MX•COM, INC. MiXed Signal ICs

APPLICATION NOTE

Tone Generation - An Application of the MX105A

This Application Note describes how to configure an MX105A as a tone generator. It may be helpful to refer to the current MX105A data sheet before reading this document. The MX105A was primarily designed as a tone detector with user configurable center frequency, detection band width and response/de-response time (refer to the MX105A data sheet for this use). However, it can also be configured as a low distortion sinusoidal tone generator with minimal filtering. Figure 1 depicts a recommended circuit configuration for tone generation. Figure 2 details the circuit of Figure 1 by showing a block diagram of the active circuits in the MX105A used for tone generation.
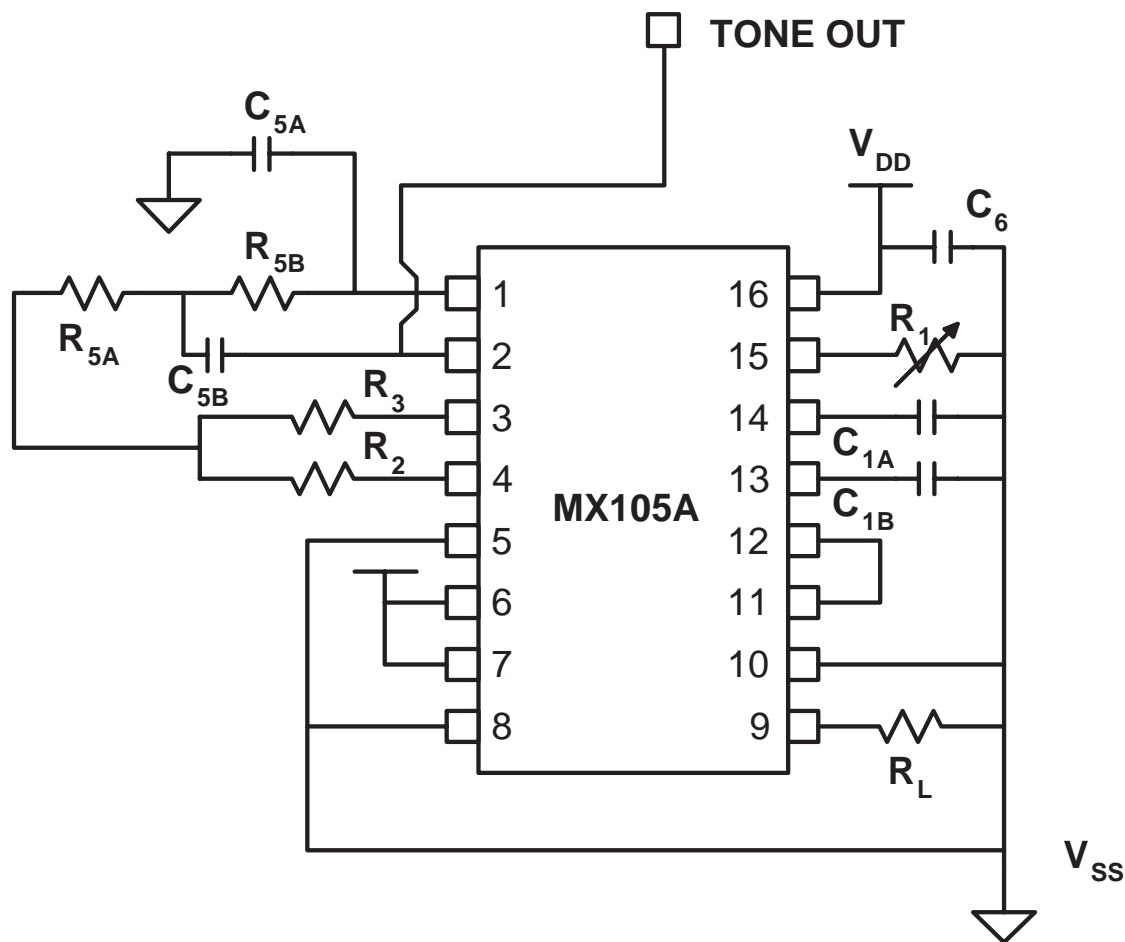

Figure 1. Simple Tone Generation Circuit using MX105A.

1. Circuit Description for Tone Generation.

An RC oscillator (pins 13-15) generates an internal clock at six times the center frequency. This clock is internally decoded to sequentially enable four analog switches configured between pins 3 and 5 (SW3A), pins 3 and 6 (SW3B), pins 4 and 7 (SW2A), and pins 4 and 8 (SW2B). The control signals for these switches are shown in Figure 3. The switch connections to R2 and R3 form a simple Digital to Analog converter to produce a three level approximation of a sine wave (1 1 0 -1 -1 0 . . .) as shown in Figure 3. This waveform is well suited for tone generation as described below. Finally, a simple low pass filter formed with the on chip buffer amplifier smoothes the three level sine wave to produce a low distortion sine wave.

Note: A large value DC blocking capacitor should be used at pin 2 if pins 6 and 7 are driven for tone level control or amplitude modulation as shown in Figure 2.
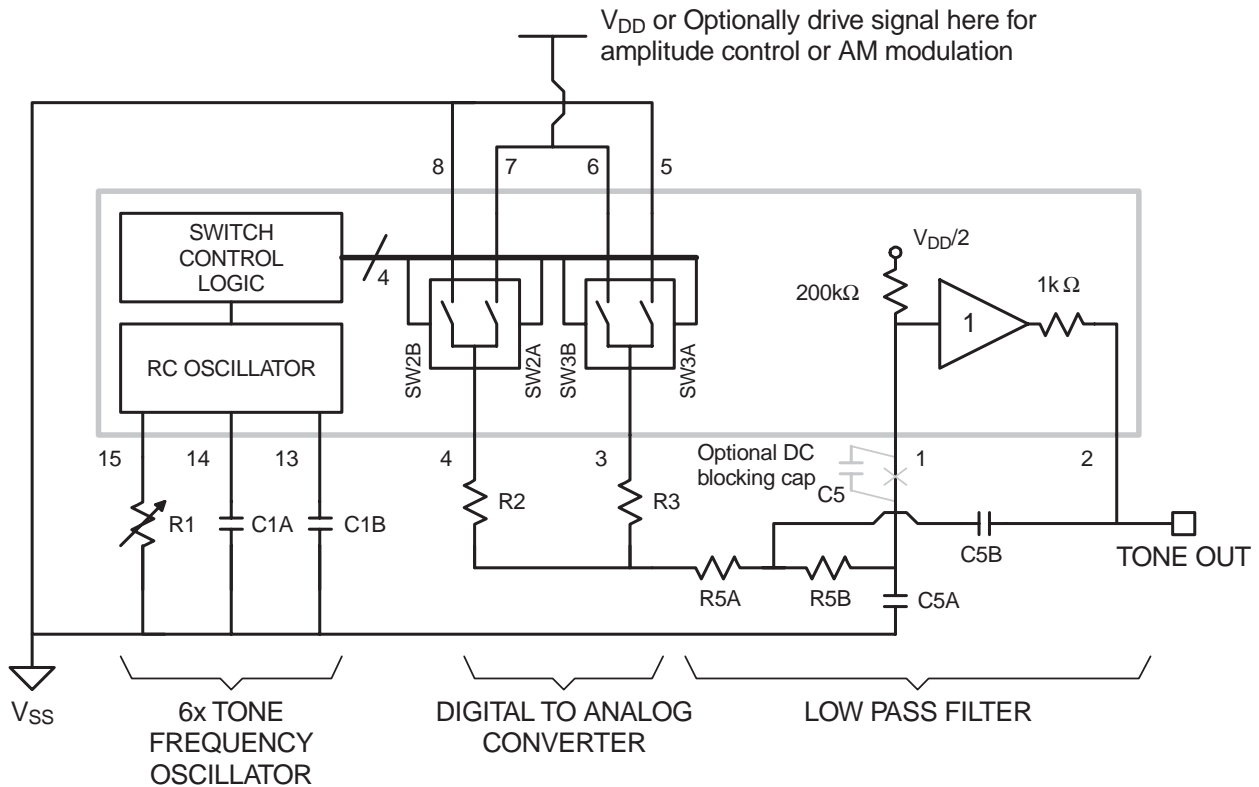

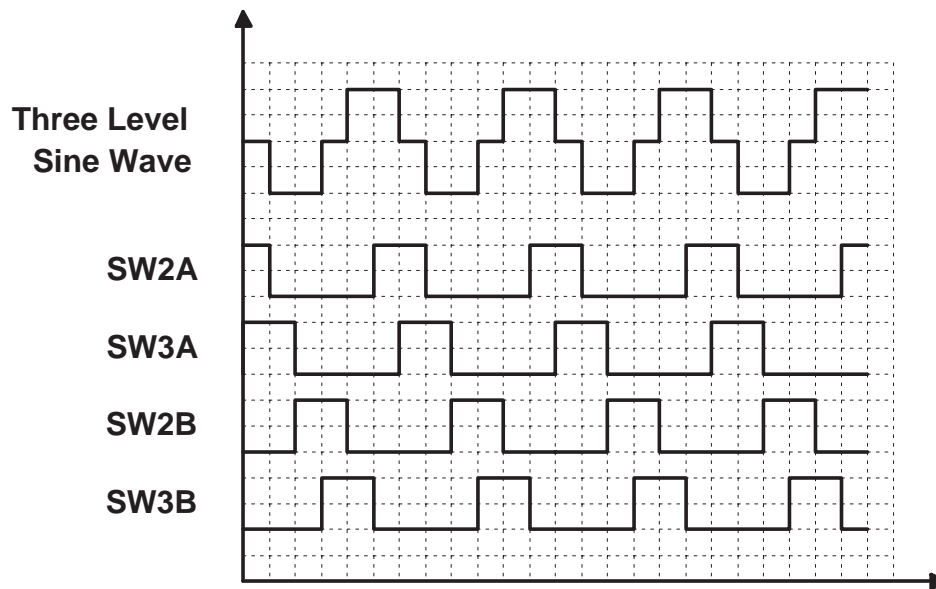**Figure 2. Block Diagram of Tone Generation Circuit.**

Figure 3. Internal Switch Control Signals and Resulting Three Level Waveform.

1.1 Fourier Series Analysis of the Three Level Waveform.

The periodic three level approximation of a sine wave can be represented by the following formula:

$$f(t) = \begin{cases} A & \text{for } |t| < \dfrac{T}{6} \\[2mm] 0 & \dfrac{T}{6} < |t| < \dfrac{T}{3} \\[2mm] -A & \text{for } \dfrac{T}{3} < |t| < \dfrac{T}{2} \end{cases} \qquad \text{where T is the period}$$

Fourier Series Expansion of f(t) yields the following coefficient formulas after some calculus:

$$a_n = \frac{2}{T}\int_0^T f(t)\cdot\cos\left(n\cdot\frac{2\pi}{T}\cdot t\right)dt$$

$$= \frac{2A}{n\cdot\pi}\sin\left(\frac{1}{3}\cdot n\cdot\pi\right)\cdot\left[1+2\cdot\cos\left(\frac{1}{3}\cdot n\cdot\pi\right)\right] \qquad \text{for positive integer n}$$

$$= \frac{2\cdot A\cdot\sqrt{3}}{\pi}\left[\frac{1}{1}, 0, 0, 0, -\frac{1}{5}, 0, \frac{1}{7}, 0, 0, 0, -\frac{1}{11}, 0, \frac{1}{13}, \ldots\right]$$

$$b_n = \frac{2}{T}\int_0^T f(t)\cdot\sin\left(n\cdot\frac{2\pi}{T}\cdot t\right)dt \;=\; 0 \qquad \text{for positive integer n}$$

These coefficients result in the following fourier series representation:

$$f(t) = \frac{2\cdot A\cdot\sqrt{3}}{\pi}\left[\cos\left(\frac{2\pi}{T}t\right) - \frac{1}{5}\cos\left(5\frac{2\pi}{T}t\right) + \frac{1}{7}\cos\left(7\frac{2\pi}{T}t\right) - \frac{1}{11}\cos\left(11\frac{2\pi}{T}t\right) + \frac{1}{13}\cos\left(13\frac{2\pi}{T}t\right) + \ldots\right]$$

This function is plotted in the time domain in Figure 4 and in the frequency domain in Figure 5. It is clear from the frequency domain plot that the first harmonic spur above the fundamental, the fifth, is already about 14 dB down. Thus the required filtering to pass the fundamental while suppressing the harmonics is simplified compared to a square wave.
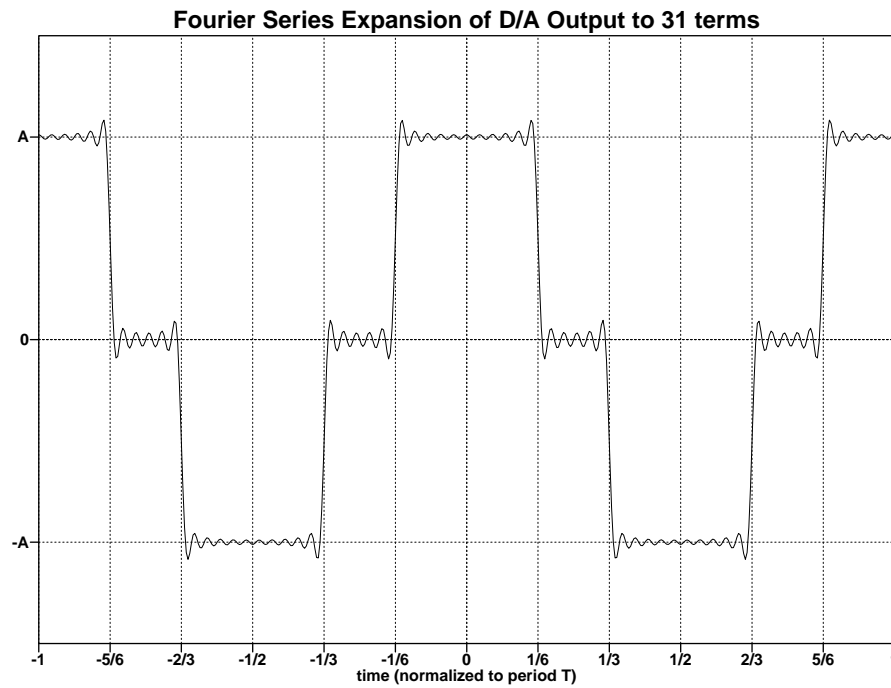
Fourier Series Expansion of D/A Output to 31 terms

Figure 4. Time Domain Plot
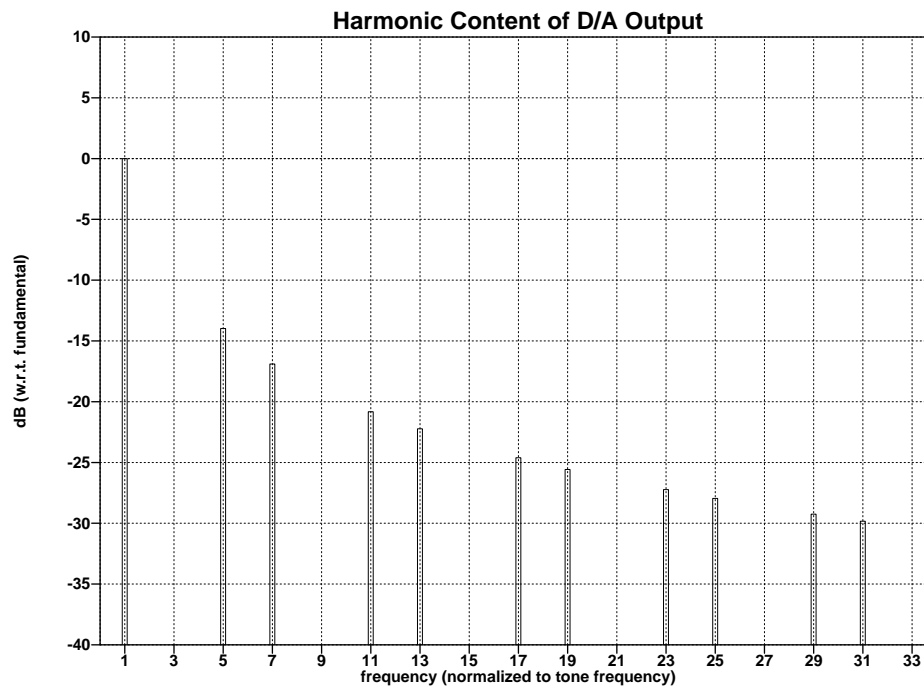
Harmonic Content of D/A Output

Figure 5. Frequency Domain Plot

1.2 Analysis of the Low Pass Smoothing Filter

A simple second order filter can provide 12 dB per octave roll-off in the filter's stop band. Thus we can expect as much as 27 dB   (i.e. $27dB \approx 12 \cdot \log_2(5)$) attenuation of the fifth harmonic and above with such a filter.

This should produce a sine wave with distortion of about 1% (i.e. harmonics more than 40 dB down). More complex filtering can be used if lower distortion is required.

A simple second order low pass filter (formed with R5A, R5B, C5A, C5B, and the internal buffer amplifier between pins 1 and 2) suppresses the harmonics of the three level waveform to produce a low distortion (<1%) sine wave at pin 2. The transfer function of this low pass filter including effects of the input impedance of the MX105A buffer amplifier is:

$$H(j\omega) = \frac{\left[\dfrac{Ri}{R5A + R5B + Ri}\right] \cdot \left[\dfrac{R5A + R5B + Ri}{C5A \cdot C5B \cdot R5A \cdot R5B \cdot Ri}\right]}{\left[\dfrac{R5A + R5B + Ri}{C5A \cdot C5B \cdot R5A \cdot R5B \cdot Ri} - \omega^2\right] + \left[\dfrac{1}{C5A \cdot R5A} + \dfrac{1}{C5A \cdot R5B} + \dfrac{1}{C5B \cdot Ri}\right]j\omega}$$

choosing to let R = R5A = R5B and C5A = 2 C5B and substituting C = C5B results in

$$H(j\omega) = \frac{\left[\dfrac{Ri}{2R + Ri}\right] \cdot \left[\dfrac{2R + Ri}{2C^2 \cdot R^2 \cdot Ri}\right]}{\left[\dfrac{2R + Ri}{2C^2 \cdot R^2 \cdot Ri} - \omega^2\right] + \left[\dfrac{1}{C \cdot R} + \dfrac{1}{C \cdot Ri}\right]j\omega}$$

From this expression the equation for the pole frequency is: (f_p is plotted in Figure 6 to help in component choices).

$$\omega_p{}^2 = \left[\frac{2R + Ri}{2C^2 \cdot R^2 \cdot Ri}\right] \quad \Rightarrow \quad f_p = \frac{\sqrt{\dfrac{2R + Ri}{2C^2 \cdot R^2 \cdot Ri}}}{2\pi}$$

The equation for the Pass Band DC Gain is: (plotted in Figure 7 to help in component choices).

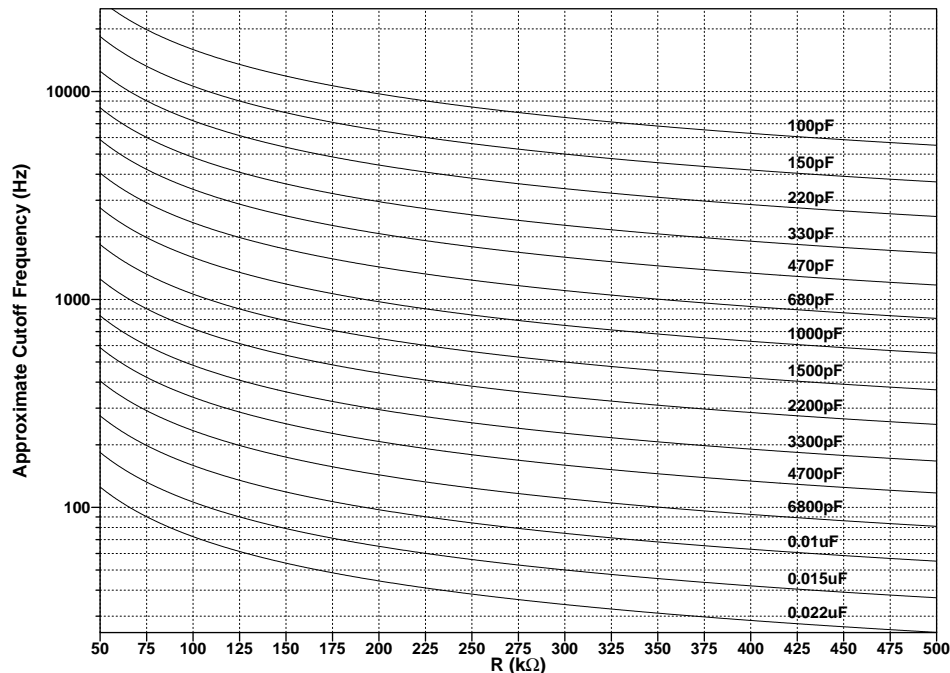$$DC\ Gain = \frac{Ri}{2R + Ri}$$

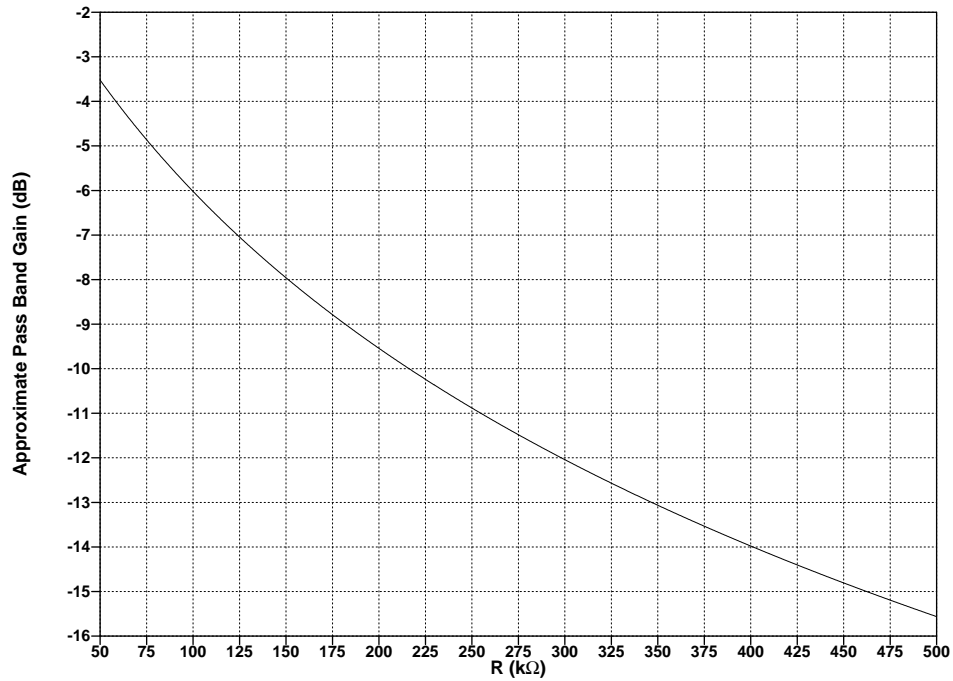**Figure 6. Approximate Cutoff Frequency Design Chart**

Figure 7. Approximate Filter Gain vs. R

Note that this filter provides attenuation in the pass band due to the input impedance of the buffer amplifier. The filtered tone level will be:

$$\text{Approximate Tone Level (in V}_{\text{p-p}}) = \frac{2 \cdot A \cdot \sqrt{3}}{\pi} \frac{Ri}{2R + Ri} \approx 1.1 \cdot A \cdot 10^{\left(\frac{\text{dB Gain}}{20}\right)}$$

where A is V_{DD} or optionally the level driven into pins 6 and 7 and dB Gain is read from Figure 7.

2. A Worked Design Example - 1700 Hz Tone Generator

The tone frequency is set according to the standard formula in the MX105A data sheet:

$$F_0 = \frac{1}{6 \cdot R1 \cdot C1A \cdot \ln(2)} \qquad \text{with C1A = C1B}$$

To generate a 1700 Hz tone while choosing C1A = C1B = 680pF

$$R1 = \frac{1}{6 \cdot F_0 \cdot C1A \cdot \ln(2)} = \frac{1}{6 \cdot 1800 \cdot 680 \cdot 10^{-12} \cdot \ln(2)} = 208 \text{ k}\Omega$$

Choosing R1 = 150kΩ in series with a 100kΩ potentiometer will allow frequency tuning if required.

Referring to Figure 6 to pick R after choosing C = 680pF for the low pass filter results in:

R = R5A = R5B = 130kΩ

C = C5B = 680pF   and C5A = 2 x C5B $\approx$ 1500pF

Calculating the approximate pole frequency to check design choices:

$$f = \frac{\sqrt{\dfrac{2R + Ri}{C5A \cdot C5B \cdot R^2 \cdot Ri}}}{2\pi} = 1838 \text{ Hz} \quad \text{(seems reasonable)}$$

Calculating the approximate tone level for V_{DD} = 5V results in:

$$\text{Tone Level} = 1.1 \cdot A \cdot 10^{\left(\frac{-7}{20}\right)} = 2.46 \, V_{p-p} = 870 \, mV_{RMS}$$

If tone amplidude control is required, drive a DC level (A) into pins 6 and 7 and use DC blocking capacitor C5 as shown in Figure 2.

Finally, choose R3 and R2 sufficiently low compared to R so as not to significantly affect the filter's frequency response and gain. For example, choose   R3 = R2 = 10kΩ.

The filter graphs and design example are based on the typical buffer input impedance of 200kΩ. This parameter varies from device to device and with supply voltage. The input impedance is approximately proportional to $\dfrac{4}{V_{DD} - 1}$ and may vary from 160kΩ to 360kΩ at VDD = 5V. These figures are given to help the designer analyze for device variation; they are not guaranteed specifications! Refer to the MX105A for all specifications. A smoothing filter built with an external amplifier may eliminate these issues.

Note: In this design example the filter cut off may vary from 1720 Hz to 2120 Hz and the filter gain may vary from -8.2 dB to -4.6 dB due to the buffer 's input impedance. Even with these variations the second order filter should provide good attenuation of the 1700 Hz tone's 5th harmonic and above.