

## Design Equations—Commonly Used Amplifier Configurations

### Voltage Follower

$V_{OUT} = V_{IN}$

**BUFFER HIGH IMPEDANCE SOURCE TO LOW RESISTANCE LOAD**

### Noninverting Op Amp

$V_{OUT} = V_{IN} \left( \frac{R_F}{R_G} + 1 \right)$

**IN-PHASE SIGNAL AMPLIFICATION**

### Inverting Op Amp

$V_{OUT} = V_{IN} \left( -\frac{R_F}{R_G} \right)$

**AMPLIFY AND INVERT INPUT**

### Op Amp Noise for Single-Pole System

**GAIN FROM "A" TO OUTPUT =**  
**NOISE GAIN =**  
 $NG = 1 + \frac{R_2}{R_1}$

**GAIN FROM "B" TO OUTPUT =**  
 $-\frac{R_2}{R_1}$

**CLOSED-LOOP BW =**  
 $f_{CL}$

**RTI NOISE =**  
 $\sqrt{BW} \times \sqrt{V_{N,R1}^2 + 4kTR_3 + 4kTR_1 \left( \frac{R_2}{R_1 + R_2} \right)^2 + I_{N,R2}^2 R_3^2 + I_{N,R2}^2 \left( \frac{R_1 \times R_2}{R_1 + R_2} \right)^2 + 4kTR_2 \left( \frac{R_1}{R_1 + R_2} \right)^2}$

**RTI NOISE =**  
 $NG \times \text{RTI NOISE}$

**RTI = REFER TO INPUT**  
**RTO = REFER TO OUTPUT**

**BW =**  
 $1.57 f_{CL}$

### Decibel (dB) Formulas (Equal Impedances)

$db = 10 \text{ Log } \frac{P_{OUT}}{P_{IN}} = 20 \text{ Log } \frac{V_{OUT}}{V_{IN}}$

$= 20 \text{ Log } \frac{I_{OUT}}{I_{IN}} \text{ (Gain)}$

### Sinusoidal Voltages and Currents

**RMS = Root Mean Square = Effective**

$V_{RMS} = 0.707 V_{PEAK} = V_{EFF}$   
 $V_{AVE} = 0.637 V_{PEAK}$   
 $V_{EFF} = 1.11 V_{AVE}$   
 $V_{PEAK} = 1.57 V_{AVE}$   
 $V_{AVE} = 0.9 V_{EFF}$

### Voltage Subtractor/Difference Amplifier

$V_{OUT} = (V_B - V_A) \left( \frac{R_2}{R_1} \right)$

**AMPLIFY THE DIFFERENCE BETWEEN TWO VOLTAGES, REJECT COMMON-MODE VOLTAGE**

### Voltage Adder

$V_{OUT} = \left( \frac{V_A}{R_1} + \frac{V_B}{R_2} + \frac{V_C}{R_3} + \frac{V_N}{R_N} \right) (-R_F)$

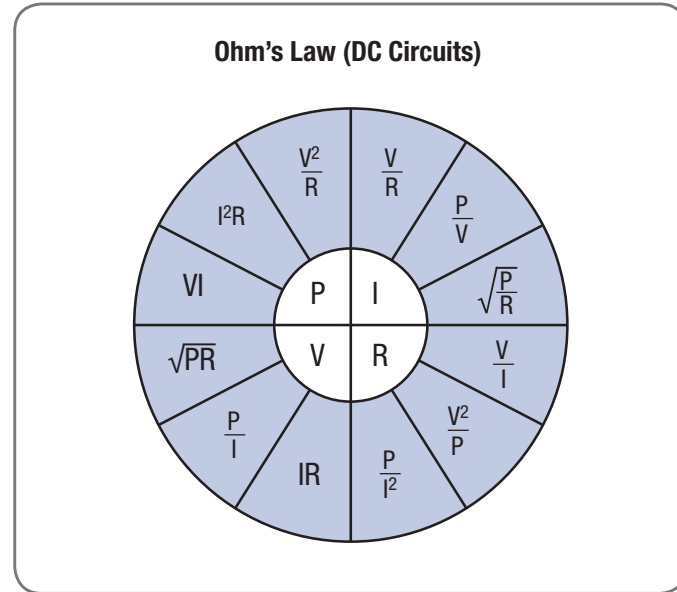
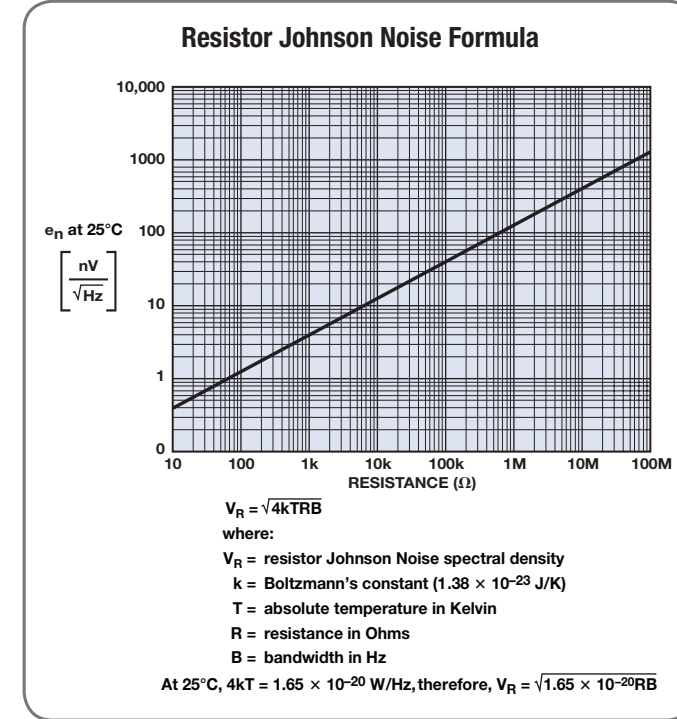
**SUM MULTIPLE VOLTAGES**

### Low-Pass Filter/Integrator

$t = RC = R_F C$

$V_{OUT} = V_{IN} \left( -\frac{R_F}{R_1} \times \frac{1}{R_F C S + 1} \right)$

**LIMIT BANDWIDTH OF SIGNAL**



### High-Pass Filter/Differentiator

$V_{OUT} = V_{IN} \left( -\frac{R_F}{R_{IN}} \times \frac{R_{IN} C_{IN} S}{R_{IN} C_{IN} S + 1} \right)$

**BLOCK DC, AMPLIFY AC**

### Differential Amplifier

$V_{OUT_{diff}} = \left( \frac{R_F}{R_G} \right) V_{IN}$

$V_{OUT_{cm}} = V_{OCM}$

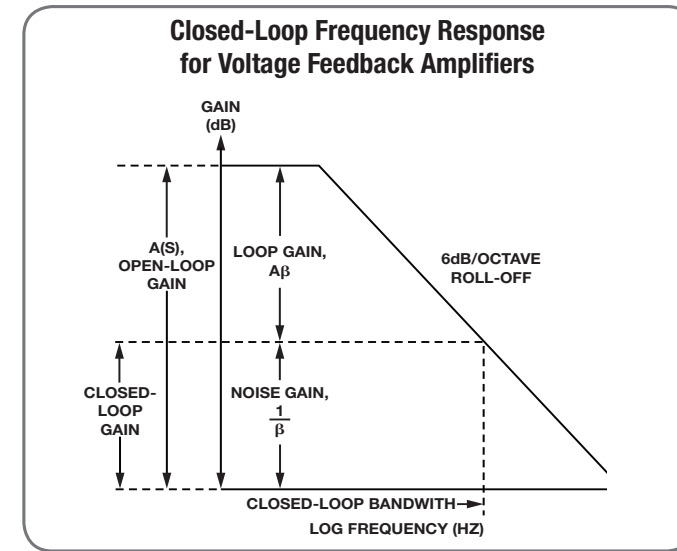
**DRIVE A DIFFERENTIAL INPUT ADC FROM A DIFFERENTIAL OR SINGLE-ENDED SOURCE**

### Instrumentation Amplifier

$V_{OUT} = V_{diff} \times \left( \frac{R_2}{R_1} \right) \left( 1 + \frac{2R_3}{R_4} \right)$

IF  $R_2 = R_3$ ,  $G = 1 + \frac{2R_1}{R_4}$

**AMPLIFY LOW LEVEL DIFFERENTIAL SIGNAL, REJECT COMMON-MODE SIGNAL**



### Resistors in Series/Capacitors in Parallel

$R_{TOTAL} = R_1 + R_2 + R_3 + \dots$  /  $C_{TOTAL} = C_1 + C_2 + C_3 + \dots$

### Resistors in Parallel/Capacitors in Series

$R_{TOTAL} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots}$  /  $C_{TOTAL} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots}$

### Two Resistors in Parallel

$R_{TOTAL} = \frac{R_1 R_2}{R_1 + R_2}$

### Equal Resistors in Parallel

$R_{TOTAL} = \frac{R}{N}$  Where R is the value of one of the equal resistors, and N is the number of equal resistors

### Reactance Formulas

$X_C = \frac{1}{2\pi fC}$

$X_L = 2\pi fL$

### Impedance Formulas (Series)

$Z = \sqrt{R^2 + X_L^2}$  (Series RL)  
 $Z = \sqrt{R^2 + X_C^2}$  (Series RC)  
 $Z = X_L - X_C$  (Series LC)  
 $Z = \sqrt{R^2 + (X_L - X_C)^2}$  (Series RLC)  
 $Z = \frac{V_A}{I}$

### Voltage and Impedance Formulas (Parallel)

$Z = \frac{RX_L}{\sqrt{R^2 + X_L^2}}$  (RL)  $Z = \frac{V_A}{I_{LINE}}$   
 $Z = \frac{RX_C}{\sqrt{R^2 + X_C^2}}$  (RC)  $V_A = V_L = V_C = V_R$   
 $Z = \frac{X_L X_C}{X_L - X_C}$  (LC)  $V_A = I_{LINE} Z$   
 $Z = \frac{RX}{\sqrt{R^2 + X^2}}$  (RLC)

### Transformers (Step-Up or Step-Down Ratios)

$\frac{N_p}{N_s} = \frac{E_p}{E_s} = \frac{I_s}{I_p} = \sqrt{\frac{Z_p}{Z_s}}$

### Common 1% Resistor Values

1% standard values decade multiples are available from 10.0 Ω through 1.00 MΩ (also 1.10 MΩ, 1.20 MΩ, 1.30 MΩ, 1.50 MΩ, 1.60 MΩ, 1.80 MΩ, 2.00 MΩ, and 2.20 MΩ).

Standard base resistor values are given in the following table for the most commonly used tolerance (1%), along with typically available resistance ranges. To determine values other than the base, multiply the base value by 10, 100, 1000, or 10,000.

10.0	10.2	10.5	10.7	11.0	11.3	11.5	11.8	12.1	12.4	12.7	13.0
13.3	13.7	14.0	14.3	14.7	15.0	15.4	15.8	16.2	16.5	16.9	17.4
17.8	18.2	18.7	19.1	19.6	20.0	20.5	21.0	21.5	22.1	22.6	23.2
23.7	24.3	24.9	25.5	26.1	26.7	27.4	28.0	28.7	29.4	30.1	30.9
31.6	32.4	33.2	34.0	34.8	35.7	36.5	37.4	38.3	39.2	40.2	41.2
42.2	43.2	44.2	45.3	46.4	47.5	48.7	49.9	51.1	52.3	53.6	54.9
56.2	57.6	59.0	60.4	61.9	63.4	64.9	66.5	68.1	69.8	71.5	73.2
75.0	76.8	78.7	80.6	82.5	84.5	86.6	88.7	90.9	93.1	95.3	97.6

### Common Capacitor Values

pF	pF	pF	pF	μF	μF	μF	μF	μF	μF	μF	μF
1.0	10	100	1000	0.01	0.1	1.0	10	100	1000	10,000	
1.1	11	110	1100								
1.2	12	120	1200								
1.3	13	130	1300								
1.5	15	150	1500	0.015	0.15	1.5	15	150	1500		
1.6	16	160	1600								
1.8	18	180	1800								
2.0	20	200	2000								
2.2	22	220	2200	0.022	0.22	2.2	22	220	2200		
2.4	24	240	2400								
2.7	27	270	2700								
3.0	30	300	3000								
3.3	33	330	3300	0.033	0.33	3.3	33	330	3300		
3.6	36	360	3600								
3.9	39	390	3900								
4.3	43	430	4300								
4.7	47	470	4700	0.047	0.47	4.7	47	470	4700		
5.1	51	510	5100								
5.6	56	560	5600								
6.2	62	620	6200								
6.8	68	680	6800	0.068	0.68	6.8	68	680	6800		
7.5	75	750	7500								
8.2	82	820	8200								
9.1	91	910	9100								