

## Description

The RU5621A and RU5622A are double-poly NMOS resistor-programmable switched-capacitor universal active filters. The RU5621A consists of two second-order state variable filters packaged in a 14-pin DIP. The RU5622A is a quad second-order section (four 2-pole filters) housed in a 20-pin DIP. With only an external clock and up to seven external resistors, any classical filter type can be configured. Center frequencies of all filter types including all pass and notch can be adjusted by changing the external resistor ratios or varying the clock frequency. Therefore, filter accuracy and stability are relatively insensitive to component variations. Filter Qs are also adjustable using resistor ratios. The filter sections are cascadable and up to an eighth-order filter may be achieved with only one package. The pinout configurations for these devices are shown in Figure 1, and package dimensions are shown in Figure 5.

## Key Features

- Easy to use
- Small size: 14- or 20-pin DIP
- Low power consumption: as low as 25 mW per package
- Wide power supply range:  $\pm 5V$  to  $\pm 10V$
- Up to four 2-pole sections per package
- High dynamic range: up to 96 dB
- Wide signal range: 2.5 Hz to 30 kHz
- Low cost
- Low sensitivity to external component variation
- Wide Q range: 0.5 up to 500
- Wide clock-to-center/corner frequency range: 25:1 to over 100:1
- Clock-to-center frequency accuracy  $\leq 0.5\%$  (device to device)

## Device Operation

The RU5621A and RU5622A resistor-programmable universal active filters are based on a two-integrator state variable second-order switched-capacitor filter (see Figure 2). The time constant is controlled by the sample rate applied to the filters and is nominally a clock-to-corner ratio of 25 to 1. All of the standard filter transfer function characteristics can be controlled by feeding back the output signal to the four inputs. For example, the gain from  $V_{out}$  to LP controls the filter clock-to-center ratio. If  $V_{out}$  is applied directly to LP, then the clock-to-center frequency ratio is 25 to 1. If a resistor divider is tied between  $V_{out}$  and LP then the clock-to-center frequency ratio can be adjusted to a value greater than 25 to 1. If the input signal is also resistor summed into this junction then a low-pass filter is implemented.

The gain from  $V_{out}$  to BP- can be used to control the Q of the second-order section. If  $V_{out}$  is tied directly to BP- then the Q is nominally 0.5 (this will vary as a function of feedback to LP). If a resistor divider is tied between  $V_{out}$  and BP- then the Q can be adjusted to a value greater than 0.5. If the input signal is resistor summed into this input, then an inverting bandpass filter can be implemented. The BP+ and HP inputs are used primarily as inputs for the high pass and non-inverting bandpass modes.

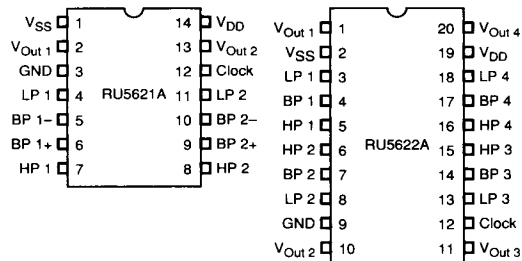
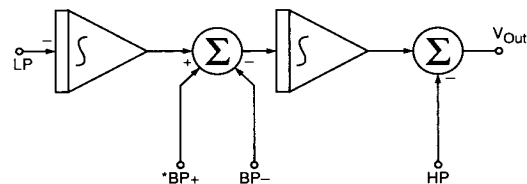


Figure 1. Pinout Configurations

## Filter Types Available

	RU5621A	RU5622A
Lowpass	Yes	Yes
Bandpass	Yes	Yes
Highpass	Yes	Yes
Lowpass elliptical	Yes	Yes
Highpass elliptical	Yes	Yes
Notch	Yes	Yes
All Pass	Yes	No
Biquad	Yes	No



\* BP+ Input not available on the RU5622A

Figure 2. Block Diagram (Single Section)

## Operational Considerations

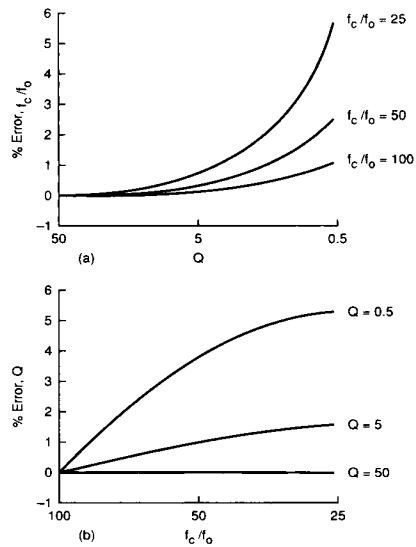
The optimal clock-to-center frequency ratio of the RU5621A and RU5622A is 50 to 1. This ratio will yield maximum p-p output signal and dynamic range. Dynamic range will drop about 6 dB for each halving or doubling of this ratio.

Selection of resistor values is also important. The total parallel resistance on the output should be kept above 10K $\Omega$  so that the maximum output signal swing will not be reduced. The parallel combination of all resistors going to a summing junction (BP- or LP) should be less than 100K $\Omega$  to reduce input noise. In all cases, unused inputs should be grounded to prevent crosstalk from these pins (see Table 4).

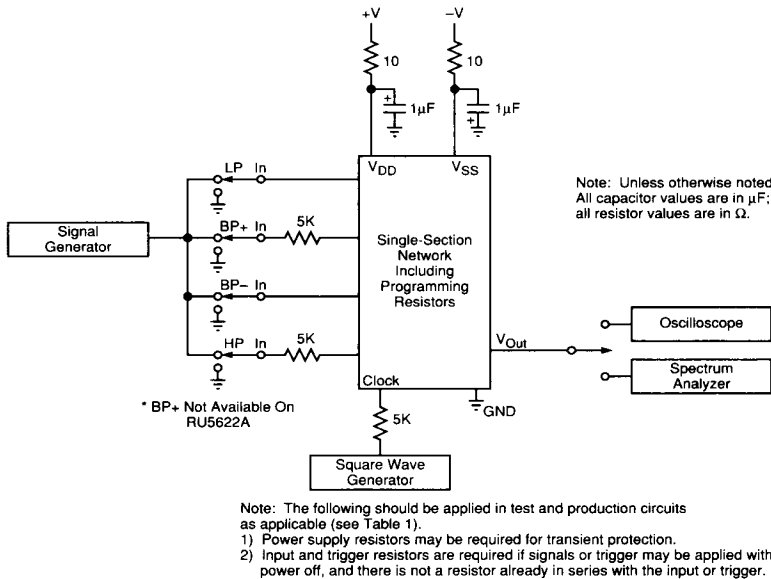
When high accuracy filters are being designed, the special characteristics of switched-capacitor filters should be considered. The equations describing the clock-to-center frequency ratio are accurate for filters that have high  $Q_s$  ( $>5$ ) and large clock-to-center frequency ratios ( $f_c/f_o > 50$  to 1). Filters that do not fall into these two categories may have significant errors due to the sampled data effects that are characteristic of all switched-capacitor filters as shown in Figure 4. Once the final filter design is established, center frequency tolerance for the filter chips (not including external resistor tolerances) will be less than  $\pm 0.5\%$ .

### Aliasing Considerations

As with all sampled data devices, care should be taken to prevent aliasing of signals into the passband. If signals exist near the sample rate or its harmonics that might be aliased into the passband, then prefiltering is required. Since clock-to-center frequency ratios on switched-capacitor filters are quite large, this can usually be accomplished with a simple RC filter. The output of the devices will contain about 30 mV<sub>rms</sub> clock feedthrough. If this noise can affect system performance, it should be removed. Once again, a simple RC is usually adequate. When cascading second-order sections that have the same sample rate, it is only necessary to provide antialias filtering to the first filter section.



**Figure 4. Programming Errors**



**Figure 3. Test Circuit (Single Section)**

### Transfer Functions

#### Low-pass :

$$H(s) = - \left( \frac{\omega_0^2}{s^2 + (\omega_0/Q)s + \omega_0^2} \right)$$

#### Bandpass :

$$H(s) = - \left( \frac{-(\omega_0/Q)s}{s^2 + (\omega_0/Q)s + \omega_0^2} \right)$$

#### High-pass :

$$H(s) = - \left( \frac{s^2}{s^2 + (\omega_0/Q)s + \omega_0^2} \right)$$

#### Lowpass Elliptic :

$$H(s) = - \left( \frac{(\omega_0/\omega_z)^2 s^2 + \omega_0^2}{s^2 + (\omega_0/Q)s + \omega_0^2} \right)$$

#### Highpass Elliptic :

$$H(s) = - \left( \frac{s^2 + (\omega_z/\omega_0)^2 \omega_0^2}{s^2 + (\omega_0/Q)s + \omega_0^2} \right)$$

#### Notch :

$$H(s) = - \left( \frac{s^2 + \omega_0^2}{s^2 + (\omega_0/Q)s + \omega_0^2} \right)$$

#### All Pass :

$$H(s) = - \left( \frac{s^2 - (\omega_0/Q)s + \omega_0^2}{s^2 + (\omega_0/Q)s + \omega_0^2} \right)$$

## Design Procedure

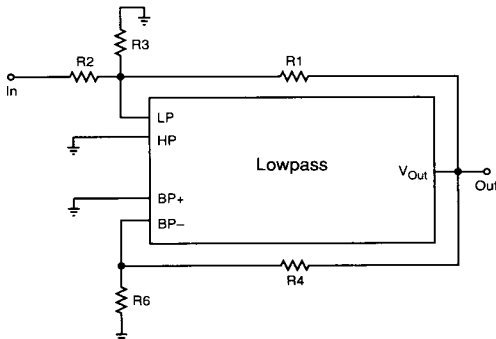
All of the resistor values that determine filter parameters such as clock-to-center (or corner) frequency ratio ( $f_c/f_o$ ), Q and elliptic notch frequency ( $f_z$ ) can be calculated from simple equations.

The most general equations are listed under the biquad filter type and should be used if the simplified equations are not suitable. Any filter type utilizing the BP+ input is not available with the RU5622A. Detailed programming instructions for each filter type are described below.

### 1. General Design Procedure

- Select  $f_o$ ,  $f_c$ , Q, and  $f_z$  (if required).
  - Calculate the " $K_1$ " values using the desired  $f_o$ ,  $f_c$ .
  - Calculate the " $K_2$ " values using the desired Q, plus  $K_1$ .
  - Select values for  $R_1$  and  $R_4$  in accordance with the resistor limits in Table 4.
- Note: (1) For elliptic low-pass filters, calculate the " $K_3$ " values using the desired  $f_z$ ,  $f_o$ .  
 (2) For elliptic high-pass filters, calculate values for  $R_1$  and  $R_2$  before calculating the values of  $R_3$  and  $R_6$ .
- Calculate  $R_3$  and  $R_6$  using the "K" values determined in Steps B and C.

**Note:** All programming schematics are for a single section only. Repeat as required.



Note:  $f_c/f_o \geq 36$

For lowpass, lowpass elliptical, highpass elliptical, all pass and notch filters. This limitation due to the particular ratio of  $R_1$  and  $R_2$  and allows realizable values of  $R_3$ . Other minimum values of  $f_c/f_o$  can be obtained by using other values of  $R_1$  and  $R_2$  in the basic biquad equations.

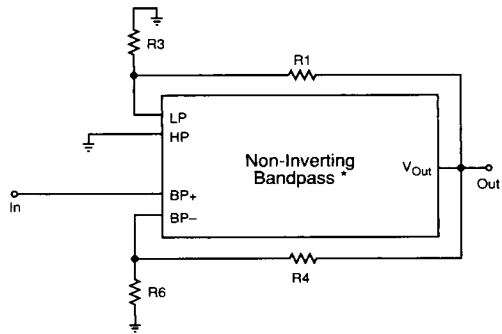
Assumptions: <sup>1</sup>  $R_1 = R_2$ ; DC Gain = Unity

$$f_o = \sqrt[3]{K_1''} \cdot \frac{f_c}{25} \quad K_1'' = \frac{R_3}{R_1 + 2R_3}$$

$$Q = \frac{\sqrt[3]{K_1''}}{K_2'} \quad K_2' = \frac{R_6}{R_4 + R_6}$$

### Note:

- If a gain other than unity is desired then gain =  $R_1 / R_2$  and  $K_1$  from the biquad equations should be substituted for  $K_1''$



$$\text{Gain}^1 = \frac{1}{K_2'}$$

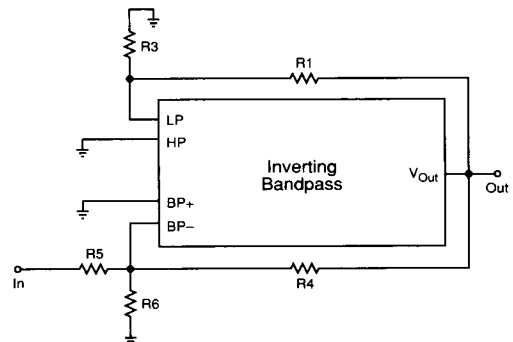
$$f_o = \sqrt[3]{K_1'} \cdot \frac{f_c}{25} \quad K_1' = \frac{R_3}{R_1 + R_3}$$

$$Q = \frac{\sqrt[3]{K_1'}}{K_2'} \quad K_2' = \frac{R_6}{R_4 + R_6}$$

### Note:

- Gain may be adjusted independent of Q using the resistor divider described by  $K_5$  from the biquad equations. Use the  $K_5$  equation in place of  $K_2'$  for the gain equation only.

\* Not available on RU5622A



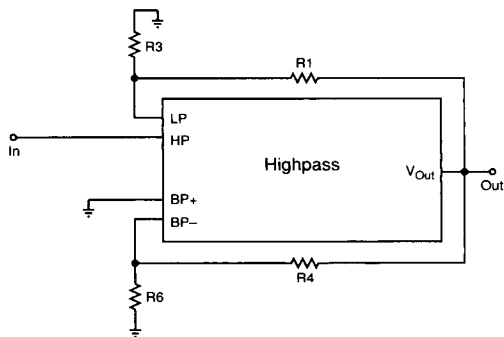
Assumptions: <sup>1</sup>  $R_4 = R_5$ ; Gain = Unity

$$f_o = \sqrt[3]{K_1''} \cdot \frac{f_c}{25} \quad K_1'' = \frac{R_3}{R_1 + R_3}$$

$$Q = \frac{\sqrt[3]{K_1''}}{K_2''} \quad K_2'' = \frac{R_6}{R_4 + 2R_6}$$

### Note:

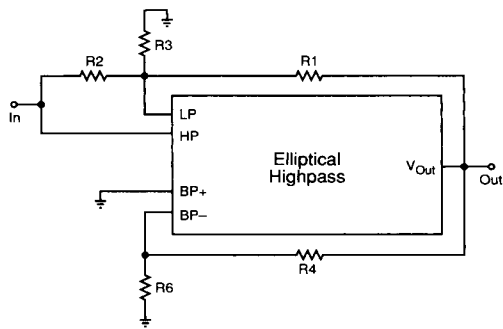
- For gains not equal to unity, gain =  $R_4/R_5$  and  $K_2''$  should be replaced with  $K_2$  from the biquad equations.



Gain = Unity

$$f_o = \sqrt{K_1'} \cdot \frac{f_c}{25} \quad K_1' = \frac{R_3}{R_1 + R_3}$$

$$Q = \frac{\sqrt{K_1'}}{K_2'} \quad K_2' = \frac{R_6}{R_4 + R_6}$$



Gain<sup>1</sup> = Unity

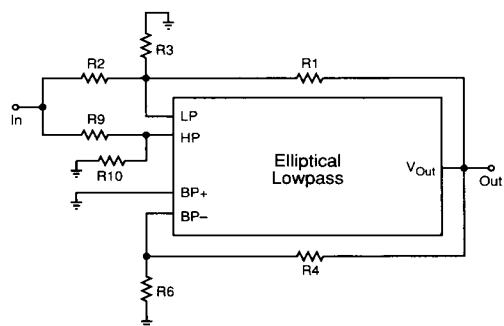
$$f_o = \sqrt{K_1'} \cdot \frac{f_c}{25} \quad K_1 = \frac{R_2 R_3}{R_1 R_2 + R_1 R_3 + R_2 R_3}$$

$$Q = \frac{\sqrt{K_1}}{K_2'} \quad K_2' = \frac{R_6}{R_4 + R_6}$$

$$f_z = \sqrt{\frac{R_1}{R_2}} \cdot f_o$$

**Note:**

<sup>1</sup> For this case only, the resistor value  $R_1$  and  $R_2$  should be determined for  $f_z$  before the resistor values for  $f_o$  ( $R_3$ ) are calculated.



DC Gain<sup>1</sup> = Unity;  $R_1 = R_2$

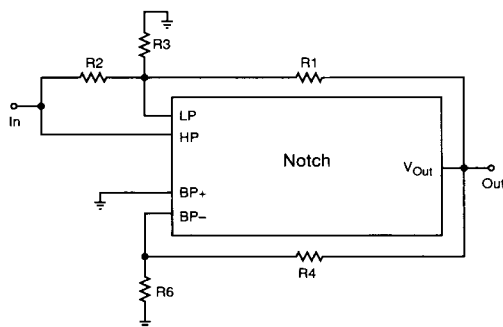
$$f_o = \sqrt{K_1''} \cdot \frac{f_c}{25} \quad K_1'' = \frac{R_3}{R_1 + 2R_3}$$

$$Q = \frac{\sqrt{K_1''}}{K_2'} \quad K_2' = \frac{R_6}{R_4 + R_6}$$

$$f_z = \sqrt{\frac{1}{K_3}} \cdot f_o \quad K_3 = \frac{R_{10}}{R_9 + R_{10}}$$

**Note:**

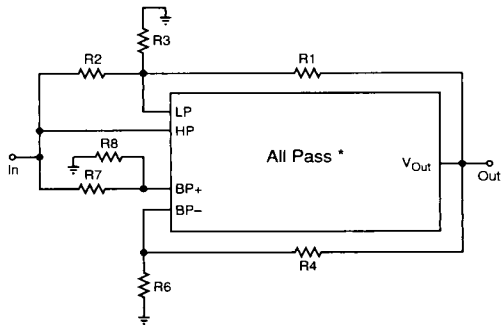
<sup>1</sup> For gain other than unity, gain =  $R_1/R_2$  and  $K_1$  should be substituted for  $K_1''$ . The  $\sqrt{1/K_3}$  term should also be multiplied times the gain



Gain = Unity;  $R_1 = R_2$

$$f_o = \sqrt{K_1''} \cdot \frac{f_c}{25} \quad K_1'' = \frac{R_3}{R_1 + 2R_3}$$

$$Q = \frac{\sqrt{K_1''}}{K_2'} \quad K_2' = \frac{R_6}{R_4 + R_6}$$

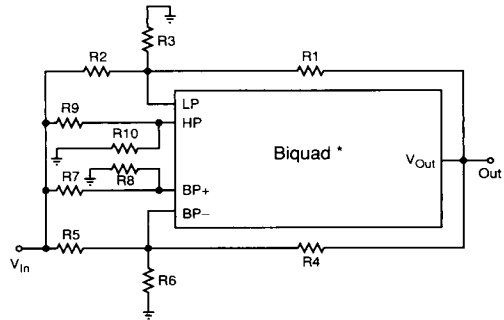


Gain = Unity;  $R_1 = R_2$ ;  $R_7 = R_4$ ;  $R_8 = R_6$

$$f_o = \sqrt{K_1''} \cdot \frac{f_c}{25} \quad K_1'' = \frac{R_3}{R_1 + 2R_3}$$

$$Q = \frac{\sqrt{K_1''}}{K_2'} \quad K_2' = \frac{R_6}{R_4 + R_6}$$

\* Not available on the RU5622A



The biquad is the most general purpose filter type. By adjusting the values of  $K_1$  through  $K_6$ , virtually any second-order transfer function can be achieved. In some cases it may be necessary to use an inverting op amp to achieve the correct polarity on these constants.

\*The term defined by  $K_5$  is not available on the RU5622A

$$V_{Out} = \frac{V_{In} \left( -K_3 s^2 - K_4 s \frac{f_c}{4} + K_5 s \frac{f_c}{4} - K_6 \frac{f_c^2}{16} \right)}{\left( s^2 + K_2 s \frac{f_c}{4} + K_1 \frac{f_c^2}{16} \right)}$$

$$K_1 = \frac{R_2 R_3}{R_1 R_2 + R_1 R_3 + R_2 R_3}$$

$$K_4 = \frac{R_4 R_6}{R_4 R_5 + R_4 R_6 + R_5 R_6}$$

$$K_2 = \frac{R_5 R_6}{R_4 R_5 + R_4 R_6 + R_5 R_6}$$

$$K_5 = \frac{R_8}{R_7 + R_8}$$

$$K_3 = \frac{R_{10}}{R_9 + R_{10}}$$

$$K_6 = \frac{R_1 R_3}{R_1 R_2 + R_1 R_3 + R_2 R_3}$$

**Table 1. Absolute Maximum/Minimum Ratings**

	Min	Max	Units
Input voltage – any terminal with respect to substrate ( $V_{SS}$ )	-0.4	21	V
Output short – circuit duration – any terminal	Indefinite		
Operating temperature	0	70	°C
Storage temperature	-55	125	°C
Lead temperature (Soldering 10 sec)		300	°C

**CAUTION:** Observe MOS Handling & Operating Procedures

**NOTE:** This table shows stress ratings *exclusively*: functional operation of this product under any conditions beyond those listed under standard operating conditions is not suggested by the table. Permanent damage may result if the device is subject to stresses beyond these absolute min/max values. Moreover, reliability may be diminished if the device is run for protracted periods at absolute maximum values.

Although devices are internally gate-protected to minimize the possibility of static damage, MOS handling precautions should be observed. Do not apply instantaneous supply voltages to the device or insert or remove device from socket while under power. Use decoupling networks to suppress power supply turn-off/on switching transients and ripple. Applying AC signals or clock to device with power off may exceed negative limit.

**Table 2. Device Characteristics & Operation Range Limits <sup>1</sup>**

Parameter	Conditions & Comments	Sym	Min	Typ	Max	Units
Supply voltages		V <sub>DD</sub>	+5		+10	V
		V <sub>SS</sub>	-5		-10	V
Input bias current		I <sub>B</sub>		0.1		μA
Quiescent current <sup>2</sup>						
RU5621A	No load +5V	I <sub>Q</sub>		2.5		mA
	±10V			4.0	10	mA
RU5622A	±5V			4		mA
	±10V			6.5	12	mA
Clock frequency	f <sub>clock</sub> = f <sub>sample</sub>	f <sub>c</sub>	0.250 <sup>3</sup>		750 <sup>4</sup>	kHz
Clock pulse width	Ext. drive	t <sub>cp</sub>	50% duty cycle square wave			
Input clock levels		V <sub>IL</sub>	V <sub>SS</sub>		0.8	V
		V <sub>IH</sub>	2.0		V <sub>DD</sub>	V
Output signal <sup>3</sup>		V <sub>o</sub>			14	V <sub>p-p</sub>
Center/corner	R <sub>L</sub> ≥ 10KΩ					
frequency range		f <sub>o</sub>	2.5 <sup>3</sup>		30,000 <sup>4</sup>	Hz
Q-Range			0.5		500	
Input impedance		R <sub>i</sub>		1		MΩ
Load impedance			10			KΩ
Output impedance	Small-signal	R <sub>o</sub>		10	250	Ω
Output offset	RU5621A	V <sub>off</sub>		100	200	mV
voltage(s) <sup>5</sup>	RU5622A			20	200	mV

**Notes:**

- <sup>1</sup> V<sub>DD</sub> = 10V, V<sub>SS</sub> = -10V, f<sub>c</sub>/f<sub>o</sub> = 50  
Q = 1, f<sub>c</sub> = 50 kHz, 25°C  
<sup>2</sup> Increase 15% for operation at 0°C  
<sup>3</sup> Performance degrades at temperatures above 25°C  
<sup>4</sup> For low Q values only (≤2). High Q values for center frequencies below 20 kHz and sample rates below 500 kHz  
<sup>5</sup> For f<sub>c</sub>/f<sub>o</sub> ≤ 100:1

**Table 3. Performance Standards <sup>1</sup>**

Parameter		Sym	Min	Typ	Max	Units
Output noise <sup>1</sup>	RU5621A			0.240	3	mV <sub>rms</sub>
	RU5622A				1.5	mV <sub>rms</sub>
Power supply rejection	V <sub>SS</sub>	PSRR	10			dB
ratio <sup>1</sup>	V <sub>DD</sub>		30			dB
Dynamic range <sup>1</sup>		DR		96		dB
Total harmonic distortion <sup>1</sup>		THD			-56	dB
@ f <sub>o</sub> = 1 kHz						
Crosstalk	RU5621A				-60	dB
	RU5622A				-45	dB
Clock feedthrough				30	45	mV <sub>rms</sub>

**Note:**

- <sup>1</sup> Measured with ±10V supplies, Q = 1,  
f<sub>c</sub>/f<sub>o</sub> = 50, f<sub>c</sub> = 50 kHz. Performance will degrade with higher Qs and lower or higher  
f<sub>c</sub>/f<sub>o</sub>. Dynamic range is P-P signal to RMS noise.

Table 4. Resistor Limits

Resistor	Min	Max
R <sub>1</sub>	20K	100K
R <sub>2</sub>	*	∞
R <sub>3</sub>	0	∞
R <sub>4</sub>	20K	100K
R <sub>5</sub>	*	∞
R <sub>6</sub>	0	∞
R <sub>7</sub>	*	100K
R <sub>8</sub>	0	∞
R <sub>9</sub>	*	100K
R <sub>10</sub>	0	∞

\* Value depends on driving capability of external circuitry. If preceding stage is an RU5621A or RU5622A, then the minimum is 20KΩ.

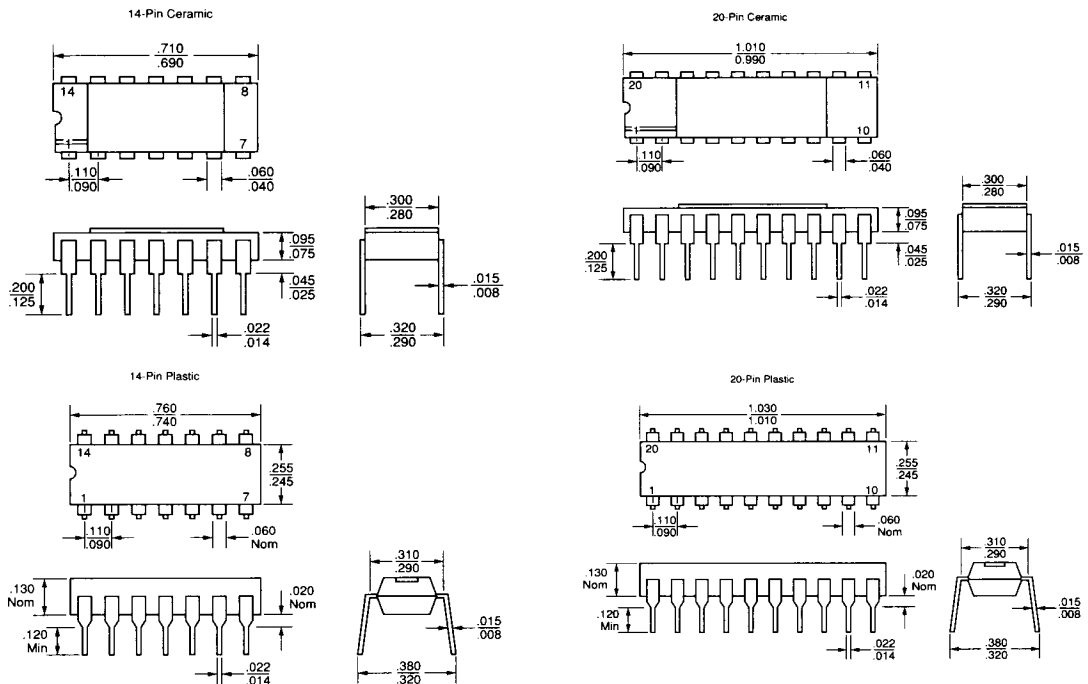


Figure 5. Package Dimensions

**Ordering Information**

Part Number	Description
RU5621ANP-011	Resistor-programmable switched-capacitor filter, 2 2nd-order stages, 14-pin plastic package
RU5621ANB-011	Resistor-programmable switched-capacitor filter, 2 2nd-order stages, 14-pin ceramic package
RU5622ANP-011	Resistor-programmable switched-capacitor filter, 4 2nd-order stages, 20-pin plastic package
RU5622ANB-011	Resistor-programmable switched-capacitor filter, 4 2nd-order stages, 20-pin ceramic package

**055-0108**  
**September 1991**