De-Integrating Integrated Circuit Preamps

Less Delivers More?

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Today’s Topics

- Where we’ve been, and where we’re going
  - The old to the “new” topology

- Optimizing this new topology
  - Noise
  - Bandwidth
  - Gain control, taper, & dc offset
  - Output configuration

- Wrap-up
Out with the Old
... In with the New

Some historical perspective...
In the Beginning (for IC Preamps)

- **Solid State Music**
  - Ron Dow
  - Dan Parks
- **SSM 2011 (~1982)**
  - Integrated preamp
  - External feedback
- **SSM2015 (~1983)**
  - Integrated preamp
  - One external resistor controls gain: $R_G$
“Standard” IC Preamp Configuration

- Differential input
- Single-ended output
- Current feedback
- Single resistor controls gain
  - $R_G$
- Minimum gain: 0dB
  - Requires infinite $R_G$
Many Followed In SSM’s Footsteps

- **SSM2016 (1986)**
  - Derek Bowers’ design
- **SSM2017 (1989)**
  - By this time, SSM was part of Analog Devices
- **SSM2019 (2003)**
  - Derek Bowers (at ADI)
  - INA217 (2002)
- **THAT 1510 (2004)**
- **THAT1512 (2004)**
  - External $R_G$
  - Diff-amp gain: -6dB
  - Credit: Cal Perkins (at Mackie)
- **Not considered: AD524 (1982)**
  - Also included internal $R_A$ & $R_B$, as well as choice of (internal) $R_G$
  - Scott Wurcer’s design
  - Noise too high for a mic preamp (~5nV/√Hz)
Benefits of “Standard” Topology

• Wide bandwidth at high gain due to current, not voltage feedback
• Can be very quiet at high gains
  – Many reach $1\text{nV/}\sqrt{\text{Hz}}$ voltage noise
• Easy to control gain with single $R_G$
• Integrated approach allows wide input dynamic range
  – See G. Hebert’s presentation at the 2010 US AES convention
Detriments of “Standard” Topology

• Feedback network adds noise at low gains
  – Resistor self-noise
  – Current noise in $R_G$ pins drawn across the feedback network’s impedance

• Maximum gain is affected by pot’s effective end-resistance

• Smooth taper is hard to achieve
  – Depends on $R_G$ vs. $R_A$ & $R_B$

• Must convert output from single-ended to differential to drive A/D converters
Let’s De-Integrate the Topology

• Start with the “standard” IC

• Remove the output diff amp
Let’s De-Integrate the Topology

• Remove internal $R_A$ & $R_B$

• Take away the external $R_G$
What Does That Leave?

• Uncommitted
  – Completely configurable
• Differential In
• Differential Out
  – 0dB common-mode gain
• Current Feedback
• Low Voltage Noise
• THAT’s the 1570 & 1583
The 1570/1583 “Uncommitted” Topology Makes Optimization Easy

• Noise vs. gain
• Bandwidth vs. gain
• Pot end resistance
• Gain vs. pot rotation
• Output amp performance
  – Noise
  – CMRR
Optimization Details

- Noise
- Bandwidth
- Gain control, taper & DC offset
- Output & Common-Mode Rejection
Noise Model for 1570/1583-Type Preamp

- Voltage \(e_n\) & Current \(i_n\) noise flows in each input pin
- \(e_n\) is amplified by gain
  - 0dB at minimum gain
  - +60dB at 60dB gain
- \(i_n\) creates a noise voltage based on the impedance it flows through
  - Then amplified by gain
- Sources are uncorrelated
  - Add in RMS fashion (root of the sum of the squares)
Noise Model for 1570/1583-Type Preamp

- $e_{nRG}$ can be lumped into the $e_{nIN+}$ and $e_{nIN-}$ sources
- Contributions of $i_{nIN+}$ & $i_{nIN-}$ depend on source impedance at $In+$ & $In-$
  $= (R_3+R_4+R_S) \parallel (R_1+R_2)$
- Contribution of $i_{nRG}$ depends on feedback network impedance
  $= (R_A + R_B) \parallel R_G$
  - Current times impedance generates the voltage
- Because gain varies with $R_A$, $R_B$ & $R_G$, relative contribution of each source depends on gain
1570/1583 Noise At High Gains
(60dB shown)

- $R_G$ is small, so $i_{nR_G}$ contribution is small
- $R_S$ is small, so the $i_{nIN+}$ & $i_{nIN-}$ contributions are small
  - But, if $R_S$ is large (e.g., open inputs), $i_{nIN}$ contributions can be significant
- $e_{nIN+}$ & $e_{nIN-}$ dominate, along with the self-noise of $R_S$

High-gain noise depends more on IC characteristics and source impedance than anything else
1570/1583 Noise At Low Gains (0dB shown)

- $e_{n IN+}$ & $e_{n IN-}$ are small, along with the self-noise of $R_S$
- $R_S$ is small, so the $i_{IN+}$ & $i_{IN-}$ contributions are small
- $R_G$ is open, so the two $i_{nRG}$ currents flow through $R_A$ & $R_B$
  - $i_{nRG}$ currents dominate the noise floor
- To reduce noise at low gains, reduce $R_A$ & $R_B$

Low-gain noise depends more on IC characteristics and feedback ($R_A$ & $R_B$) impedance than anything else
1510 (Front End) Noise At High Gains (60dB Shown)

- $R_G$ is small, so $i_{nR_G}$ contribution is small
- $R_S$ is small, so the $i_{nIN+}$ & $i_{nIN-}$ contributions are small
  - As with 1570, if $R_S$ is large (e.g., open inputs), $i_{nIN}$ contributions can be significant
- $e_{nIN+}$ & $e_{nIN-}$ dominate, along with the self-noise of $R_S$

High-gain noise depends more on IC characteristics and source impedance than anything else
1510 (Front End) Noise At Low Gains  
(0dB Shown)

• $e_{nIN^+}$ & $e_{nIN^-}$ are small, along with the self-noise of $R_S$
• $R_S$ is small, so the $i_{nIN^+}$ & $i_{nIN^-}$ contributions are small
• $R_G$ is open, so $i_{nRG1}$ flows through $R_A$, & $i_{nRG2}$ flows through $R_B$
  - $i_{nRG}$ currents dominate the noise floor
• Since $R_A$ & $R_B$ are fixed (internal), designers don’t have freedom to affect this noise source

Noise at low gains depends only on IC characteristics: no flexibility with the “standard” topology
Controlling Noise: “Standard” vs. “New” Topology

• High-gain noise is same (1nV/√Hz) across 1510, 1512, & 1570

• Low-gain noise can be controlled in new topology, but not in standard topology
  - Requires the designer to supply $R_A$ & $R_B$

1570’s 0dB gain noise is
-9dB lower compared to 1510,
-5dB lower compared to 1512
Controlling Noise: “Standard” vs. “New” Topology

• 1583 high-gain noise (1.9 nV/√Hz, or 5.6dB) is higher than 1510, 1512, & 1570

• But, low-gain noise for the 1583 is almost as low as the 1512

• New topology preserves better low-gain noise, even with a higher-noise part

1583’s 0dB gain noise is
~3dB lower than 1510
~1.4dB higher than 1512
Optimization Details

- Noise
- Bandwidth
- Gain control, taper & DC offset
- Output & Common-Mode Rejection
Optimizing Bandwidth Vs. Gain

- Bandwidth is determined by amplifier design and feedback resistor \((R_A \& R_B)\)
- In 1510/12, you’re limited to \(R_A = R_B = 5k\Omega\)
- In 1570 & 1583, you can vary \(R_A \& R_B\)
  - Lower values \(\Rightarrow\) higher bandwidth
  - Minimum value is 2k\Omega

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<th>10</th>
<th>20</th>
<th>30</th>
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Optimization Details

- Noise
- Bandwidth
- Gain control, taper & DC offset
- Output & Common-Mode Rejection
Practical Considerations for $R_A$ & $R_B$

- $R_G$ is determined by maximum gain and $R_A$, $R_B$ values
- To minimize output (differential) offset with gain, use $C_G$
- $C_G$ works against $R_G$ to determine LF cutoff ($f_0$)
  - Small $R_G$ and low $f_0$ means big $C_G$
Varying Gain in the “Standard” Circuit

- $R_G$ varies to set gain
- Max gain when $R_{GV}$ is maximum
- Min gain when $R_{GV}$ is minimum
- Highest low-frequency cutoff occurs at max gain
- $C_G$ depends on desired LF cutoff and $R_{GF}$ value

$C_G = 3300 \mu f$, $R_G = 10 \Omega$, $f_o = 4.43 Hz$
Practical Considerations for Varying Gain in the “Standard Circuit”

- Effective end resistance in $R_{GV}$ limits max gain
  - Reduce $R_{GF}$ to offset
  - Variation in effective end resistance will alter max gain
- Pots used by APB Dynasonics have 2~3Ω (measured) end resistance
- Thanks to John Petrucelli for samples!
  - Check your spec sheet for your tolerances ...

Practical Considerations for Varying Gain in the “New” Circuit

- The conventional circuit is shown at right
- To minimize low-gain noise, select $R_A$ & $R_B$ as low as possible
  - For 1570, that’s 2kΩ
  - For 1583, that’s ??Ω
- For 60dB gain, $R_{GF} = 4\Omega$
- End resistance may be a significant fraction of $R_{GF}$
- To maintain < 5Hz cutoff, $C_G > 7300\mu f$
  - That’s a big, expensive cap
  - Is < 5Hz cutoff a good idea at 60dB gain?
Consider a Dual-Element Pot to vary $R_G$, $R_A$ & $R_B$ Simultaneously

- Using a dual-element pot allows $R_A$ & $R_B$ to vary in addition to $R_G$
  - Lowers $R_A$ & $R_B$ at min gain, but raises them at max gain
- This allows smaller $C_G$ for the same cutoff
  - In circuit shown $f_0 \approx 5.5\text{Hz}$
  - 60dB gain noise is still very low: 1.18nV/$\sqrt{\text{Hz}}$ (-129.1dBu with 150Ω source)
Pot Taper

• Measured taper of “5% reverse log” taper pots (thanks to APB)
• Actually two linear sections with different resistances in each section
• What curve of gain vs. rotation will this produce?

![Graph showing resistance vs pot rotation]
Gain vs. Rotation Compared: Single and Dual-Element Circuits

- Theoretical “ideal” curve shown in black
- Single-element pot (circuit of slide 26) results in red curve
- Dual-element pot (circuit of slide 29) results in blue curve
- Dual-element pot trajectory is much closer to “ideal”
Optimization Details

- Noise
- Bandwidth
- Gain control, taper & DC offset
- Output & Common-Mode Rejection
Single-Ended Output Stages

- The 1570/1583 topology is differential in, differential out
  - Common-mode gain is always unity (0dB)
  - Differential gain varies with $R_G$, $R_A$, & $R_B$ (0~>60dB)
  - CMRR is equal to differential gain
  - Output has a (negative) common-mode DC offset of 1 diode drop (~-0.6V)

- To provide CMR at low gains, add a differential amplifier after the 1570/1583

- Choose carefully to avoid adding noise and limiting bandwidth
  - 1510/1512 includes a pretty quiet, wide-band amp
  - 1570/1583 allows designers flexibility in choosing this amplifier for even greater performance
  - Circuit at right (w/ 2114) compromises low-gain noise floor by only ~2.6 dB (for the 1570) and ~0.14 dB (for the 1583)
Differential Output Stages

- In many cases (e.g., driving ADC), differential outputs are needed
- But, many designers want to remove common-mode signals
- Simple circuit (top, using 1286) has great common-mode rejection, fair noise performance
- More complex circuit (bottom, after Birt) maintains very low differential noise, but common-mode rejection depends on resistor matching
Differential Output Stages

- Variation of Birt circuit suggested for driving A/D converters
  - Includes attenuation suitable for ~2VRMS differential drive
- 1570/1583 differential output allows designers to spend on high-performance circuits & opamps when necessary, or save money when cost is more important than performance
Summing Up

Why choose the “new” topology?
Summary

• “New” 1570 & 1583 topology is a subset of the “standard” one

• Removing feedback resistors gives designers freedom to change their values
  – Optimize noise
  – Optimize bandwidth
  – Minimize blocking capacitor value while maintaining optimum noise performance
  – Optimize gain vs. rotation for analog control

• Removing output amp offers more flexibility
  – Naturally provides a differential output
  – Allows designer to set common-mode rejection
  – Optimize noise noise performance

• Less really is more!
Thank You to ...

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