Description

The RU5620A is a digitally-programmable Universal Active Filter (UAF). It is implemented using Reticon's proven double-poly NMOS switched-capacitor filter technology. It consists of a single second-order section with Q and f_0 programmable by separate 5-bit digital control words. Basic filter types are selected by hard-wiring or switch-selecting the filter inputs. Higher-order filters can be obtained by cascading RU5620A devices. This cascadability, microprocessor control, and universality make the RU5620A an ideal, cost effective filter building block. The pinout configuration is shown in Figure 1, a block diagram is shown in Figure 2, and package dimensions are in Figure 13.

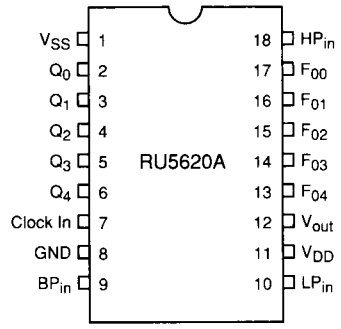

Figure 1. Pinout Configuration

Key Features

- Universal: Implement any classical filter
- Easy to use: No external components required
- Look up table responses: No calculations required
- Q and f_0 independently programmed
- Clock and control lines are TTL- and CMOS-compatible
- Small size: 18-pin DIP
- Low current consumption: Typically 4.5 mA
- Wide supply voltage range : ±5V to ±10V

Filter Types Available

- Low-pass
- Bandpass
- High-pass
- Low-pass elliptical *
- High-pass elliptical *
- Notch
- All Pass

* These modes require external resistors

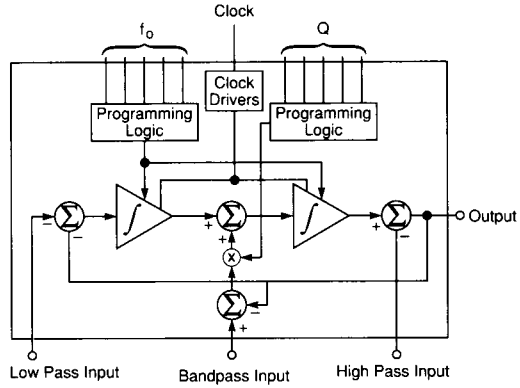

Figure 2. Functional Block Diagram

Device Operation

The Q and center frequency response of the filter are controlled by seperate 5-bit digital inputs which may be microprocessor-controlled or hard-wired. The clock-to-center frequency ratio (f_c/f_0) can be varied from 50 to 200 in 32 logarithmic increments. The Q values are selectable in 32 approximately logarithmic increments, ranging from 0.57 to 85. The typical filter responses can be chosen from Table 5, thus avoiding the cumbersome calculations and external components that other UAF devices require. The filter type is chosen by hard-wire programming the filter inputs as shown in Table 4. For optimum performance, all unused inputs should be grounded.

Operational Considerations

Plots of typical amplitude, group delay, and phase responses for a second-order continous-time analog filter are shown in Figures 6 through 10. The RU5620A uses switched-capacitors to make an excellent simulation of such filters. Some additional comments on filter response can facilitate design. (Please note that items a through d are true for any second-order analog filter.)

a. Band pass and notch characteristics are most easily defined by the relation Q = f_0/BW, where BW = bandwidth measured across the -3 dB point.

b. Beyond the -3 dB points, the rolloff rate is very dependent on Q and filter type (i.e., Butterworth, Chebyshev, Cauer, etc). The type dependency on rolloff rate is evident only if a filter is made by cascading sections.

   For a single second order section and for low Q values (i.e.,Q<1), the "classical" asymptotic rolloff rate is established as 6 dB/octave (20 dB/decade) for bandpass filters and 12 dB/octave (40 dB/decade) for non-elliptic low-pass and high-pass filters. For more exact information, refer to Figure 6 through Figure 8.

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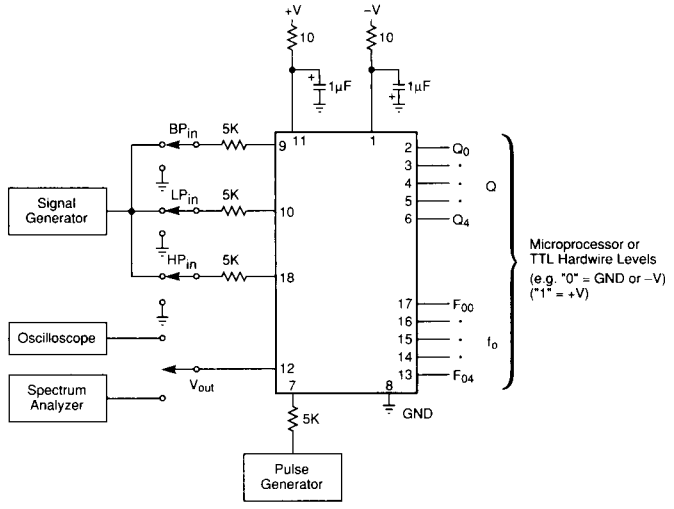


Figure 3. Test Circuit

c. Group delay is defined as the negative of the derivative of phase with respect to (angular) frequency, GD = - dø/dω. Approximations can be derived from the phase plot (arctangent of the transfer function) of Figure 10 in conjuction with the formula GD = -(Δø/360°)/2πΔf). For a small incremental change in frequency (Δf), this calculation is the slope of the curve on the phase plot at any given frequency. Plots of these calculations are shown in Figure 9. A practical alternative to this is to measure the envelope delay of a burst of oscillation. Often in signalling circuits, the relative group delay difference between two points in the passband is more important than the maximum absolute time delay through the filter.

d. Another time domain parameter is that of step response. The time required to settle or rise to 95% of a final output value is approximately Q(1/f_0). Often this parameter is referred to as the filter settling time (not to be confused with op amp settling time). The most common application of this calculation occurs when either Q or f_0 programming is changed (i.e., a step input) and it is important to know how long before the output reflects the new programmed parameters.

e. Notch operation is not recommended for Q values grater than 20. A notch depth of -40 dB is typical and can be -50 dB to -60 dB for low values of Q.

Transfer Functions

The simplified RU5620A transfer function contains the terms for any filter type:

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

If a single type is desired , the other input pins are AC grounded, which is the same as multiplying the appropriate transfer function terms by zero. An all-pass filter is implemented if all three inputs are used. For the all-pass filter, the amplitude response is unity for all frequencies and the phase shift is adjustable by varying f_0 relative to a fixed frequency. To realize a notch filter, the bandpass input is grounded and the low pass and high pass inputs are tied together. The resistor implemented low pass and high pass elliptical configurations are shown in Figure 4 and Figure 5. The transfer function equations for the major filter types are shown below.

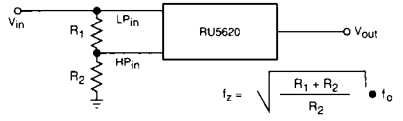


Figure 4. Low-pass Elliptic Filter

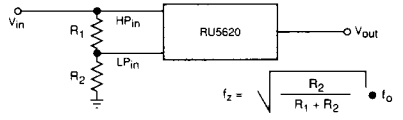


Figure 5. High-pass Elliptic Filter

Low-pass

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

Lowpass Elliptical

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

High-pass

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

Highpass Elliptical

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

Bandpass

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

All Pass

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

Notch

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

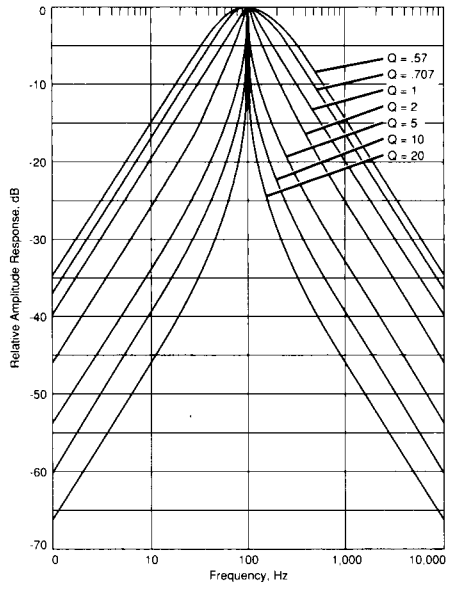


Figure 6. Typical Bandpass Amplitude Response

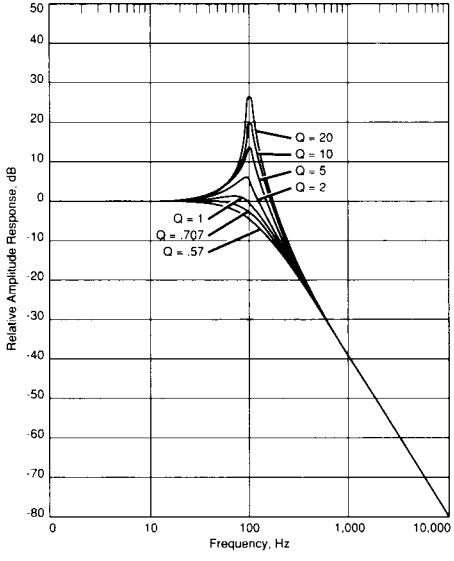


Figure 7. Typical Low Pass Amplitude Response

Practical Considerations

Tolerances - Design tolerances for f_C/f_O and Q are typically ±1.5% and ±10%, respectively. Device-to-device variations dominate these tolerances since the typical temperature coefficient for f_C/f_O is between 20-50 ppm/°C at $f_O \leq 10$ kHZ. The design values of f_C/f_O may be more closely realized by utilizing the digital control words on the appropriate side of the design value. Another common method of adjusting the f_C/f_O ratio is to vary the master clock by the desired amount. This latter method is particularly helpful when evaluating the phase shift (measured at any given frequency in the pass band) due to device-to-device or temperture variations.

Aliasing and Reconstruction - If signals or noise exist in the input signal near the sample rate or its harmonics, pre-filtering may be required to ensure that the difference (lower side band or beat) frequency(ies) don't fall or alias into the pass band. Since f_C/f_O ratios of SCF's are relatively quite large, this can usually be accomplished with a simple RC filter. Typically, the corner frequency of the RC filter is chosen to be 2 to 10 times the corner frequency of the pass band.

In general, it is not necessary to provide antialias filtering between cascaded sections that have the same sample rates. Exceptions are cascaded high pass sections, or low pass sections when DC offset shifts are critical.

Post-filtering with an RC filter can minimize sample rate feedthrough (typically 30 mV_{rms}) and can serve as a reconstruction or smoothing filter for the staircase/sampled-data output waveform. Using an RC corner frequency of less than 10 times the pass band corner frequency (f_O) will improve antialiasing and reconstruction characteristics but will increase the risk of modifying pass band amplitude and phase performance.

Second-Order Effects - Departures from the programmed values of f_C/f_O and Q are to be expected at low values of Q and f_C/f_O. Primarily these reflect the differences (mainly the need for compensation for the curved mapping of the $j\omega$-axis into the z-domain) between the s-domain used in state-variable filter analysis and the z-domain used to model the sampled-data nature of SCF's. Typical effects of the interdependency of Q and f_C/f_O are shown in Figure 12a and 12b. Table 5 already includes the necessary correction factors for Q as a function of f_C/f_O. Neither the table nor the figure include Q and f_C/f_O error tolerances.

Active Element Limitations - Footnote 3 of Table 2 alludes to temperature-dependent parameters of leakage current and transconductance. For example, leakage current roughly doubles for every 7°C rise in temperature. Thus to maintain a given leakage current level, the clock frequency and the corresponding f_C/f_O should be changed by the same proportion. The maximum frequency limit for both parameters, for either high or low Q's, should be lowered by approximately 20% when operating at 70°C.

For an insertion loss of less than 1 dB, the load impedance should be more than 1000 times the output impedance. When cascading sections there is generally no problem, since for almost all filter configurations and programming, the input impedance is several megohms. Exceptions occur for some low pass and bandpass modes where the impedance may fall to 480KΩ.

Sources of noise such as harmonic distortion, clock feedthrough, and power supply ripple can generally be removed by various means. Noise that cannot be removed is labeled output noise in Table 3, which is broadband to1/2 of the sample rate.

There are trade-offs between selecting a maximum f_C/f_O and the gain of the internal op-amps at the upper frequency range. To avoid detailed calculations, it is recommended to use an f_C/f_O that is 75% of maximum.

Double-poly NMOS capacitors are extremely stable over temperature. However, the impedances of parasitic capacitances (which affect clock feedthrough and power supply ripple rejection noise contributions) will vary in amplitude as a function of clock frequency or the frequency content of the power supply ripple. Filtering of the power supply lines will minimize ripple noise and will help protect the device from random power line transients, including power-up spikes.

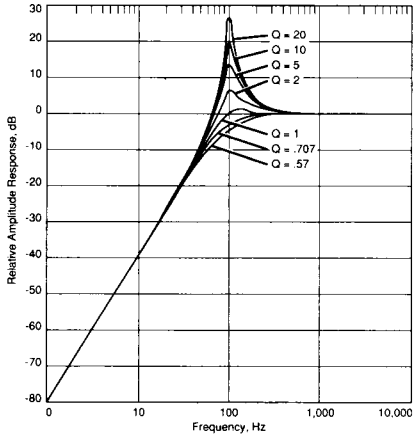


Figure 8. Typical High Pass Amplitude Response

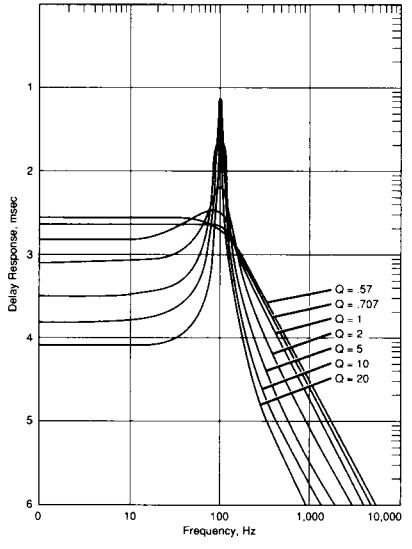


Figure 9. Typical Delay Responses (Bandpass, Low Pass, High Pass)

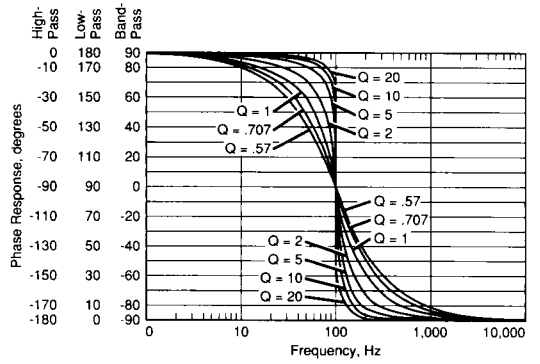


Figure 10. Typical Phase Response

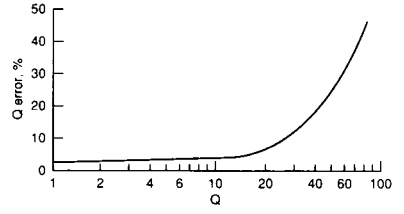


Figure 11. Typical Q Error as a Function of Q

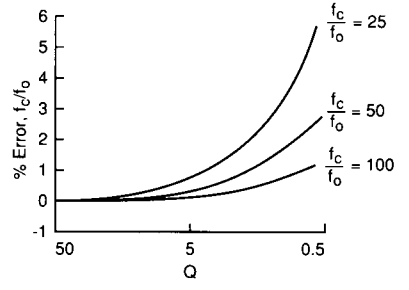


Figure 12a. Typical f_O Error as a Function of Q

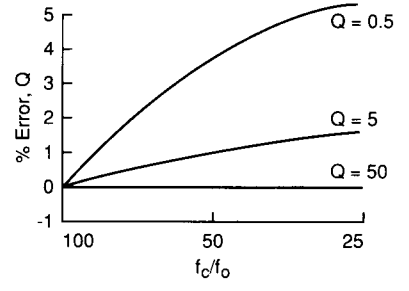


Figure 12b. Typical Q Error as a Function of f_C/f_O

Table 1. Absolute Maximum/Minimum Ratings *

Parameter	Min	Max	Units
Input voltage - any terminal with respect to substrate pin 1 (V_{SS})	-0.4	21	V
Output short circuit duration - any terminal		Indefinite	
Input/Output current - any terminal (externally forced)		10	mA
Storage temperature	-55	125	°C
Operating temperature	0	70	°C
Lead temperature (soldering, 10 sec)		300	°C

Caution: Observe MOS Handling and Operating Procedures

* Continued operation at these limits may cause permanent damage.

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 and Comments	Symbol	Min	Typ	Max	Units
Supply voltages		V_{DD}	+5		+10	V
		V_{SS}	-5		-10	V
Quiescent current [2]	No load	I_{DD}		4.5	10	mA
		I_{SS}		-4.5	-10	mA
Clock frequency [4]	$f_c = 2(f_s)$	f_c	0.5		1250	kHz
Clock pulse width		T_{cp}	200		$10^9/f_c$-200	nsec
Digital input level		V_{IL}	V_{SS}		0.8	V
(clock, Q, and f_c/f_o control)		V_{IH}	2.0		V_{DD}	V
Output signal [3]	$R_L \geq 10K$	V_o		10	12	V_{p-p}
Center/Corner frequency range [3]		f_o	10	See Table 5	20,000	Hz
Q-Range			0.57		85	
Input impedance		R_i		10		MΩ
		C_i			10	pF
Load impedance			10			KΩ
					50	pF
Output impedance	Small signal	R_o		10-100		Ω
Output offset voltage		V_{off}		50		mV

Notes:
1 V_{DD} = +10V, V_{SS} = -10V, T = 25°C
2 Increase 15% for operation to 0°C
3 Performance degrades at temperatures above 25°C
4 For low value Q's, operation 2 MHz for f_c is possible

Table 3. Performance Standards [1]

Parameter	Conditions and Comments	Symbol	Min	Typ	Max	Units
Output noise	BW = $f_s/2$	e_n		0.27		mV_{rms}
Dynamic range	V_o/e_n Q = 1	DR		94		dB
	Q = 40			84		dB
Total harmonic distortion	f_{in} = 1 kHz, V_{in} = 4.95 V_{rms} Q = 1.05, f_c = 200 kHz	THD			-0.5	%
Insertion loss	f_c/f_o = 200, f_c = 1 MHz, V_{in} = 2 V_{rms}		+2	0	-2	dB
Clock feedthrough				30	60	mV_{rms}

Note:
1 Measured with ±10V supplies, T = 25°C

Table 4. Filter Select Table

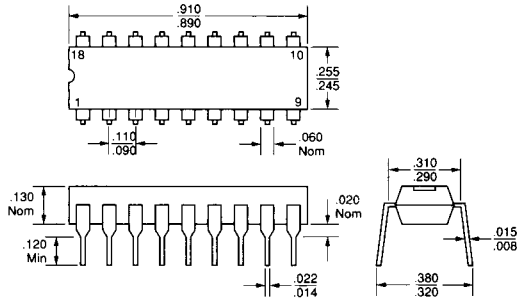
Filter Type	Connections		
	LP_{in}	HP_{in}	BP_{in}
Low pass	V_{in}	GND	GND
High pass	GND	V_{in}	GND
Bandpass	GND	GND	V_{in}
Notch	V_{in}	V_{in}	GND
All pass	V_{in}	V_{in}	V_{in}

Table 5. Q, f_c/f_o Programming Table (Typical Values)

Q [1]	Code	f_c/f_o	Code
(30% +10%)	Q4...Q0	(±3% max)	F04...F00
.57	00000	200.0	00000
.65	00001	191.3	00001
.71	00010	182.9	00010
.79	00011	174.9	00011
.87	00100	167.2	00100
.95	00101	159.9	00101
1.05	00110	152.9	00110
1.2	00111	146.2	00111
1.35	01000	139.8	01000
1.65	01001	133.7	01001
1.95	01010	127.9	01010
2.2	01011	122.3	01011
2.5	01100	116.9	01100
3.0	01101	111.8	01101
3.5	01110	106.9	01110
4.25	01111	102.3	01111
5.0	10000	97.8	10000
5.8	10001	93.5	10001
7.2	10010	89.4	10010
8.7	10011	85.5	10011
10.0	10100	81.8	10100
11.5	10101	78.2	10101
12.0	10110	74.8	10110
13.5	10111	71.5	10111
15.5	11000	68.4	11000
17.5	11001	65.4	11001
20.0	11010	62.5	11010
24.0	11011	59.8	11011
30.0	11100	57.2	11100
35.0	11101	54.8	11101
55.0	11110	52.3	11110
85.0	11111	50.0	11111

Note:
[1] See Figure 11

18-pin Plastic



18-pin Ceramic

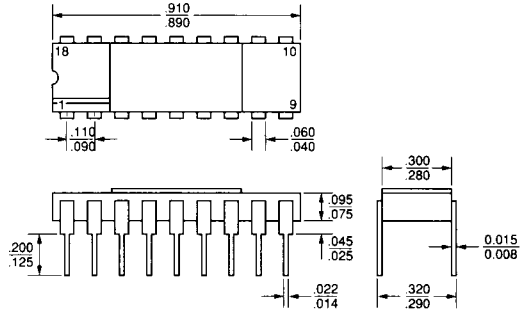


Figure 13. Package Dimensions

Ordering Information

Part Number	Description
RU5620ANP-011	Digitally-programmable second-order switched-capacitor filter section, plastic package
RU5620ANB-011	Digitally-programmable second-order switched-capacitor filter section, ceramic package

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