EG&G RETICON

RU5621A/RU5622A
RU5621A 4-Pole Resistor Programmable
RU5622A 8-Pole Resistor Programmable
Universal Active Filters

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: ±5V to ±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 ≤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.

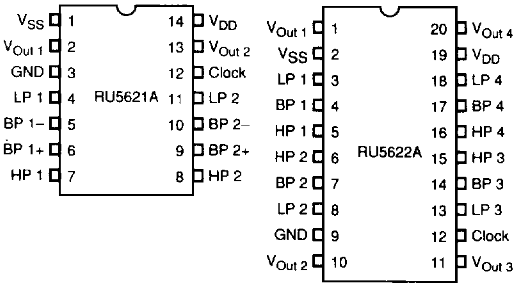
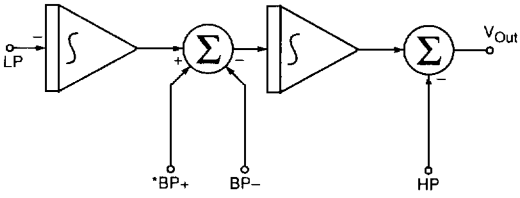


Figure 1. Pinout Configurations

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 10KΩ 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 100KΩ 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 Qs (>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 ±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_{rms} 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.

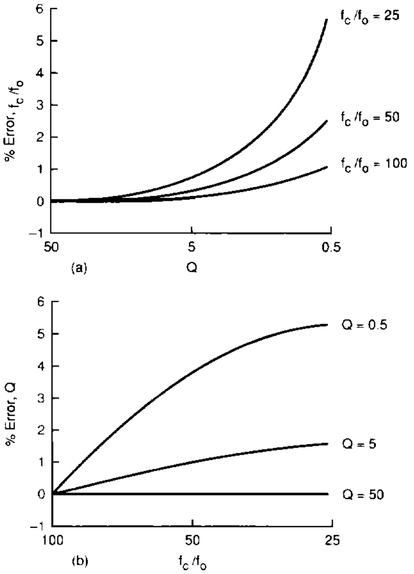
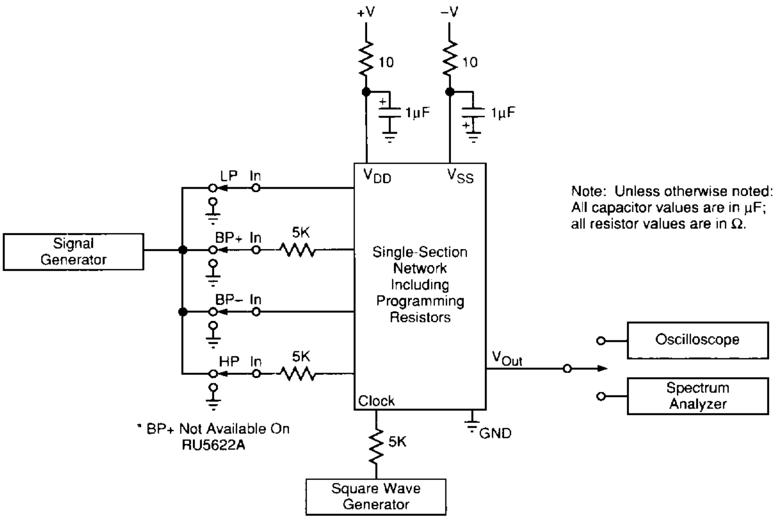


Figure 4. Programming Errors



Note: Unless otherwise noted:
All capacitor values are in µF;
all resistor values are in Ω.

* BP+ Not Available On RU5622A

Note: The following should be applied in test and production circuits as applicable (see Table 1).

1) Power supply resistors may be required for transient protection.
2) Input and trigger resistors are required if signals or trigger may be applied with power off, and there is not a resistor already in series with the input or trigger.

Figure 3. Test Circuit (Single Section)

Transfer Functions

Low-pass :

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

Bandpass :

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

High-pass :

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

Lowpass Elliptic :

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

Highpass Elliptic :

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

Notch :

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

All Pass :

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

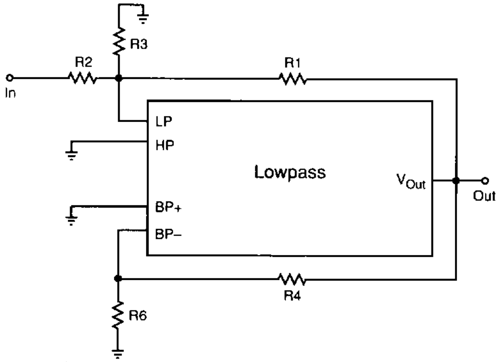
Design Procedure

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
   - A. Select f_o, f_c, Q, and f_z (if required).
   - B. Calculate the "K_1" values using the desired f_o, f_c.
   - C. Calculate the "K_2" values using the desired Q, plus K_1.
   - D. 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.
   - E. 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.

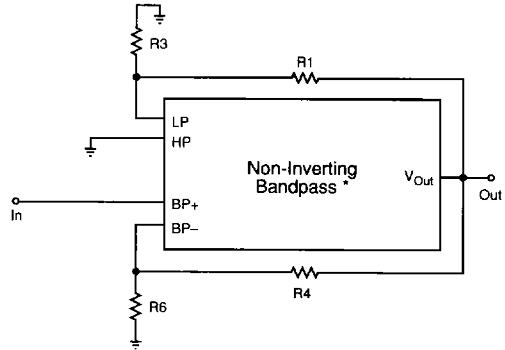
Assumptions: [1] $R_1 = R_2$; DC Gain = Unity

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

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

Note:

[1] 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''



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

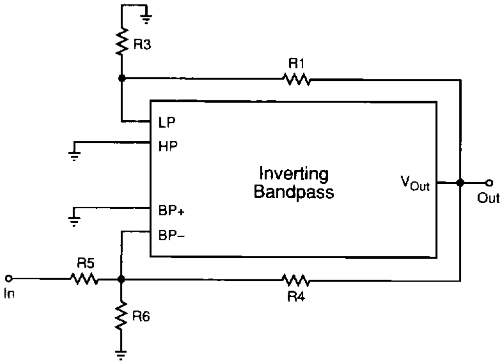
$$f_o = \sqrt{K_1'} \cdot \frac{f_c}{25} \qquad K_1' = \frac{R_3}{R_1 + R_3}$$

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

Note:

[1] 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



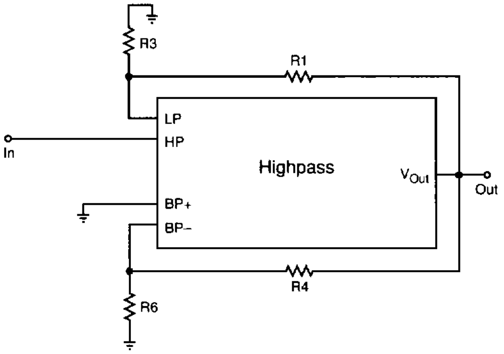
Assumptions: [1] $R_4 = R_5$; Gain = Unity

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

$$Q = \frac{\sqrt{K_1'}}{K_2''} \qquad K_2'' = \frac{R_6}{R_4 + 2R_6}$$

Note:

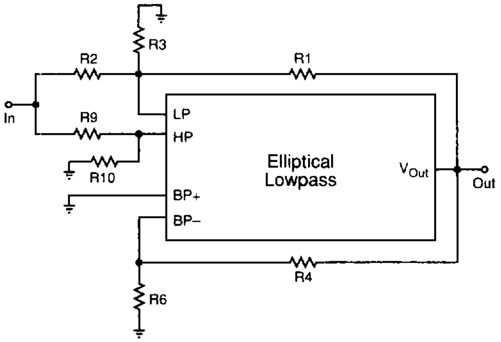
[1] For gains not equal to unity, gain = R_4/R_5 and K_2'' should be replaced with K_2 from the biquad equations.



Gain = Unity

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

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



DC Gain[1] = Unity; $R_1 = R_2$

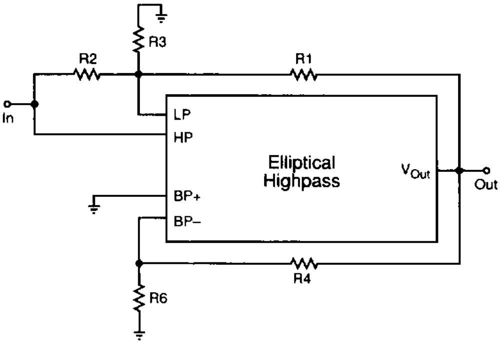
$$f_o = \sqrt{K_1''} \cdot \frac{f_c}{25} \qquad K_1'' = \frac{R_3}{R_1 + 2R_3}$$

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

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

Note:

[1] 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[1] = Unity

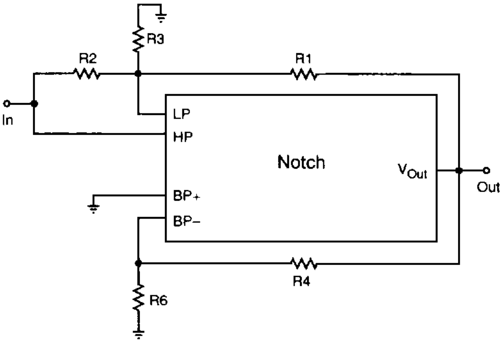
$$f_o = \sqrt{K_1} \cdot \frac{f_c}{25} \qquad K_1 = \frac{R_2 R_3}{R_1 R_2 + R_1 R_3 + R_2 R_3}$$

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

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

Note:

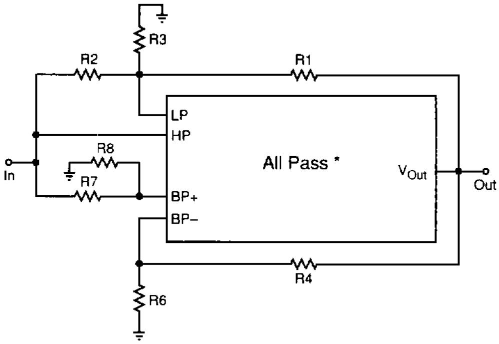
[1] For this case only, the resistor value R_1 and R_2 should be determined for f_z before the resistor values for f_o (R_3) are calculated.



Gain = Unity; $R_1 = R_2$

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

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

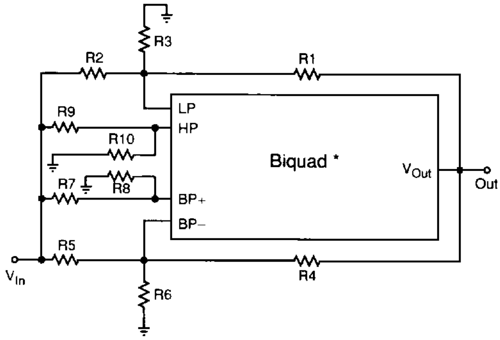


Gain = Unity; $R_1 = R_2$; $R_7 = R_4$; $R_8 = R_6$

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

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

* 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

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

$$K_1 = \frac{R_2 R_3}{R_1 R_2 + R_1 R_3 + R_2 R_3} \qquad K_4 = \frac{R_4 R_6}{R_4 R_5 + R_4 R_6 + R_5 R_6}$$

$$K_2 = \frac{R_5 R_6}{R_4 R_5 + R_4 R_6 + R_5 R_6} \qquad K_5 = \frac{R_8}{R_7 + R_8}$$

$$K_3 = \frac{R_{10}}{R_9 + R_{10}} \qquad K_6 = \frac{R_1 R_3}{R_1 R_2 + R_1 R_3 + R_2 R_3}$$

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[1]

Parameter	Conditions & Comments	Sym	Min	Typ	Max	Units
Supply voltages		V_{DD}	+5		+10	V
		V_{SS}	–5		–10	V
Input bias current		I_B		0.1		µA
Quiescent current[2]						
RU5621A	No load +5V	I_Q		2.5		mA
	±10V			4.0	10	mA
RU5622A	±5V			4		mA
	±10V			6.5	12	mA
Clock frequency	$f_{clock} = f_{sample}$	f_c	0.250[3]		750[4]	kHz
Clock pulse width	Ext. drive	t_{cp}	50% duty cycle square wave			
Input clock levels		V_{IL}	V_{SS}		0.8	V
		V_{IH}	2.0		V_{DD}	V
Output signal[3]	$R_L \geq 10K\Omega$	V_o			14	$V_{p\text{-}p}$
Center/corner frequency range		f_o	2.5[3]		30,000[4]	Hz
Q-Range			0.5		500	
Input impedance		R_i		1		MΩ
Load impedance			10			KΩ
Output impedance	Small-signal	R_o		10	250	Ω
Output offset voltage(s)[5]	RU5621A	V_{off}		100	200	mV
	RU5622A			20	200	mV

Notes:

[1] $V_{DD} = 10V$, $V_{SS} = -10V$, $f_c/f_o = 50$
$Q = 1$, $f_c = 50$ kHz, 25°C

[2] Increase 15% for operation at 0°C

[3] Performance degrades at temperatures above 25°C

[4] For low Q values only (≤2). High Q values for center frequencies below 20 kHz and sample rates below 500 kHz

[5] For $f_c/f_o \leq 100:1$

Table 3. Performance Standards[1]

Parameter		Sym	Min	Typ	Max	Units
Output noise[1]	RU5621A			0.240	3	mV_{rms}
	RU5622A				1.5	mV_{rms}
Power supply rejection ratio[1]	V_{SS}	PSRR	10			dB
	V_{DD}		30			dB
Dynamic range[1]		DR		96		dB
Total harmonic distortion[1] @ $f_o = 1$ kHz		THD			–56	dB
Crosstalk	RU5621A				–60	dB
	RU5622A				–45	dB
Clock feedthrough				30	45	mV_{rms}

Note:

[1] Measured with ±10V supplies, Q = 1,
$f_c/f_o = 50$, $f_c = 50$ kHz. Performance will degrade with higher Qs and lower or higher f_c/f_o. Dynamic range is P-P signal to RMS noise.

Table 4. Resistor Limits

Resistor	Min	Max
R_1	20K	100K
R_2	*	∞
R_3	0	∞
R_4	20K	100K
R_5	*	∞
R_6	0	∞
R_7	*	100K
R_8	0	∞
R_9	*	100K
R_{10}	0	∞

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

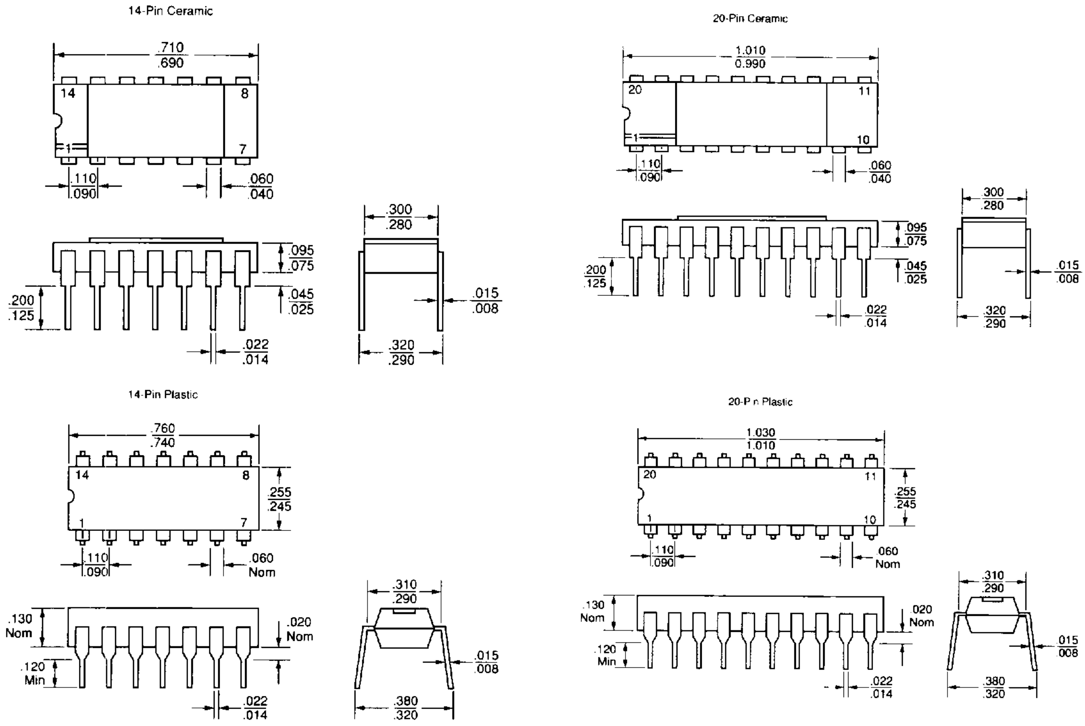


Figure 5. Package Dimensions

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