Do I Filter Now, Later, or Never?
Analog vs Digital Filters

- **Do I Need an Analog Filter if I am Only Measuring a DC Signal?**
  - **YES** - Noise Generators Have no “Knowledge” of Your Intent

- **Do I Need an Analog Filter as Opposed to Digital?**
  - **YES** - Once the Converted Signal is “Contaminated” with Aliased Noise, it Takes Time and Memory to Eliminate (if possible)
  - **YES** - Eliminates the Effects of Overdriven Signals that Usually Occur Beyond the Bandwidth of the Filter
When to Pick Analog Over Digital

- **Analog Filters**
  - Reduces Fold Back Signals (Aliased Signals)
  - Minimizes Impact of Noise Peaks

- **Digital Filters**
  - Can Reduce in Band Noise
  - Removes Noise Injected During Conversion
  - Easy to Program

![Diagram showing analog input signal, analog low pass filter, A/D conversion, and digital filter.](image-url)
Applying Filtering Blocks

- **Analog** -
  - Butterworth,
  - Chebyshev,
  - Bessel, etc.

- **Digital** -
  - Infinite Impulse Response (IIR)
  - Moving Average
  - Finite Impulse Response (FIR)

- Where do you make the cut
Frequency Response

5th order Butterworth

5th order Chebyshev

5th order Bessel

Step Response

5th order Butterworth

5th order Chebyshev

5th order Bessel
Nyquist Theorem

- Harmonics that Fold Back into the Conversion Output

\[ f_{\text{ALIASED}} = |f_{\text{IN}} - Nf_s| \]
- Find \( N \) by making \( f_{\text{ALIASED}} < \frac{f_s}{2} \)
Applying Filtering Blocks

- **Analog** -
  - Butterworth,
  - Chebyshev,
  - Bessel, etc.

- **Digital** -
  - Infinite Impulse Response (IIR)
  - Moving Average
  - Finite Impulse Response (FIR)
IIR Filter

\[ x(n) \rightarrow + \rightarrow -a_1 \rightarrow + \rightarrow -a_2 \rightarrow + \rightarrow z^{-1} \rightarrow + \rightarrow b_1 \rightarrow + \rightarrow b_2 \rightarrow + \rightarrow y(n) \]

Direct From II Realization

can implement functions such as Bessel, Butterworth, Chebyshev, etc.
Digital Filters Using Averaging

Analog Input Levels

Full-scale

Delta sigma modulator

1-bit data

1/2 full scale input

1/4 full scale input

3/4 full scale input

1-bit data streams

1/2 full scale input

1/4 full scale input

3/4 full scale input

0V

1

0

1

0

1

0

1

0

1

0

Average

= 0.5

= 0.25

= 0.75

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Oversampling and Signal to Noise

- **Oversampling improves SNR**
  - Each oversample by a factor of 4 gives a 6 dB or **1-bit improvement in SNR**

- **For a 1-bit ADC and oversampling** there are:
  - 2-bits for 4 x oversampling \((4^1)\)
  - 3-bits for 16 x oversampling \((4^2)\)
  - 4-bits for 64 x oversampling \((4^3)\)
  - ... 
  - 24-bits for \(4^{23}\) x oversampling !!!!!

- **Oversampling to 24-bits from a 1-bit ADC is not practical**
Sinc\(^3\) Frequency and Step Response

**Frequency Response**

3rd order FIR

<table>
<thead>
<tr>
<th>Attenuation (dB)</th>
<th>0</th>
<th>-40</th>
<th>-80</th>
<th>-120</th>
<th>-160</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>0</td>
<td>50</td>
<td>100</td>
<td>150</td>
<td>200</td>
</tr>
</tbody>
</table>

**Step Response**

3rd order FIR

- Samples at Output of A/D Converter

FIR Filter Characteristics at 60Hz
The Best Design Approach

- Gain
- Mux
- LPF
- μC

μC → Piecewise Linearization → Digital Filter → +

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Conclusion

- Analog Filters
  - Locate Before the Controller
  - Reduces Fold Back Signals (Aliased Signals)
  - Minimizes Impact of Noise Peaks

- Digital Filters
  - Locate in the Controller
  - Can Reduce Inband Noise
  - Removes Noise Injected During Conversion
  - Easy to Program
References

- Application Notes
  - ADN003, “Select the Right Operational Amplifier for your Filtering Circuits”, Bonnie C Baker
  - AN699, “Anti-Aliasing, Analog Filters for Data Acquisition Systems”, Bonnie C Baker
  - AN737, “Using Digital Potentiometers to Design Low Pass Adjustable Filters”, Bonnie C. Baker
  - AN852 - “Implementing FIR and IIR Digital Filters Using PIC18 Microcontrollers”, Ananthma Ramu
  - AN616 - “Digital Signal Processing with the PIC16C74”, Darius Mostowfi

- Books
  - Analog and Digital Filter Design, Second Edition by Steve Winder, Newnes
  - The Scientist and Engineers Guide to Digital Signal Processing, Steven W Smith, WWW.DSPguide.com

- Feature Articles
  - EDN, February 20, 2003, Filtering? Before or after?

- FilterLab™ Active Filter Design Software, Microchip