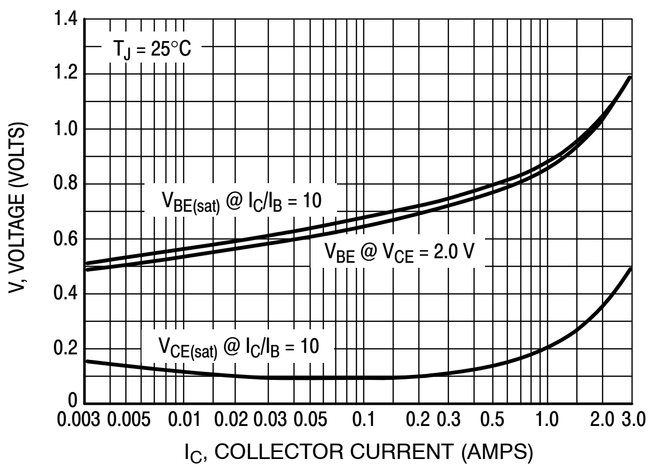


Figure 11. “On” Voltages

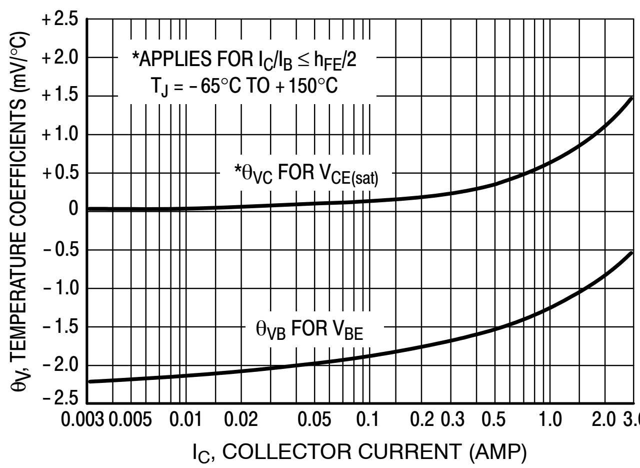


Figure 12. Temperature Coefficients

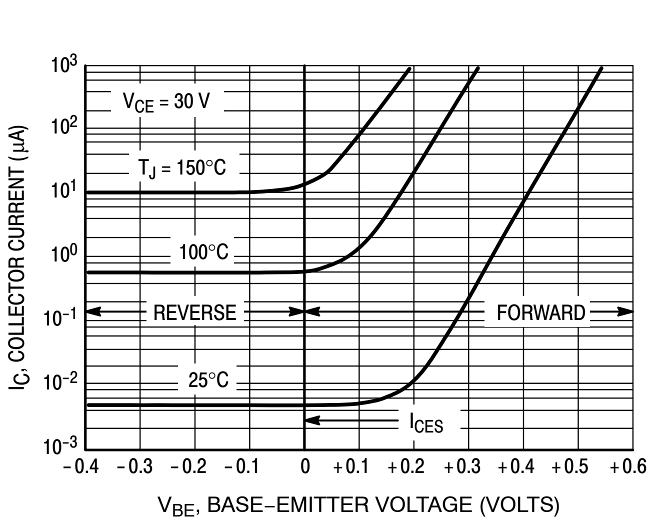


Figure 13. Collector Cut−Off Region

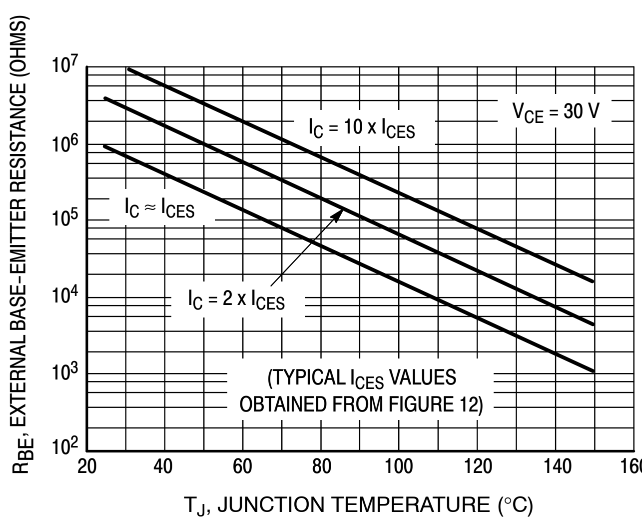


Figure 14. Effects of Base−Emitter Resistance