# De-Integrating
# Integrated Circuit Preamps

## Less Delivers More?

Les Tyler, President, THAT Corporation

# Today's Topics

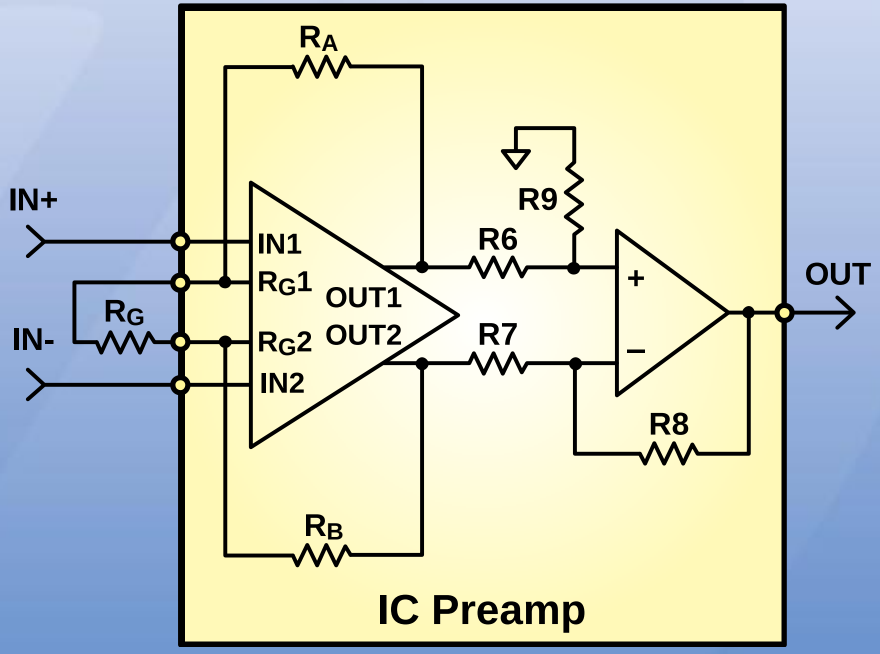
- Where we've been, and where we're going
  - The old to the "new" topology
- Optimizing this new topology
  - Noise
  - Bandwidth
  - Gain control, taper, & dc offset
  - Output configuration
- Wrap-up

# Out with the Old
# … In with the New

Some historical perspective…

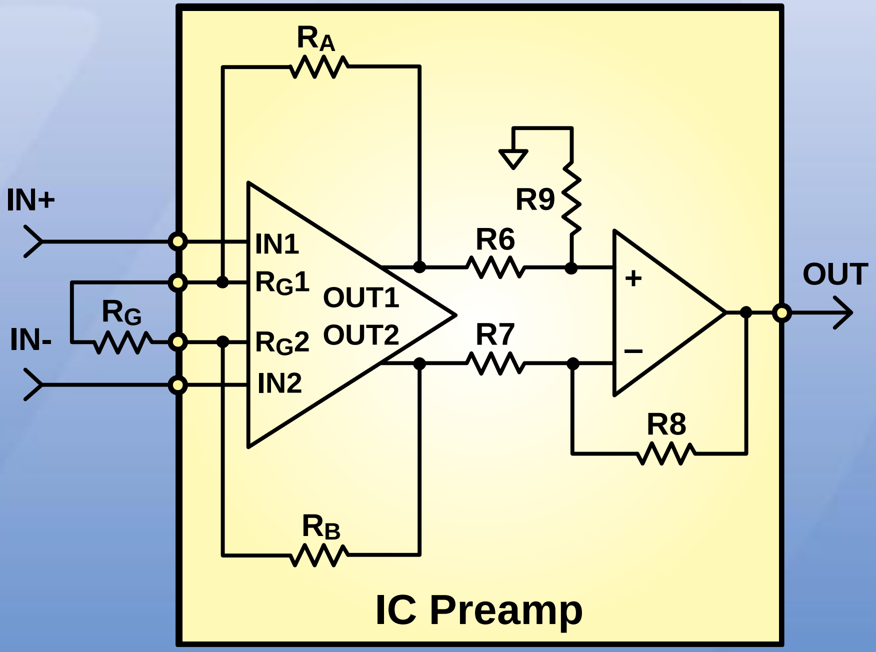
# In the Beginning (for IC Preamps)

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



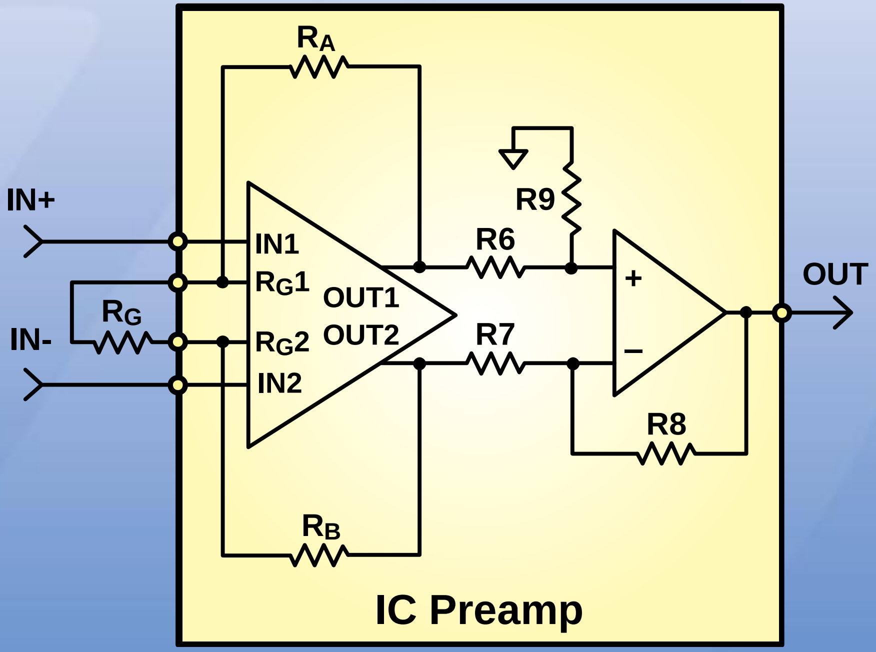
# “Standard” IC Preamp Configuration

- 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)
- TI INA163 (~2000)
  - 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

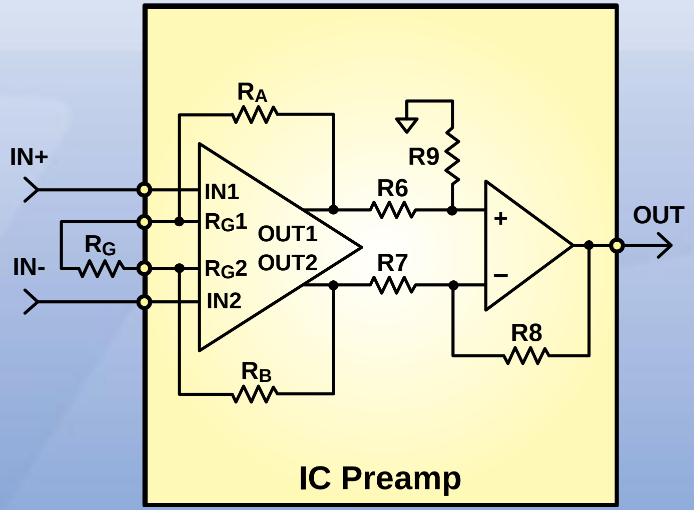
- Wide bandwidth at high gain due to current, not voltage feedback
- Can be very quiet at high gains
  - Many reach 1nV/√Hz voltage noise
- Easy to control gain with single $R_G$
- Integrated approach allows wide input dynamic range
  - See G. Hebert's presentation at the 2010 US AES convention

# Detriments of "Standard" Topology

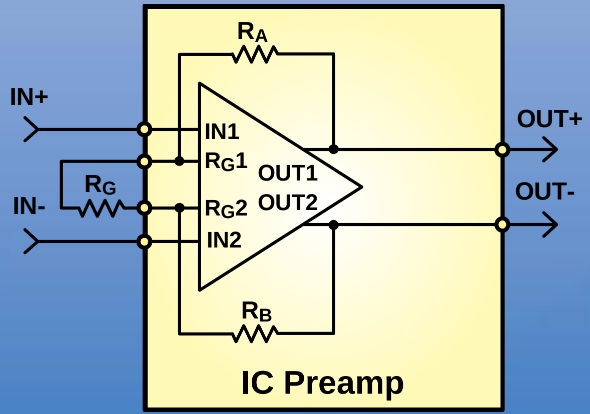
- Feedback network adds noise at low gains
  - Resistor self-noise
  - Current noise in $R_G$ pins drawn across the feedback network's impedance
- Maximum gain is affected by pot's effective end-resistance
- Smooth taper is hard to achieve
  - Depends on $R_G$ vs. $R_A$ & $R_B$
- Must convert output from single-ended to differential to drive A/D converters

# Let's De-Integrate the Topology

- Start with the "standard" IC

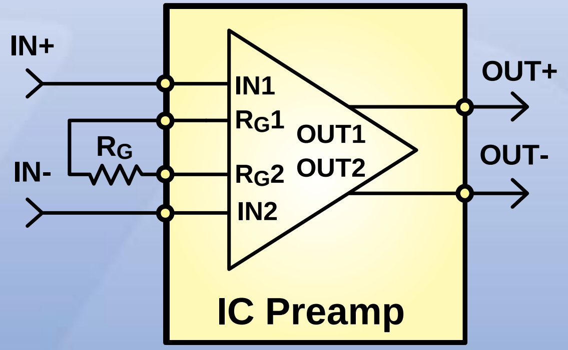


- Remove the output diff amp

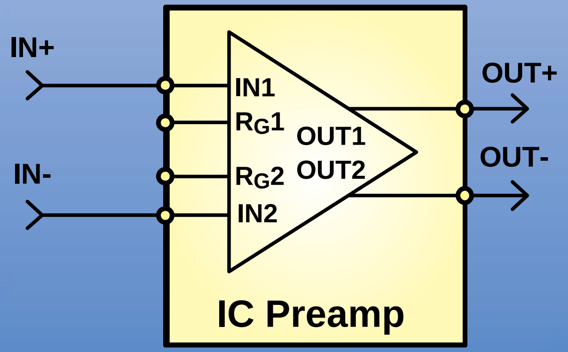


# Let's De-Integrate the Topology

- Remove internal $R_A$ & $R_B$

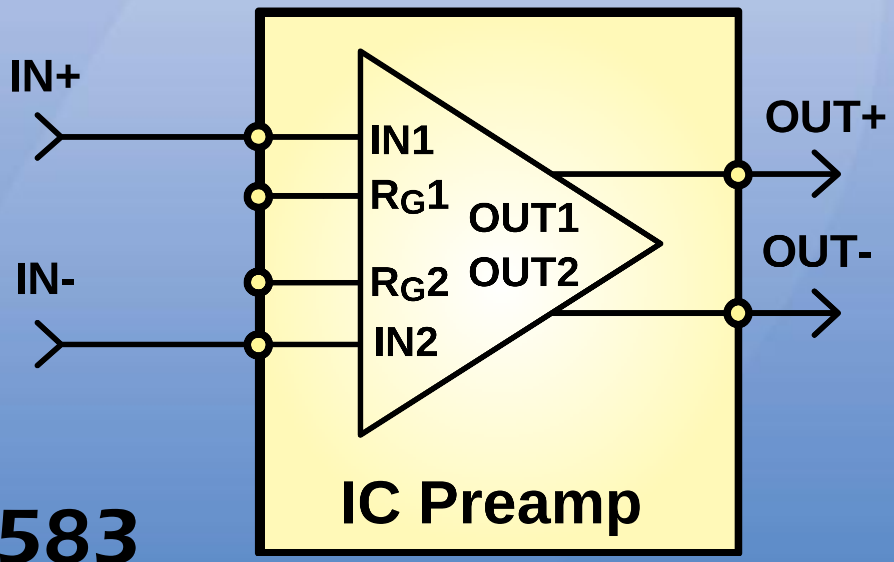


- Take away the external $R_G$



# 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

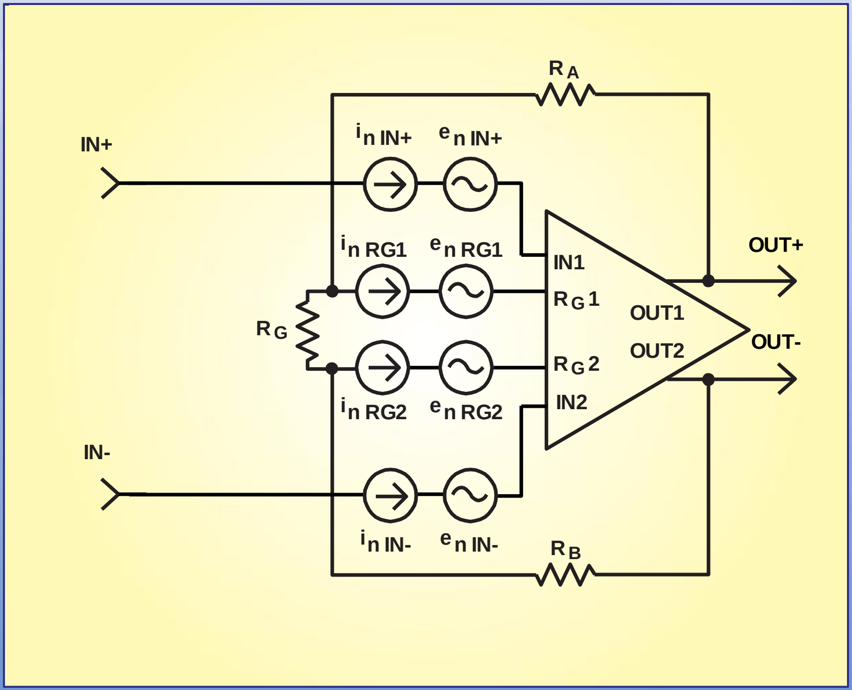
Bandwidth

Gain control, taper & DC offset

Output & Common-Mode Rejection

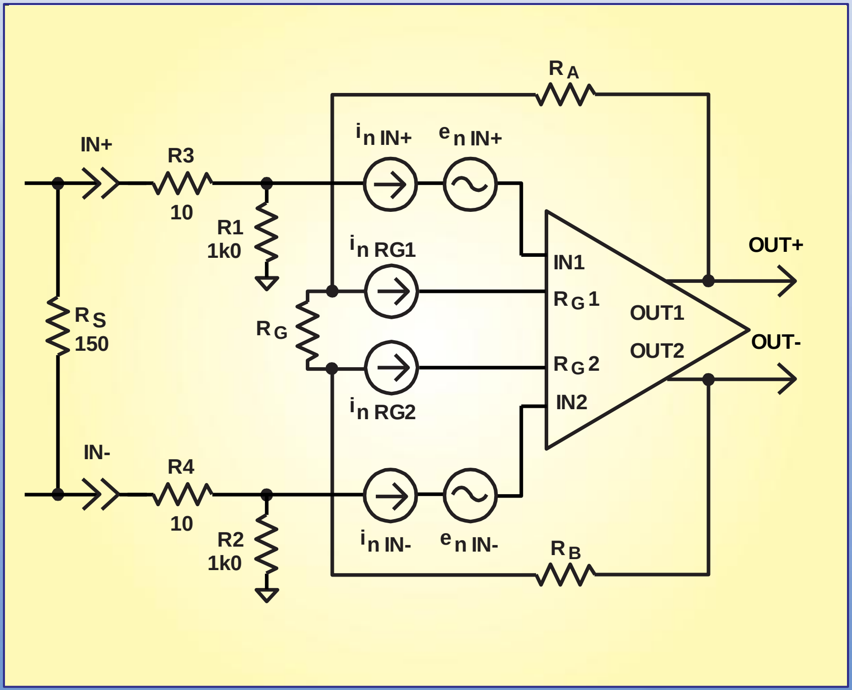
# Noise Model for 1570/1583-Type Preamp

- 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)



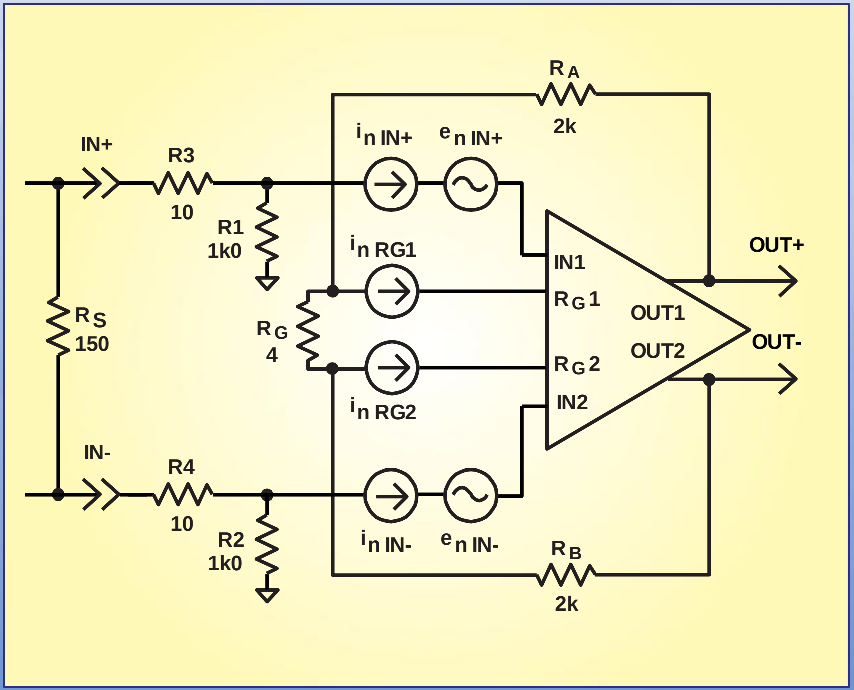
# Noise Model for 1570/1583-Type Preamp

- $e_{nRG}$ can be lumped into the $e_{nIN+}$ and $e_{nIN-}$ sources
- Contributions of $i_{nIN+}$ & $i_{nIN-}$ depend on source impedance at In+ & In-
  $= (R_3+R_4+R_S)||(R_1+R_2)$
- Contribution of $i_{nRG}$ depends on feedback network impedance
  $= (R_A + R_B)||R_G$
  - 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)

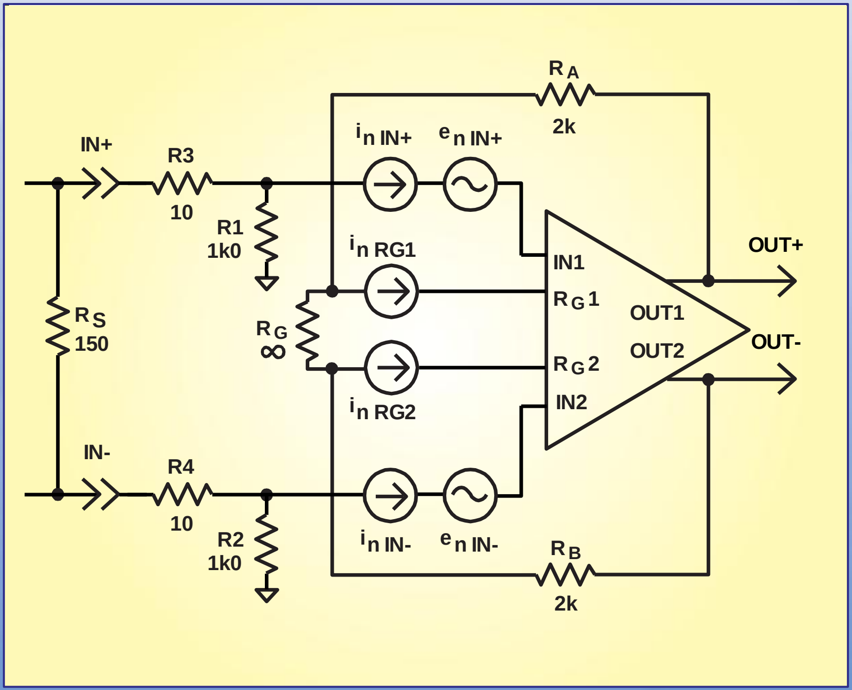
- $R_G$ is small, so $i_{nR_G}$ contribution is small
- $R_S$ is small, so the $i_{nIN+}$ & $i_{nIN-}$ contributions are small
  - But, if $R_S$ is large (e.g., open inputs), $i_{nIN}$ contributions can be significant
- $e_{nIN+}$ & $e_{nIN-}$ dominate, along with the self-noise of $R_S$



**High-gain noise depends more on IC characteristics and source impedance than anything else**

# 1570/1583 Noise At Low Gains (0dB shown)

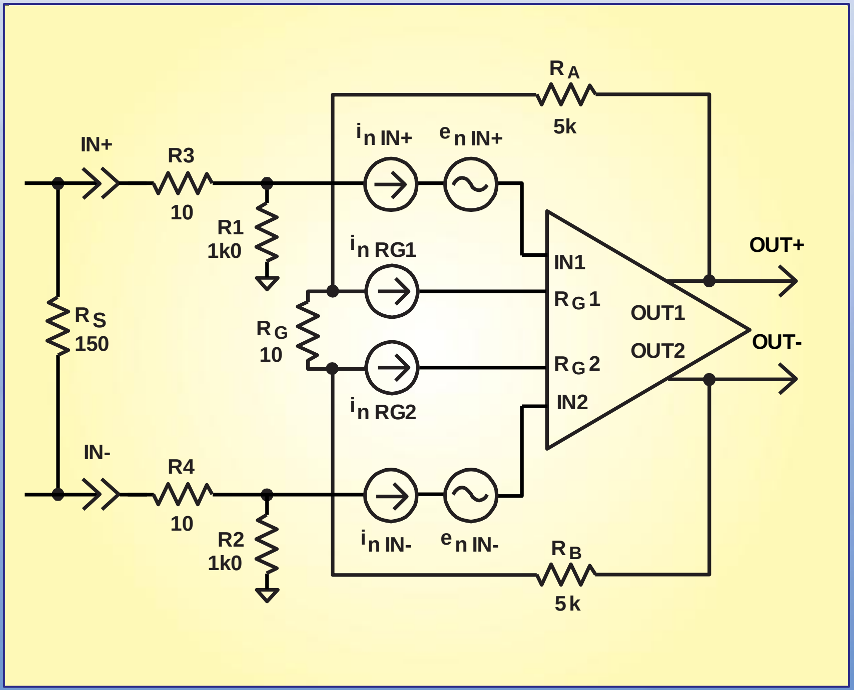
- $e_{nIN+}$ & $e_{nIN-}$ are small, along with the self-noise of $R_S$
- $R_S$ is small, so the $i_{IN+}$ & $i_{IN-}$ contributions are small
- $R_G$ is open, so the two $i_{nR_G}$ currents flow through $R_A$ & $R_B$
  - $i_{nR_G}$ currents dominate the noise floor
- To reduce noise at low gains, reduce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



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)

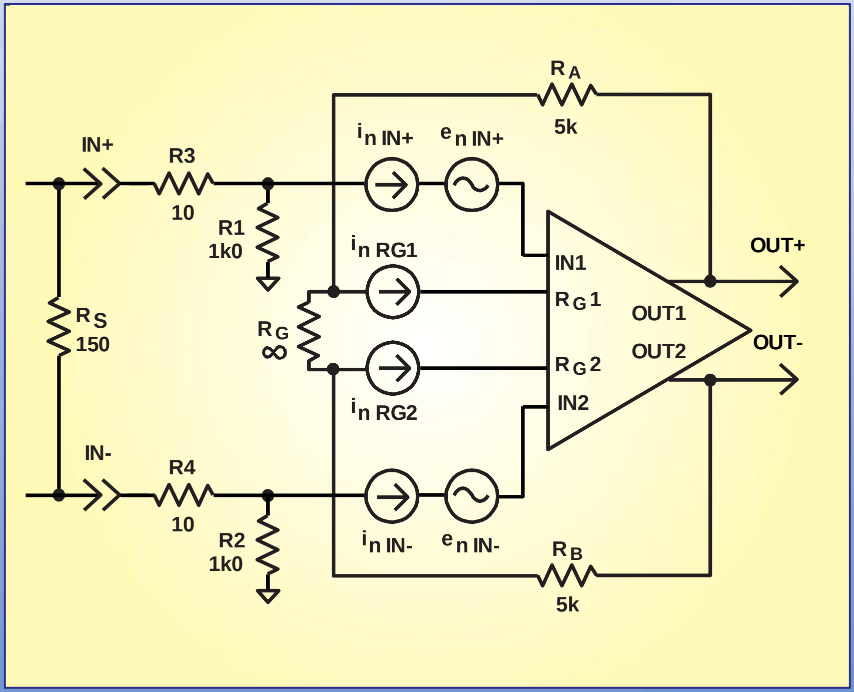
- $R_G$ is small, so $i_{nR_G}$ contribution is small
- $R_S$ is small, so the $i_{nIN+}$ & $i_{nIN-}$ contributions are small
  - As with 1570, if $R_S$ is large (e.g., open inputs), $i_{nIN}$ contributions can be significant
- $e_{nIN+}$ & $e_{nIN-}$ dominate, along with the self-noise of $R_S$



High-gain noise depends more on IC characteristics and source impedance than anything else

# 1510 (Front End) Noise At Low Gains (0dB Shown)

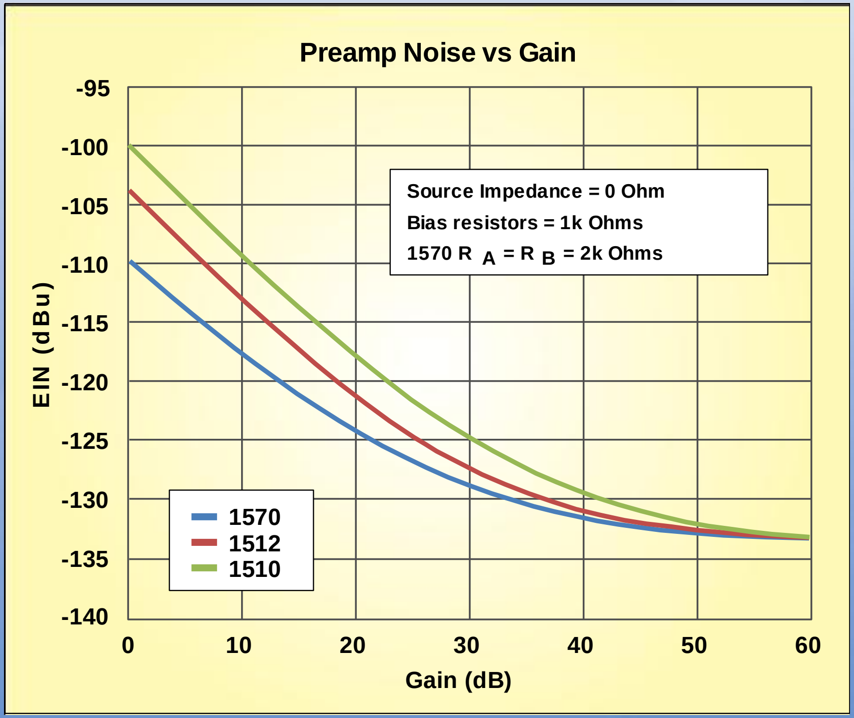
- $e_{nIN+}$ & $e_{nIN-}$ are small, along with the self-noise of $R_S$
- $R_S$ is small, so the $i_{nIN+}$ & $i_{nIN-}$ contributions are small
- $R_G$ is open, so $i_{nRG1}$ flows through $R_A$, & $i_{nRG2}$ flows through $R_B$
  - $i_{nRG}$ currents dominate the noise floor
- Since $R_A$ & $R_B$ are 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

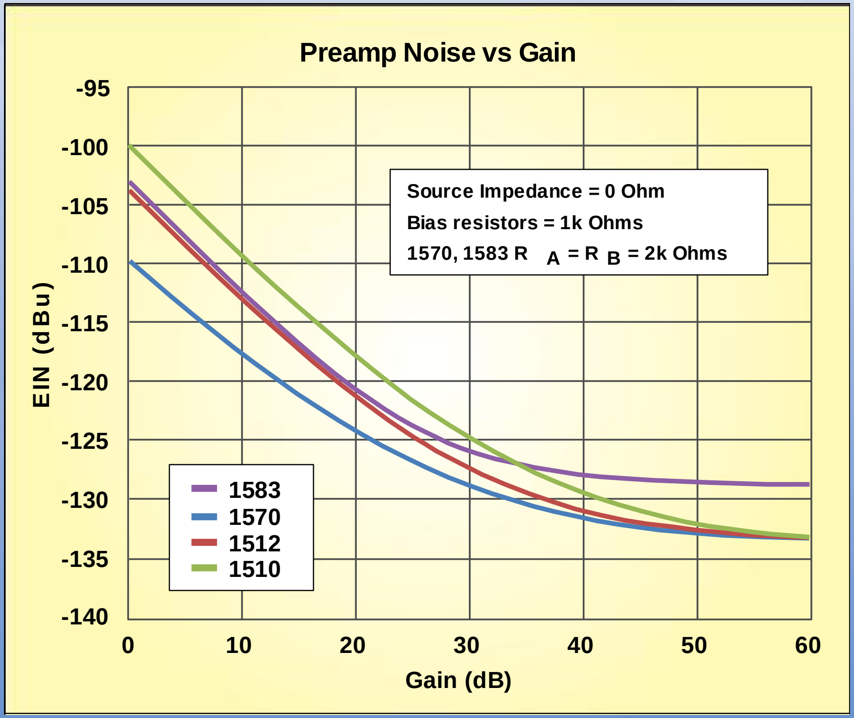
- High-gain noise is same (1nV/√Hz) across 1510, 1512, & 1570
- Low-gain noise can be controlled in new topology, but not in standard topology
  - Requires the designer to supply $R_A$ & $R_B$



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 $R_A = R_B = 5\text{k}\Omega$
- In 1570 & 1583, you can vary $R_A$ & $R_B$
  - Lower values => higher bandwidth
  - Minimum value is 2kΩ

| Gain (dB)<br>Part | 0 | 6 | 10 | 20 | 30 | 40 | 50 | 60 | |
|---|---|---|---|---|---|---|---|---|---|
| 1510 | 10.39 | 10.22 | 10.14 | 9.95 | 9.48 | 8.11 | 5.25 | 2.28 | MHz |
| 1512 | 11.95 | 11.84 | 11.65 | 11.15 | 9.76 | 6.66 | 3.04 | 1.07 | MHz |
| 1570 (2kΩ) | 16.78 | 16.78 | 15.65 | 12.71 | 7.83 | 3.65 | 1.38 | 0.46 | MHz |
| 1570 (5kΩ) | 4.19 | 4.19 | 4.19 | 3.91 | 3.41 | 2.41 | 1.12 | 0.43 | MHz |
| 1570 (10kΩ) | 1.93 | 1.91 | 1.91 | 1.86 | 1.72 | 1.39 | 0.87 | 0.40 | MHz |
| 1583 (2kΩ) | 13.97 | 13.00 | 12.01 | 8.73 | 4.33 | 1.69 | 0.59 | 0.19 | MHz |
| 1583 (5kΩ) | 3.92 | 3.60 | 3.40 | 2.95 | 2.20 | 1.24 | 0.52 | 0.19 | MHz |
| *1583 (10kΩ)* | 1.56 | 1.50 | 1.47 | 1.38 | 1.19 | 0.84 | 0.44 | 0.17 | MHz |

# Optimization Details

Noise

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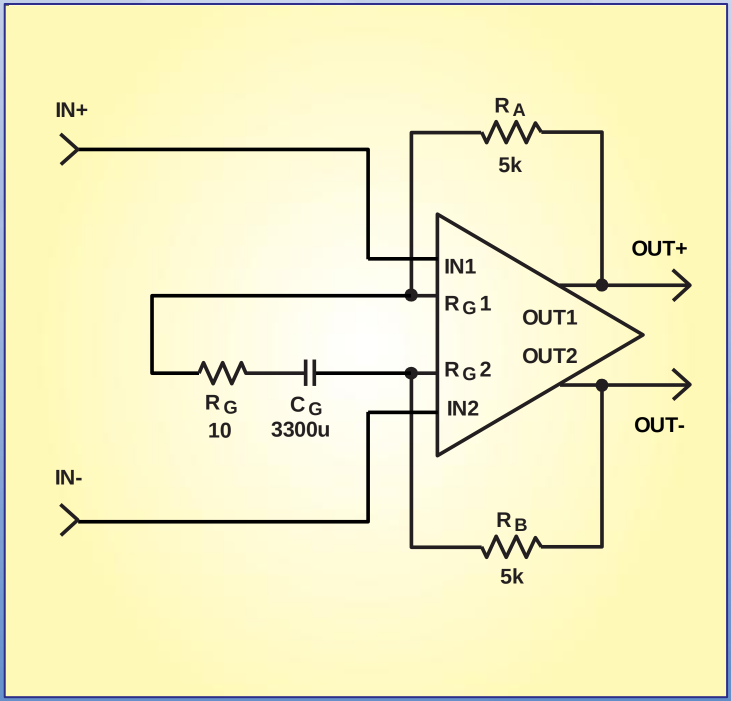
Output & Common-Mode Rejection

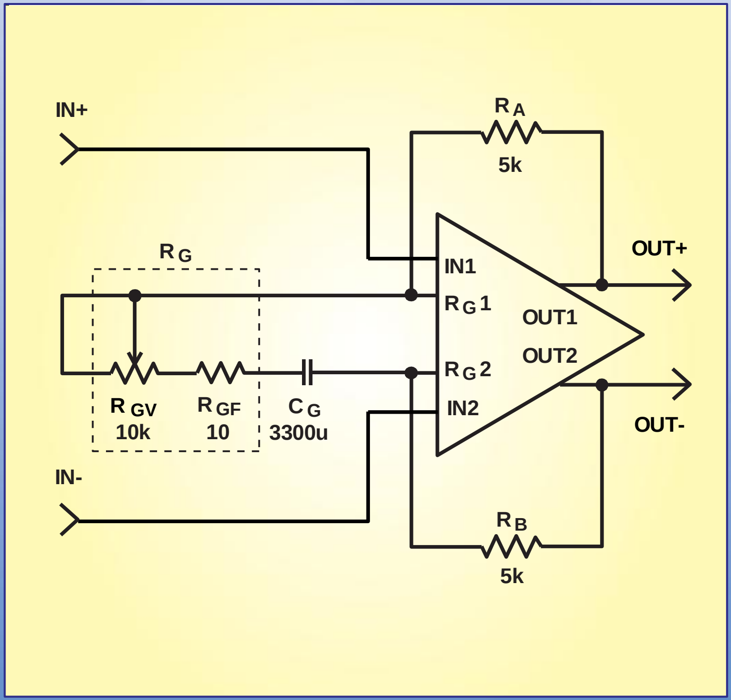
# Practical Considerations for $R_A$ & $R_B$

- $R_G$ 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

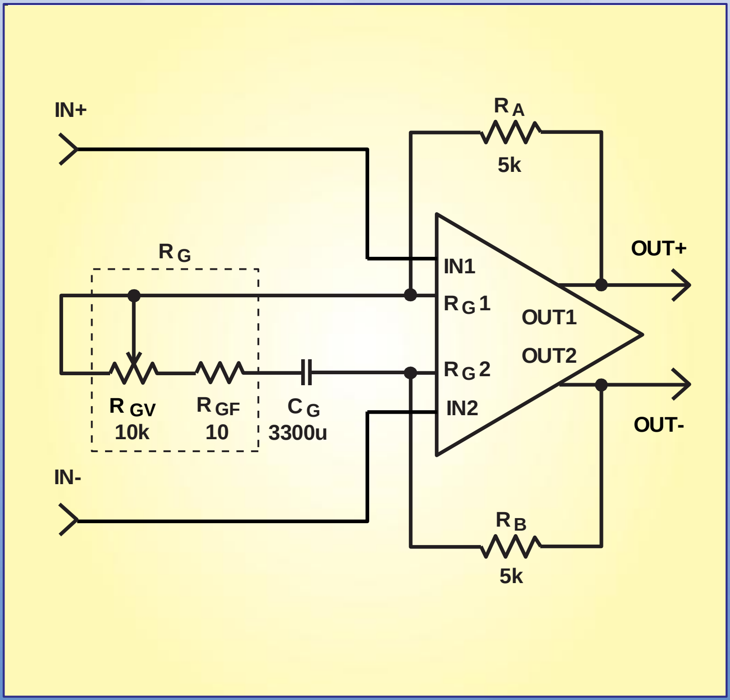
- $R_G$ varies to set gain
- Max gain when $R_{GV}$ is maximum
- Min gain when $R_{GV}$ is minimum
- Highest low-frequency cutoff occurs at max gain
- $C_G$ depends on desired LF cutoff and $R_{GF}$ value



$C_G$=3300µf, $R_G$=10Ω, $f_o$= 4.43Hz

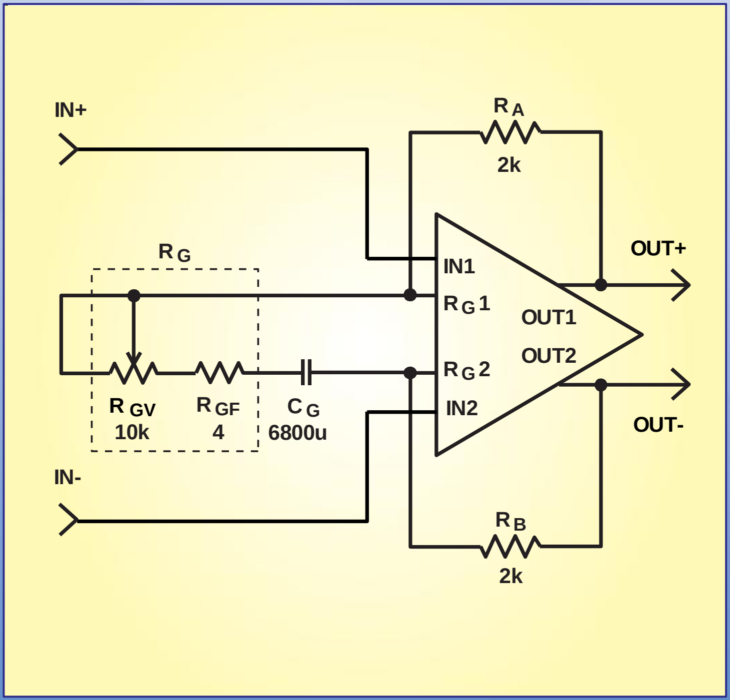
# Practical Considerations for Varying Gain in the "Standard Circuit"

- 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 …



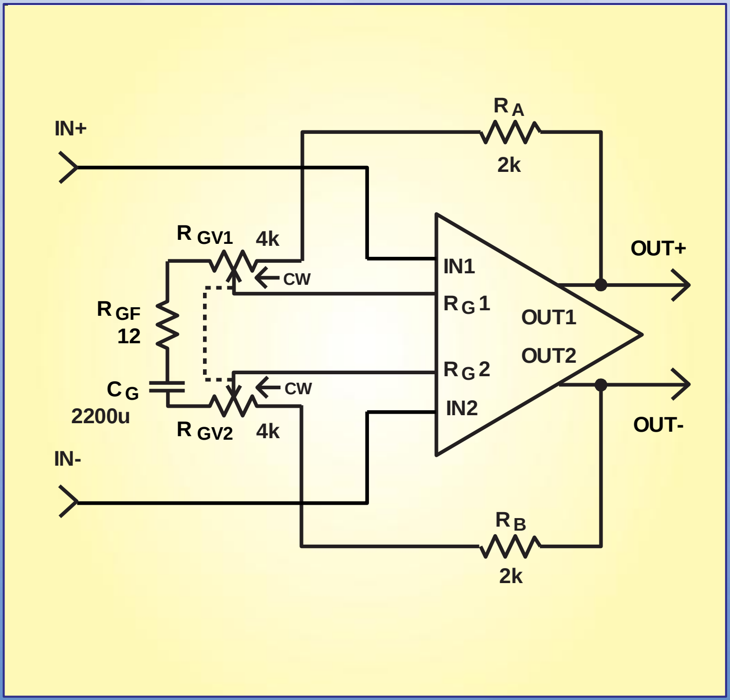
# Practical Considerations for Varying Gain in the "New" Circuit

- 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?



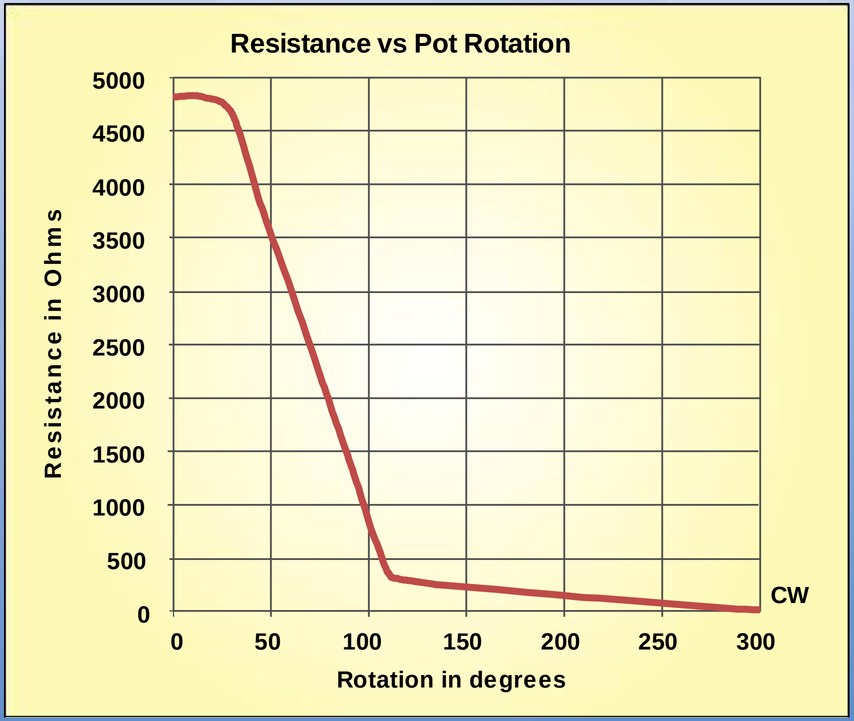
# Consider a Dual-Element Pot to vary $R_G$, $R_A$ & $R_B$ Simultaneously

- 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 $f_o \approx 5.5$Hz
  - 60dB gain noise is still very low: 1.18nV/√Hz (-129.1dBu with 150Ω source)



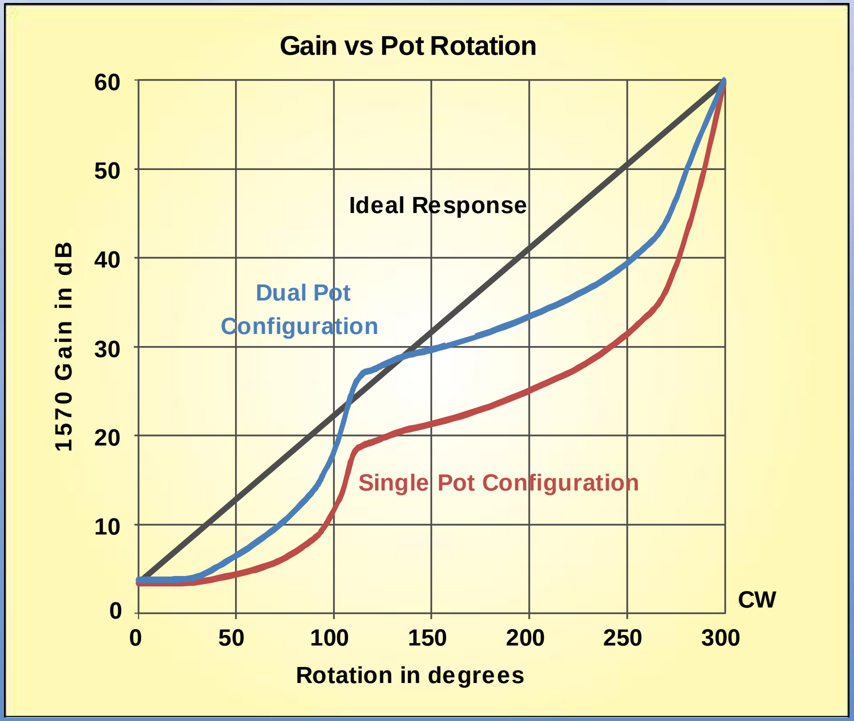
# Pot Taper

- 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?



# 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

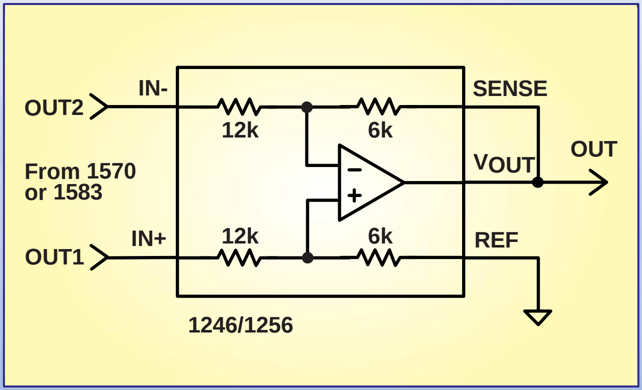
Bandwidth

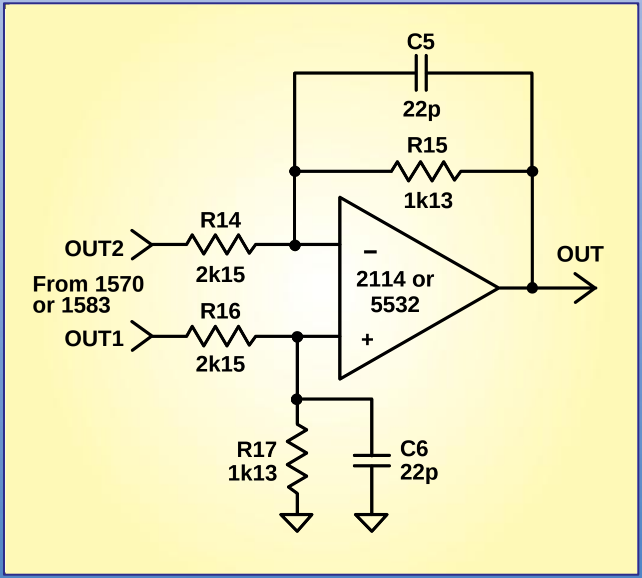
Gain control, taper & DC offset

Output & Common-Mode Rejection

# Single-Ended Output Stages

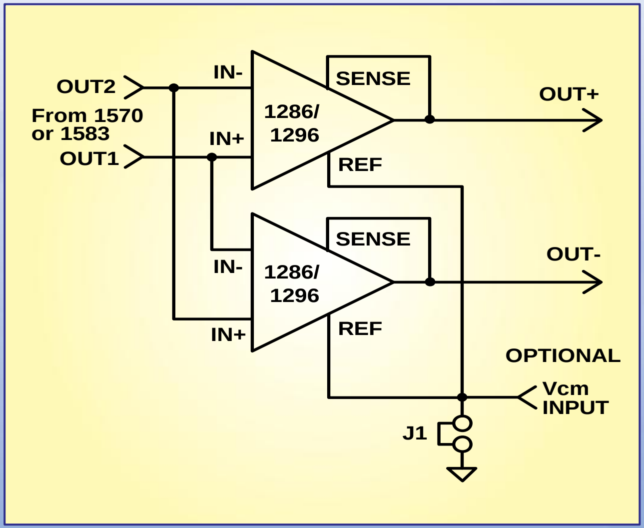
- The 1570/1583 topology is differential in, differential out
  - Common-mode gain is always unity (0dB)
  - Differential gain varies with $R_G$, $R_A$, & $R_B$ (0~>60dB)
  - CMRR is equal to differential gain
  - Output has a (negative) common-mode DC offset of 1 diode drop (~-0.6V)
- To provide CMR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

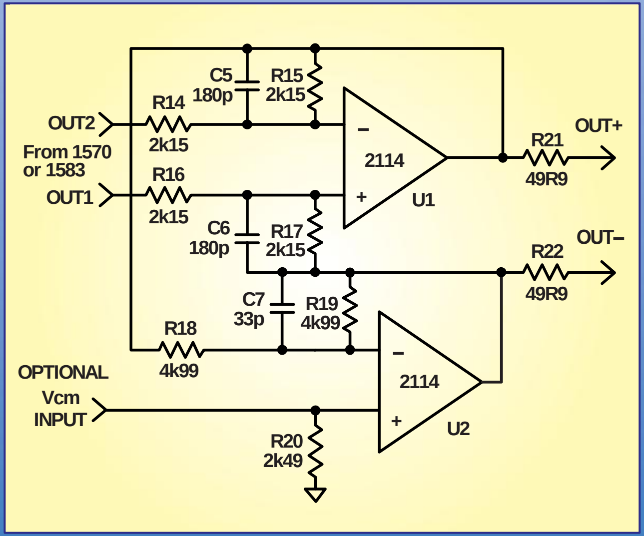




# Differential Output Stages

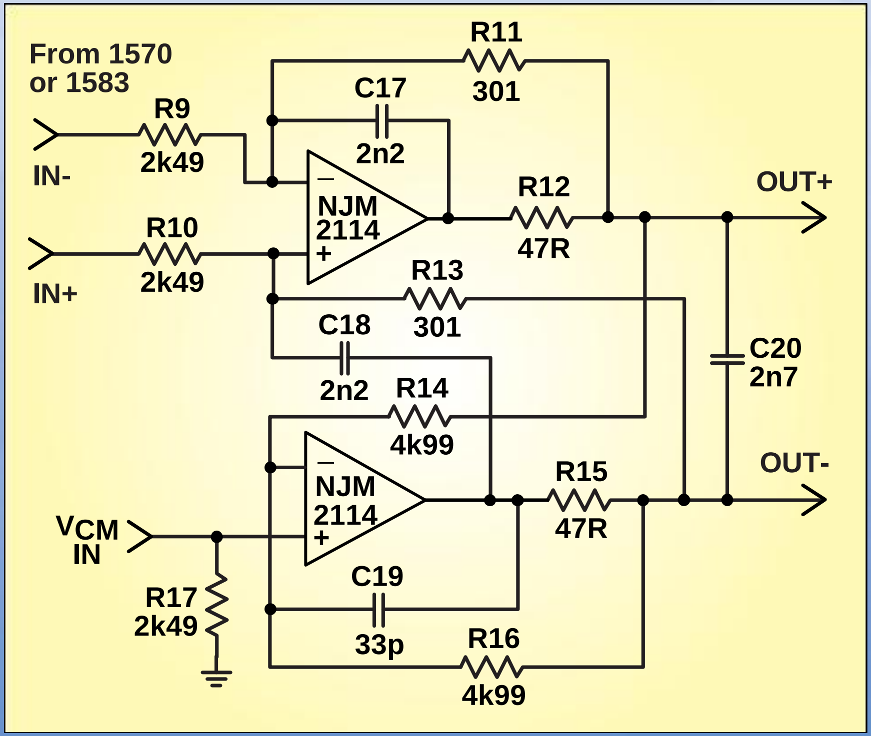
- In many cases (e.g., driving ADC), differential outputs are needed
- But, many designers want to remove common-mode signals
- Simple circuit (top, using 1286) has great common-mode rejection, fair noise performance
- More complex circuit (bottom, after Birt) maintains very low differential noise, but 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 performance
- Less really is more!

# Thank You to …

- Joe Lemanski (THAT's Applications Engineering Manager), for many of the facts & figures contained herein
- Gary Hebert (THAT's Chief Technical Officer) & Fred Floru (THAT's Principal IC Design Engineer) for general review and much tutoring in $R_A/R_B$'s influence on noise
- Dave Lail (THAT's Art Director) for providing the drawings, and putting up with endless revisions
- Steve Green (THAT's Technical Marketing Manager) for many suggestions
- Dan Parks (now President of Cruz Tools, was the marketing guy at SSM), for help with early preamp chronology and credits.
- All of you in the audience for attending and supporting us!