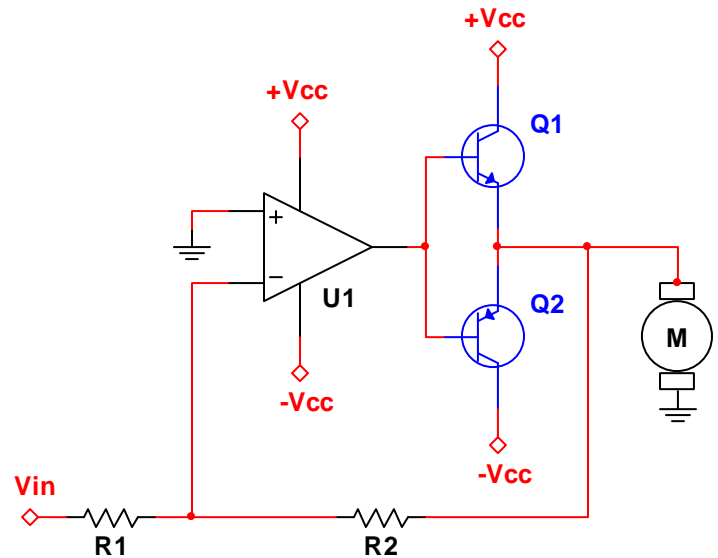


## 1 problem for 20 pts

## Push-Pull Current Booster

Design a voltage amplifier to drive a 5V DC motor with a max power consumption of 1W. 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.
- 12, 18, 24, and 30 °C/W heat sinks are available
- $V_{CC}$  is either 4.5, 6, 9, or 12V
- Input impedance  $Z_{IN} \geq 20 \text{ kohm}$
- All resistors are 5% standard values.



- (a) Perform a “quick” analysis to choose  $V_{CC}$ . Show all calculations!
- (b) Perform a “quick” analysis and datasheets to show why Q1 should be the TIP31 rather than the 2N4401. If Q1 needs a heat sink, choose one of the available values (assume  $\theta_{CS} = 0.5^\circ\text{C/W}$  and  $T_A = 25^\circ\text{C}$ ).
- (c) Show that the op amp can provide the required output voltage and current **under worst-case transistor conditions**.
- (d) Suppose the input signal is 0.2V. Choose R1 and R2 so that the motor voltage is close to -5V. Show all work!  
NOTE:  $Z_{IN} = R1$  for an inverting amplifier.

(extra sheet for work)

# 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 @ $T_A = 25^\circ\text{C}$ Derate above $25^\circ\text{C}$	$P_D$	625 5.0	mW mW/ $^\circ\text{C}$
Total Device Dissipation @ $T_C = 25^\circ\text{C}$ Derate above $25^\circ\text{C}$	$P_D$	1.5 12	W mW/ $^\circ\text{C}$
Operating and Storage Junction Temperature Range	$T_J, T_{stg}$	-55 to +150	$^\circ\text{C}$

#### THERMAL CHARACTERISTICS

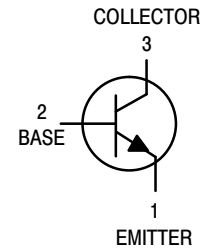
Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction-to-Ambient	$R_{\theta JA}$	200	$^\circ\text{C}/\text{W}$
Thermal Resistance, Junction-to-Case	$R_{\theta JC}$	83.3	$^\circ\text{C}/\text{W}$

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.

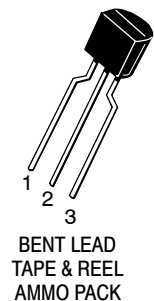
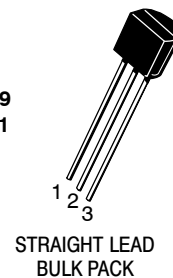


ON Semiconductor®

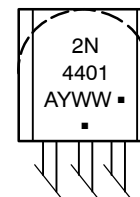
<http://onsemi.com>



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.

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

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



ON Semiconductor®

<http://onsemi.com>

## Complementary Silicon Plastic Power Transistors

Designed for use in general purpose amplifier and switching applications.

### Features

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

### MAXIMUM RATINGS

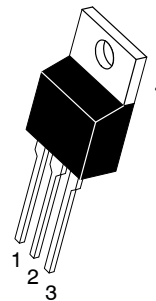
Rating	Symbol	Value	Unit
Collector – Emitter Voltage TIP31, TIP32 TIP31A, TIP32A TIP31B, TIP32B TIP31C, TIP32C	$V_{CEO}$	40 60 80 100	Vdc
Collector–Base Voltage TIP31, TIP32 TIP31A, TIP32A TIP31B, TIP32B TIP31C, TIP32C	$V_{CB}$	40 60 80 100	Vdc
Emitter–Base Voltage	$V_{EB}$	5.0	Vdc
Collector Current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

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.  $I_C = 1.8 \text{ A}$ ,  $L = 20 \text{ mH}$ , P.R.F. = 10 Hz,  $V_{CC} = 10 \text{ V}$ ,  $R_{BE} = 100 \Omega$

\*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.

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

## THERMAL CHARACTERISTICS

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

## ELECTRICAL CHARACTERISTICS ( $T_C = 25^{\circ}\text{C}$ unless otherwise noted)

Characteristic	Symbol	Min	Max	Unit
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## OFF CHARACTERISTICS

Collector-Emitter Sustaining Voltage (Note 2) ( $I_C = 30 \text{ mAdc}$ , $I_B = 0$ )	TIP31, TIP32 TIP31A, TIP32A TIP31B, TIP32B TIP31C, TIP32C	$V_{CE(sus)}$	40 60 80 100	- - - -	Vdc
Collector Cutoff Current ( $V_{CE} = 30 \text{ Vdc}$ , $I_B = 0$ ) ( $V_{CE} = 60 \text{ Vdc}$ , $I_B = 0$ )	TIP31, TIP32, TIP31A, TIP32A TIP31B, TIP31C, TIP32B, TIP32C	$I_{CEO}$	- -	0.3 0.3	mAdc
Collector Cutoff Current ( $V_{CE} = 40 \text{ Vdc}$ , $V_{EB} = 0$ ) ( $V_{CE} = 60 \text{ Vdc}$ , $V_{EB} = 0$ ) ( $V_{CE} = 80 \text{ Vdc}$ , $V_{EB} = 0$ ) ( $V_{CE} = 100 \text{ Vdc}$ , $V_{EB} = 0$ )	TIP31, TIP32 TIP31A, TIP32A TIP31B, TIP32B TIP31C, TIP32C	$I_{CES}$	- - - -	200 200 200 200	$\mu\text{Adc}$
Emitter Cutoff Current ( $V_{BE} = 5.0 \text{ Vdc}$ , $I_C = 0$ )		$I_{EBO}$	-	1.0	mAdc

## ON CHARACTERISTICS (Note 2)

DC Current Gain ( $I_C = 1.0 \text{ Adc}$ , $V_{CE} = 4.0 \text{ Vdc}$ ) ( $I_C = 3.0 \text{ Adc}$ , $V_{CE} = 4.0 \text{ Vdc}$ )		$h_{FE}$	25 10	- 50	-
Collector-Emitter Saturation Voltage ( $I_C = 3.0 \text{ Adc}$ , $I_B = 375 \text{ mAdc}$ )		$V_{CE(sat)}$	-	1.2	Vdc
Base-Emitter On Voltage ( $I_C = 3.0 \text{ Adc}$ , $V_{CE} = 4.0 \text{ Vdc}$ )		$V_{BE(on)}$	-	1.8	Vdc

## DYNAMIC CHARACTERISTICS

Current-Gain - Bandwidth Product ( $I_C = 500 \text{ mAdc}$ , $V_{CE} = 10 \text{ Vdc}$ , $f_{test} = 1.0 \text{ MHz}$ )		$f_T$	3.0	-	MHz
Small-Signal Current Gain ( $I_C = 0.5 \text{ Adc}$ , $V_{CE} = 10 \text{ Vdc}$ , $f = 1.0 \text{ kHz}$ )		$h_{fe}$	20	-	-

2. Pulse Test: Pulse Width  $\leq 300 \mu\text{s}$ , Duty Cycle  $\leq 2.0\%$ .

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

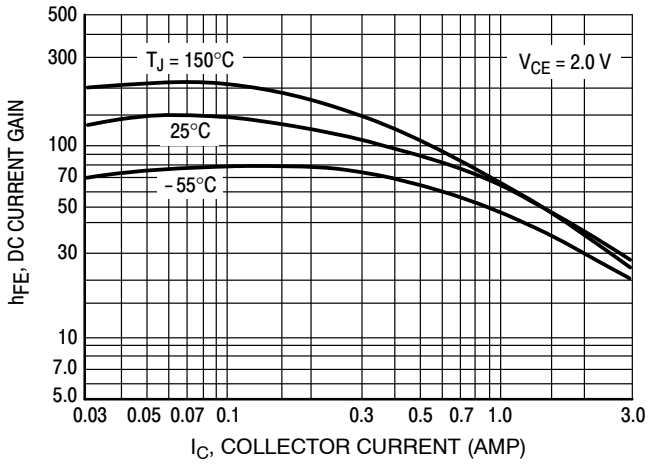


Figure 9. DC Current Gain

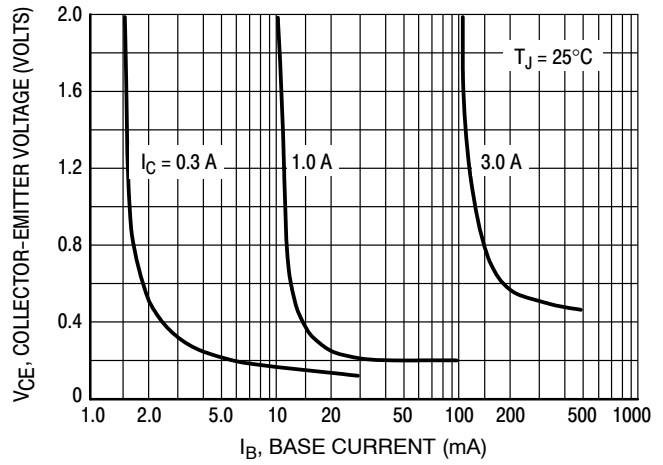


Figure 10. Collector Saturation Region

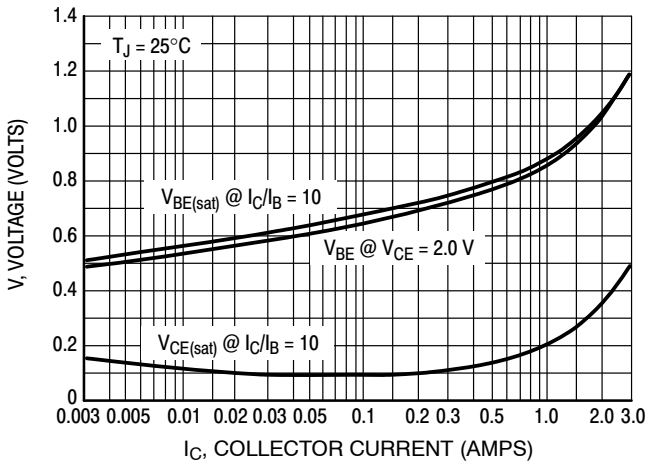


Figure 11. "On" Voltages

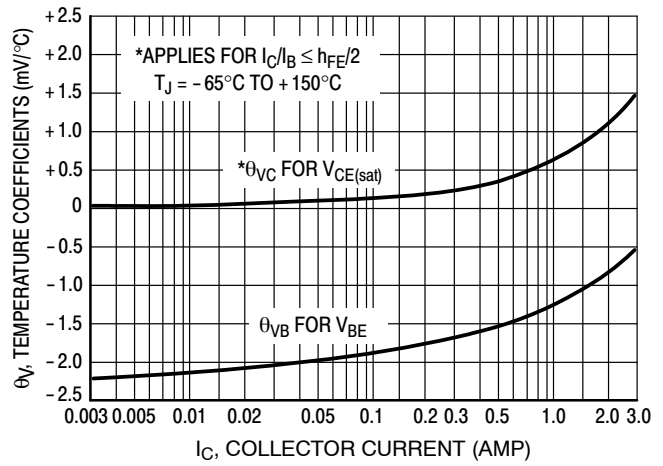


Figure 12. Temperature Coefficients

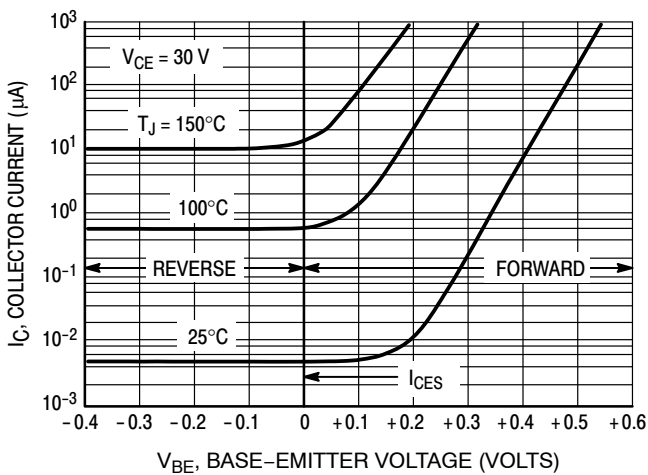


Figure 13. Collector Cut-Off Region

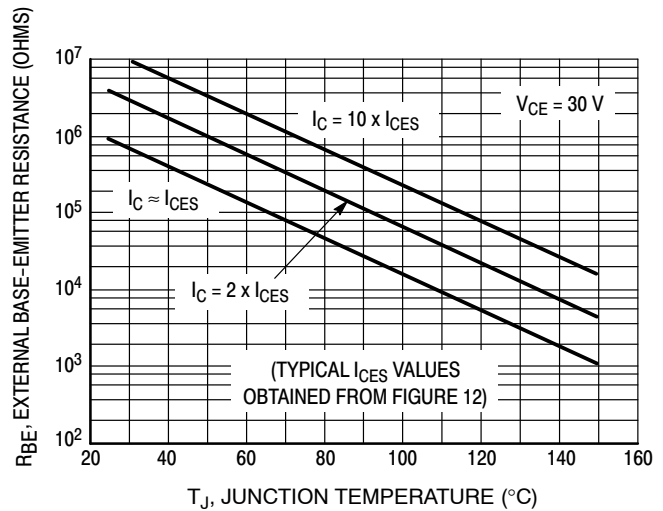


Figure 14. Effects of Base-Emitter Resistance

Typical DC Performance Characteristics (continued)

Curves are for LF155 and LF156 unless otherwise specified.

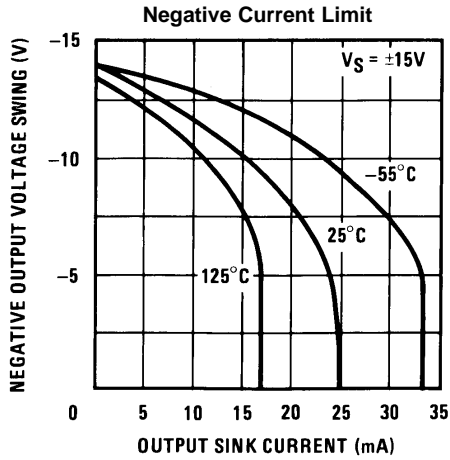


Figure 7.

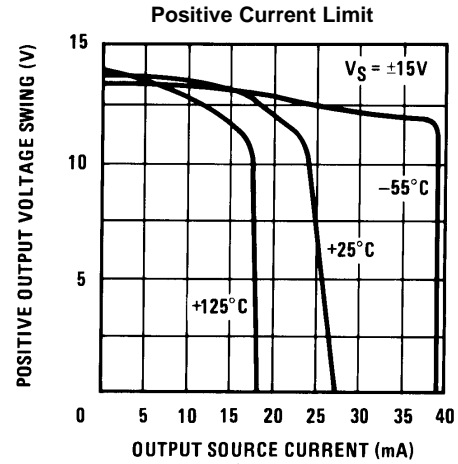


Figure 8.

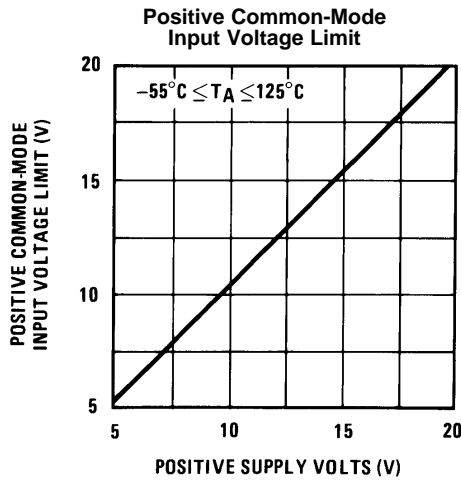


Figure 9.

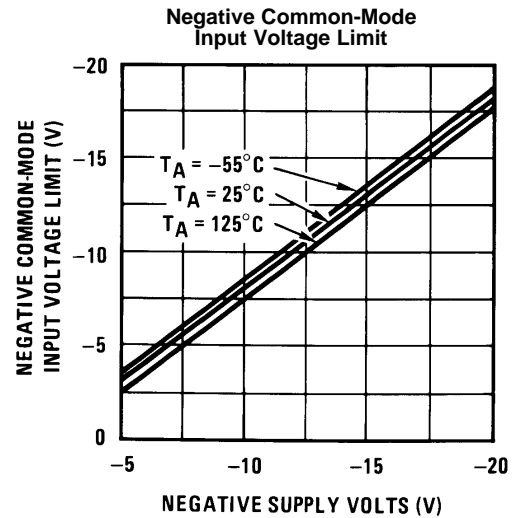


Figure 10.

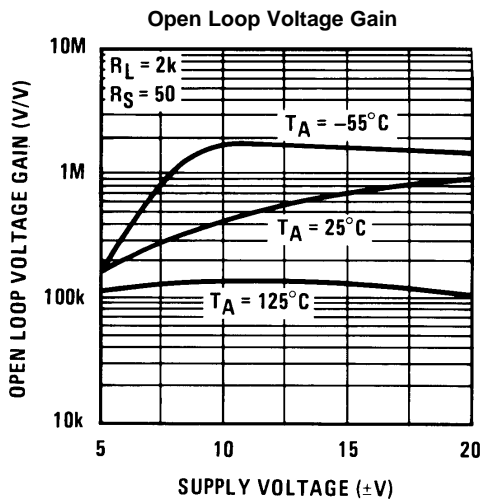


Figure 11.

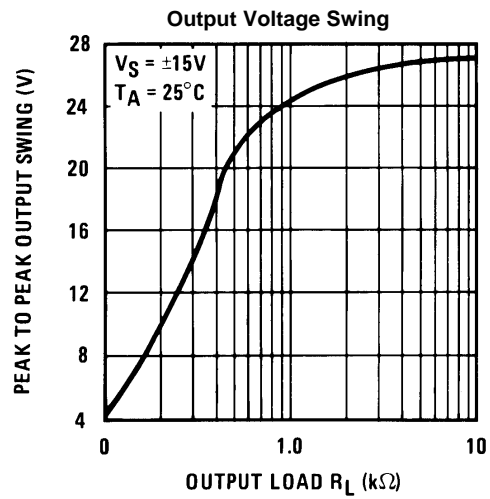


Figure 12.

Standard Resistor Values ( $\pm 5\%$ )						
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 ( $\pm 10\%$ )							
10pF	100pF	1000pF	.010 $\mu$ F	.10 $\mu$ F	1.0 $\mu$ F	10 $\mu$ F	100 $\mu$ F
12pF	120pF	1200pF	.012 $\mu$ F	.12 $\mu$ F	1.2 $\mu$ F		
15pF	150pF	1500pF	.015 $\mu$ F	.15 $\mu$ F	1.5 $\mu$ F	15 $\mu$ F	150 $\mu$ F
18pF	180pF	1800pF	.018 $\mu$ F	.18 $\mu$ F	1.8 $\mu$ F		
22pF	220pF	2200pF	.022 $\mu$ F	.22 $\mu$ F	2.2 $\mu$ F	22 $\mu$ F	220 $\mu$ F
27pF	270pF	2700pF	.027 $\mu$ F	.27 $\mu$ F	2.7 $\mu$ F		
33pF	330pF	3300pF	.033 $\mu$ F	.33 $\mu$ F	3.3 $\mu$ F	33 $\mu$ F	330 $\mu$ F
39pF	390pF	3900pF	.039 $\mu$ F	.39 $\mu$ F	3.9 $\mu$ F		
47pF	470pF	4700pF	.047 $\mu$ F	.47 $\mu$ F	4.7 $\mu$ F	47 $\mu$ F	470 $\mu$ F
56pF	560pF	5600pF	.056 $\mu$ F	.56 $\mu$ F	5.6 $\mu$ F		
68pF	680pF	6800pF	.068 $\mu$ F	.68 $\mu$ F	6.8 $\mu$ F	68 $\mu$ F	680 $\mu$ F
82pF	820pF	8200pF	.082 $\mu$ F	.82 $\mu$ F	8.2 $\mu$ F		