ECE 363 QUIZ 1

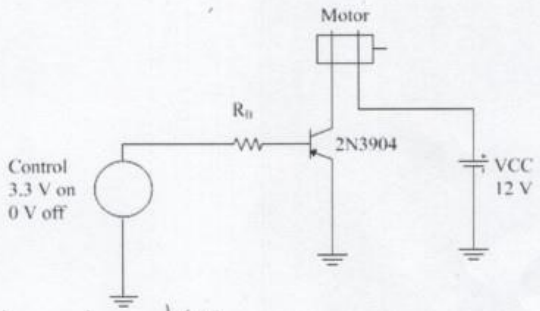
NAME: Solution

3 problems for 30 pts

Problem #1: Transistor Switch Design (10 pts)

Design an npn BJT switch to drive a small DC motor that draws 50 mA of current. The control signal is 0 to +3.3V, and V_{CC} = +12 V. Use a 2N3904 transistor – check the datasheet (see attachment) for worst-case values of β, $V_{BE,sat}$, and $V_{CE,sat}$.

(a) Choose standard 5% resistor values (see attachment for table) for R_B.
(b) Compute the power dissipated in the 2n3904 transistor.

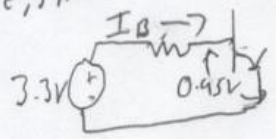


a) from data sheet

$\beta_{min} = 60$ @ 50 mA

$V_{CE,SAT} = 0.3V$ @ 50 mA

$V_{BE,SAT} = 0.95V$ @ 50 mA



For hard saturation

$I_B \approx \frac{I_C}{.1\beta_{min}} = \frac{50mA}{(.1)(60)} = 8mA$

Use KVL on base circuit

$3.3 - R_B I_B - 0.95 = 0$ $R_B = \frac{3.3 - 0.95}{8mA} = 293\Omega$

Choose 300Ω

b) $P_{DT} = I_E V_{CE}$ $I_E = I_C + I_B = 50 + 8 = 58mA$

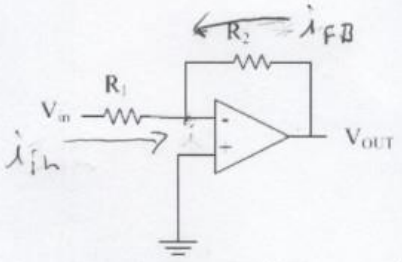
$P_{DT} = (58mA)(0.3V) = 17.4mW$

Problem # 2 Ideal Op Amp Golden Rules (10 pts)

a) List the Op Amp Golden Rules using the Ideal Op Amp model.

① $I_{in-} = I_{in+} = 0$
② with negative feedback $V_- = V_+$
③ $A_{V(OL)} = \infty$
④ $R_{in} = \infty$
⑤ $R_{out} = 0$

b) Apply the Op Amp golden rules to the circuit below to develop the equation for Gain Vout/Vin.



at node V_-

$i_{in} + i_- + i_{FB} = 0$

Use node voltage at V_- where $V_- = V_+ = 0$

$$\frac{V_{in} - 0}{R_1} = \frac{0 - V_{out}}{R_2}$$

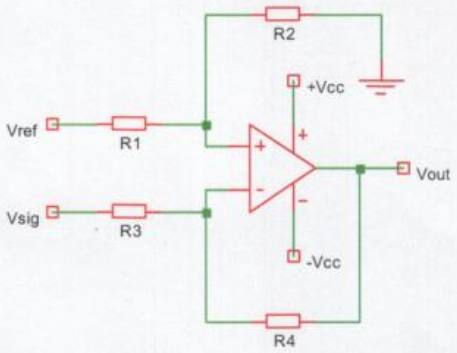
$$\frac{V_{in}}{R_1} = \frac{-V_{out}}{R_2}$$

$$\frac{V_{out}}{V_{in}} = \text{Gain} = A_V = -\frac{R_2}{R_1}$$

Problem #3: Ideal Op Amp Analysis (10 pts)

Many data acquisition systems use analog-to-digital converters that operate from 0 to +Vs. This means you cannot directly record negative voltage values! This is obviously a problem if your input signal Vsig is a sine wave, which is not unusual at all. A common technique is to use a level shifter, where an op amp shifts the signal up to a positive value somewhere between 0 and +Vs.

a) Use the Golden Rules to find an expression for V_{OUT} in- terms-of V_{REF} and V_{SIG}.
b) Let R1= R2=R3 = R4. Based on your answer to (a), what is the required value for V_{REF} to level shift the input signal to +Vs/2?
c) Suppose Vs = +5V. Your input signal is a 3V peak-to-peak sine wave at 1 kHz. Sketch both Vsig and Vout over a 3 ms time interval.



a) Voltage divider at $V_+ = V_{REF}\frac{R_2}{R_1+R_2}$

Use Rule 2

$I = \frac{V_{sig}-V_-}{R_3} = \frac{V_- - V_{out}}{R_4} \Rightarrow \left(\frac{V_{sig}}{R_3} - \frac{V_-}{R_3} = \frac{V_-}{R_4} - \frac{V_{out}}{R_4}\right)\frac{R_4}{1}$

$\frac{R_4}{R_3}V_{sig} - \frac{R_4}{R_3}V_- = V_- - V_{out} \Rightarrow V_{out} = V_-\left(1+\frac{R_4}{R_3}\right) - \frac{R_4}{R_3}V_{sig}$

Use Rule 1 $V_- = V_+$

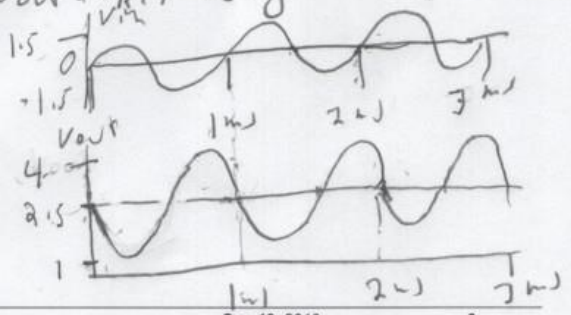
$V_{out} = V_{REF}\frac{R_2}{R_1+R_2}\left(1+\frac{R_4}{R_3}\right) - \frac{R_4}{R_3}V_{sig}$

Let $R_1 = R_2 = R_3 = R_4 \Rightarrow V_{out} = V_{REF} - V_{sig}$

$V_{REF} = \frac{V_s}{2}$ - shift

c) $= \frac{5}{2} = 2.5V$

Rough sketch



FAIRCHILD
SEMICONDUCTOR*

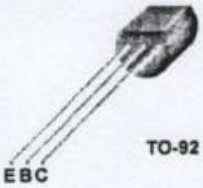
October 2011

2N3904 / MMBT3904 / PZT3904
NPN General Purpose Amplifier

Features

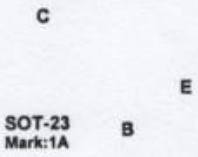
- This device is designed as a general purpose amplifier and switch.
- The useful dynamic range extends to 100 mA as a switch and to 100 MHz as an amplifier.

2N3904



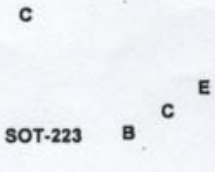
TO-92

MMBT3904



SOT-23
Mark:1A

PZT3904



SOT-223

Absolute Maximum Ratings* T_a = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CEO}	Collector-Emitter Voltage	40	V
V_{CBO}	Collector-Base Voltage	60	V
V_{EBO}	Emitter-Base Voltage	6.0	V
I_C	Collector Current - Continuous	200	mA
T_J, T_{stg}	Operating and Storage Junction Temperature Range	-55 to +150	°C

* These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

NOTES:

1) These ratings are based on a maximum junction temperature of 150 degrees C.

2) These are steady state limits. The factory should be consulted on applications involving pulsed or low duty cycle operations.

Thermal Characteristics T_a = 25°C unless otherwise noted

Symbol	Parameter	Max.			Units
		2N3904	*MMBT3904	**PZT3904	
P_D	Total Device Dissipation Derate above 25°C	625 5.0	350 2.8	1,000 8.0	mW mW/°C
$R_{\theta JC}$	Thermal Resistance, Junction to Case	83.3			°C/W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	200	357	125	°C/W

* Device mounted on FR-4 PCB 1.6" X 1.6" X 0.06".

** Device mounted on FR-4 PCB 36 mm X 18 mm X 1.5 mm; mounting pad for the collector lead min. 6 cm^2.

Electrical Characteristics T_a = 25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Max.	Units
OFF CHARACTERISTICS					
$V_{(BR)CEO}$	Collector-Emitter Breakdown Voltage	I_C = 1.0mA, I_B = 0	40		V
$V_{(BR)CBO}$	Collector-Base Breakdown Voltage	I_C = 10μA, I_E = 0	60		V
$V_{(BR)EBO}$	Emitter-Base Breakdown Voltage	I_E = 10μA, I_C = 0	6.0		V
I_{BL}	Base Cutoff Current	V_{CE} = 30V, V_{EB} = 3V		50	nA
I_{CEX}	Collector Cutoff Current	V_{CE} = 30V, V_{EB} = 3V		50	nA
ON CHARACTERISTICS*					
h_{FE}	DC Current Gain	I_C = 0.1mA, V_{CE} = 1.0V I_C = 1.0mA, V_{CE} = 1.0V I_C = 10mA, V_{CE} = 1.0V I_C = 50mA, V_{CE} = 1.0V I_C = 100mA, V_{CE} = 1.0V	40 70 100 60 30	 300 	
$V_{CE(sat)}$	Collector-Emitter Saturation Voltage	I_C = 10mA, I_B = 1.0mA I_C = 50mA, I_B = 5.0mA		0.2 0.3	V V
$V_{BE(sat)}$	Base-Emitter Saturation Voltage	I_C = 10mA, I_B = 1.0mA I_C = 50mA, I_B = 5.0mA	0.65	0.85 0.95	V V
SMALL SIGNAL CHARACTERISTICS					
f_T	Current Gain - Bandwidth Product	I_C = 10mA, V_{CE} = 20V, f = 100MHz	300		MHz
C_{obo}	Output Capacitance	V_{CB} = 5.0V, I_E = 0, f = 1.0MHz		4.0	pF
C_{ibo}	Input Capacitance	V_{EB} = 0.5V, I_C = 0, f = 1.0MHz		8.0	pF
NF	Noise Figure	I_C = 100μA, V_{CE} = 5.0V, R_S = 1.0kΩ, f = 10Hz to 15.7kHz		5.0	dB
SWITCHING CHARACTERISTICS					
t_d	Delay Time	V_{CC} = 3.0V, V_{BE} = 0.5V I_C = 10mA, I_{B1} = 1.0mA		35	ns
t_r	Rise Time			35	ns
t_s	Storage Time	V_{CC} = 3.0V, I_C = 10mA, I_{B1} = I_{B2} = 1.0mA		200	ns
t_f	Fall Time			50	ns

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

Ordering Information

Part Number	Marking	Package	Packing Method	Pack Qty
2N3904BU	2N3904	TO-92	BULK	10000
2N3904TA	2N3904	TO-92	AMMO	2000
2N3904TAR	2N3904	TO-92	AMMO	2000
2N3904TF	2N3904	TO-92	TAPE REEL	2000
2N3904TFR	2N3904	TO-92	TAPE REEL	2000
MMBT3904	1A	SOT-23	TAPE REEL	3000
MMBT3904_D87Z	1A	SOT-23	TAPE REEL	10000
PZT3904	3904	SOT-223	TAPE REEL	2500

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