Application Note AN3101-07: DSP-1K as a 20-Band 8-Channel Equalizer

by Jeff Rothermel

Introduction

This application note describes a method to implement graphic or parametric equalization on the DSP-1K.

Algorithm

The method is based on the second-order analog parametric equalizer, represented by the transfer function:

$$\frac{OUT}{IN} = Boost(s) = 1 + A * \frac{(\omega/Q)s}{s^2 + (\omega/Q)s + \omega^2}$$

$$Cut(s) = \frac{1}{Boost(s)}$$

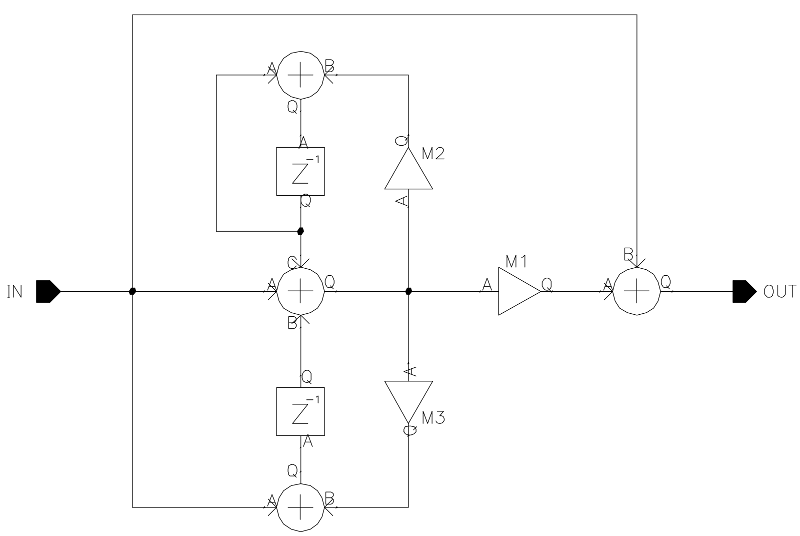
Where

$\omega = 2\pi Fc$ Fc = Center frequency

$Q = \frac{2^{BW/2}}{2^{BW} - 1}$ BW = Bandwidth in octaves

$A = G-1$ G = Gain at Fc

The bilinear transform was used to obtain a digital representation of the analog parametric section. A final architecture was chosen to minimize the number of instruction cycles per EQ band and to reduce the effects of coefficient quantization. Coefficients are calculated externally and sent to the DSP-1K as part of the instruction code.



For the Boost case:

$$M1 = \frac{ARK}{1 + RK + K^2} \qquad M2 = \frac{4K^2}{1 + RK + K^2} \qquad M3 = \frac{1 - RK + K^2}{1 + RK + K^2}$$

For the Cut case:

$$M1 = \frac{-ARK}{1 + GRK + K^2} \qquad M2 = \frac{4K^2}{1 + GRK + K^2} \qquad M3 = \frac{1 - GRK + K^2}{1 + GRK + K^2}$$

where,

$R = 1/Q$ $K = \tan(\pi FcT)$ T = Sample period

Derivation

There are many ways to manipulate the analog filter formula to generate a digital equivalent, and many ways to manipulate the digital equivalent to generate a block diagram, each giving a different result. The following is one way to arrive at the code in this application note.

⇒ Start from the transfer function

$$\frac{OUT}{IN} = H(s) = 1 + A * \frac{(\omega/Q)s}{s^2 + (\omega/Q)s + \omega^2}$$

⇒ Use the bilinear transform: $s = (2/T)(z-1)/(z+1)$, $\omega = (2/T)\tan(\omega T/2)$

⇒ Let $R = 1/Q$, and $K = \tan(\omega T/2)$

$$= 1 + \frac{ARK(z-1)/(z+1)}{[(z-1)/(z+1)]^2 + RK(z-1)/(z+1) + K^2}$$

⇒ Multiply numerator and denominator by $(z+1)/(z-1)$ to clear numerator

⇒ Collect denominator into a single fraction

$$= 1 + \frac{ARK}{[(z-1) + RK(z+1) + K^2(z+1)^2/(z-1)]/(z+1)}$$

⇒ Manipulate denominator

$$\begin{aligned}
&(z-1) + RK(z+1) + K^2(z+1)^2/(z-1) \\
&\quad = z - 1 + RKz + RK + K^2(z^2 + 2z + 1)/(z-1) \\
&\quad = z - 1 + RKz + RK + K^2[(z^2-z) + 4z - (z-1)]/(z-1) \\
&\quad = z - 1 + RKz + RK + K^2z + 4k^2z/(z-1) - k^2 \\
&\quad = z(1+RK+k^2) + 4k^2z/(z-1) - (1-RK+k^2)
\end{aligned}$$

⇒ Multiply numerator and denominator by $(z+1)/(1+RK+k^2)$

$$= 1 + \frac{(z+1)ARK/(1+RK+k^2)}{z + 4k^2z/[(z-1)(1+RK+k^2)] - (1-RK+k^2)/(1+RK+k^2)}$$

⇒ Let M1, M2, and M3 be defined as above

⇒ Convert z's into unit delay z^{-1}'s

$$= 1 + \frac{M1(z+1)}{z + M2z/(z-1) - M3} = 1 + \frac{M1(1+z^{-1})}{1 + M2z^{-1}/(1-z^{-1}) - M3z^{-1}}$$

⇒ Break up the transfer function into input and output, then manipulate

$$
\begin{aligned}
Out &= In + InM1(1+z^{-1})/[1 + M2z^{-1}/(1-z^{-1}) - M3z^{-1}] \\
&= In + M1P
\end{aligned}
$$

$$
\begin{aligned}
P &= (In+Inx)/[1 + M2z^{-1}/(1-z^{-1}) - M3z^{-1}] \\
&= In + (In\,z^{-1}+M3P\,z^{-1}) - M2P\,z^{-1}/(1-z^{-1}) \\
&= In + (In+M3P)z^{-1} - Q
\end{aligned}
$$

$$
\begin{aligned}
Q &= M2Pz^{-1}/(1-z^{-1}) \\
&= M2Pz^{-1} + Qz^{-1} \\
&= (M2P+Q)z^{-1}
\end{aligned}
$$

These three equations give the block diagram in this application note, with the point P at the junction before all 3 coefficient multiplies, and point Q at the junction between the top delay loop and the central addition. They also give the code listed in the application note.

Source Code

The implementation described requires five instruction cycles and two storage locations per band plus two instruction cycles per channel. With 1024 instruction cycles available on the DSP-1K, this permits a total of 200 EQ bands. The following is the code used for each EQ band:

Example: 12dB Cut at 1000.000000Hz, BW = 1/4 octave
Used cut equations for M1,M2,M3
Note: G=4 for both 12dB Cut and 12dB Boost

```
 CM    0x40000       0x410  ;CH0->A

XCMA   0x40000       0x17   ;A->B, A=A+REG3
 CMA   0x3c0000      0x16   ;A=A-REG2
 CAM   0x10c3 0x16   ;A=M2*A                    M2 =  0.016372
SCUB   0x3a7a8       0x16   ;A->REG2, A=B+M3*U  M3 =  0.913731
SCUB   0x3fdeed      0x17   ;A->REG3, A=B+M1*U  M1 = -0.032300

SCA    0x0           0x410  ;A->CH0
```

The middle five instructions are repeated for each band, and the outer two instructions wrap up a complete channel. The addresses of REG2 and REG3 are different for each band.

The complete example is a 20-band half-octave 8-channel graphic equalizer. The lowest frequency high-Q band is the most demanding for internal headroom, requiring eight bits. Two bits of headroom are available in the DSP-1K, so the input must be shifted down six bits to provide the rest. This effectively truncates the input to eighteen bits. The output is shifted back up six bits to provide unity gain through the system.

NOTICE

Wavefront Semiconductor reserves the right to make changes to their products or to discontinue any product or service without notice. All products are sold subject to terms and conditions of sale supplied at the time of order acknowledgement. Wavefront Semiconductor assumes no responsibility for the use of any circuits described herein, conveys no license under any patent or other right, and makes no representation that the circuits are free of patent infringement. Information contained herein is only for illustration purposes and may vary depending upon a user's specific application. While the information in this publication has been carefully checked, no responsibility is assumed for inaccuracies.

Wavefront Semiconductor products are not designed for use in applications which involve potential risks of death, personal injury, or severe property or environmental damage or life support applications where the failure or malfunction of the product can reasonably be expected to cause failure of the life support system or to significantly affect its safety or effectiveness.

All trademarks and registered trademarks are property of their respective owners.

Contact Information:

Wavefront Semiconductor
200 Scenic View Drive
Cumberland, RI 02864 U.S.A.
Tel: +1 401 658-3670
Fax: +1 401 658-3680
On the web at www.wavefrontsemi.com
Email: info@wavefrontsemi.com

Application note revised March, 2005