ANALOG DEVICES

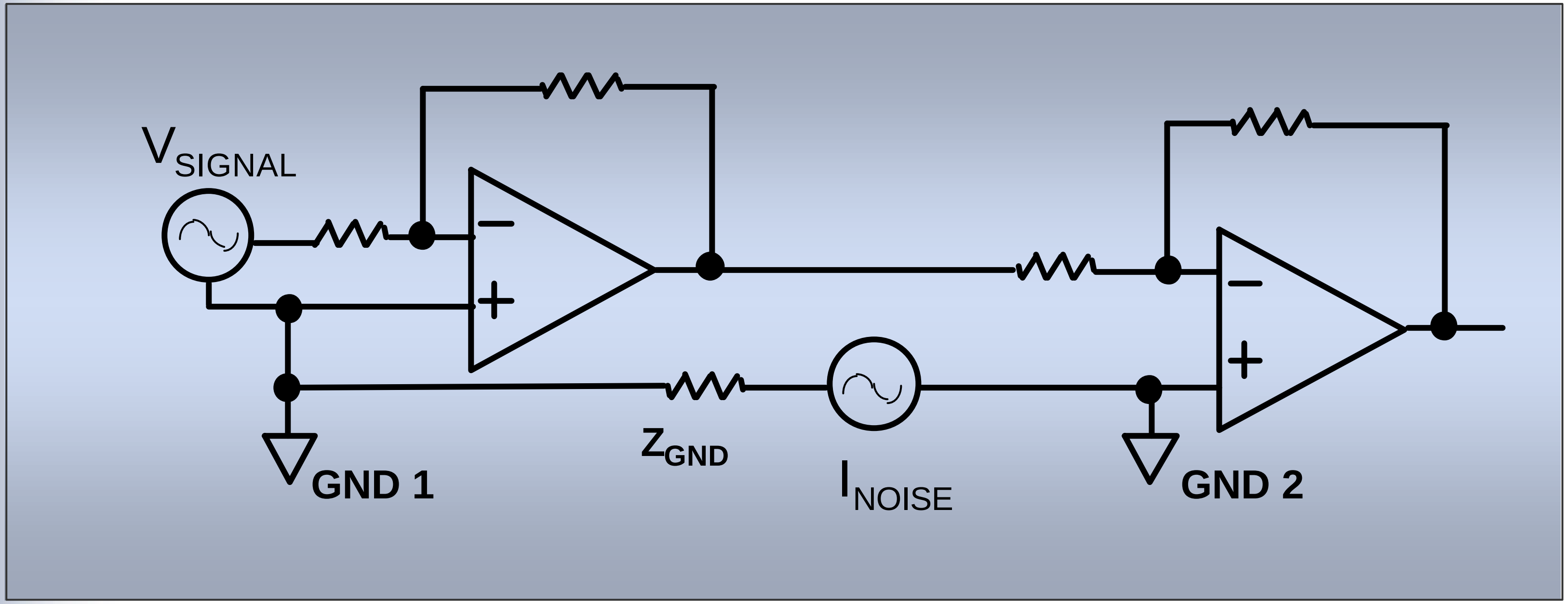
Differential Amplifiers

Benefits of Differential Signal Processing

- The Benefits Become Apparent when Trying to get the Most Speed and/or Resolution out of a Design
  - Avoid Grounding/Return Noise Problems
  - Better Distortion/Dynamic Range
    - For the same Amplitude Differential Signal the Outputs do not Swing as Close to the Rail
    - Lower Distortion especially the 2nds
  - Analog Signals in High-performance Systems Start and End Differential
    - Almost Always the Signal Source from the Real World is Differential
    - High-speed ADCs Have Differential Inputs

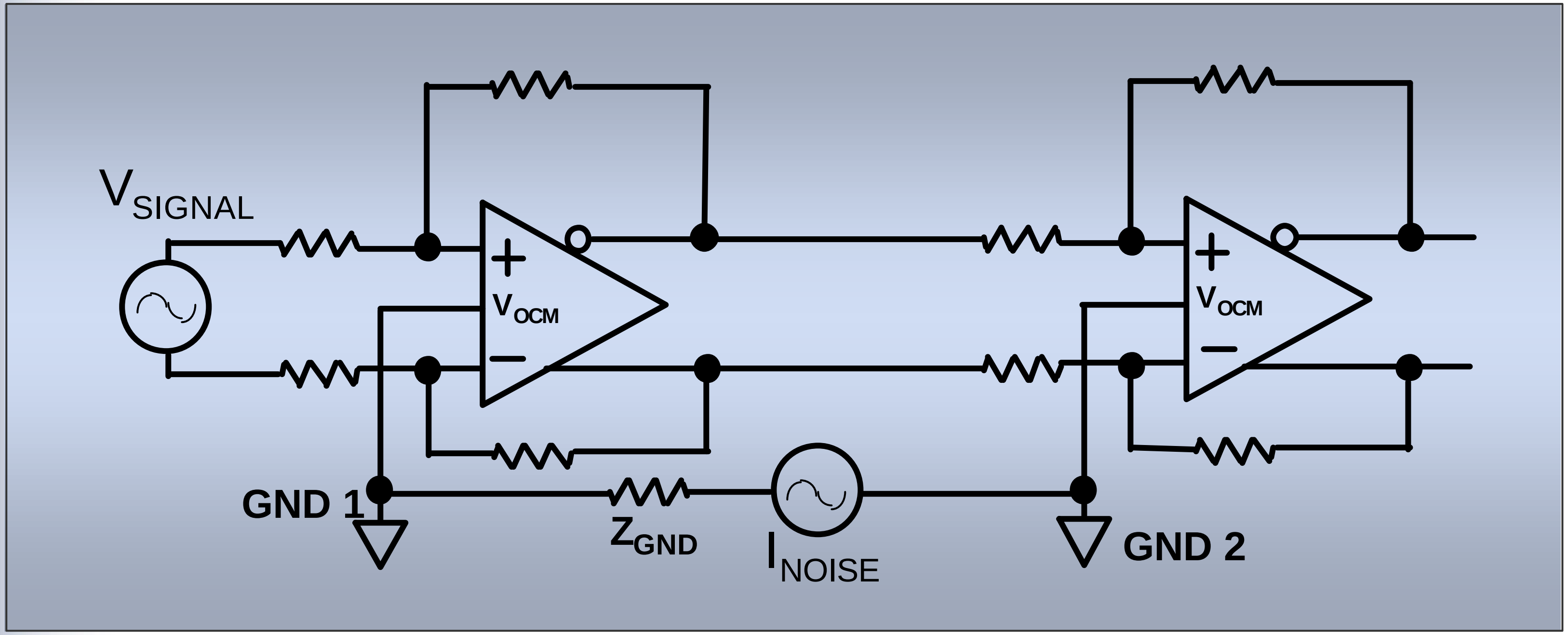
Single-ended Components Cannot Reject Ground Noise

- Each Part of the Circuit Has a Different Reference Point
- No Matter How Careful you are with Grounding High Frequency Ground Currents will Cause Some Problems which May be Difficult to Work Around
- Op Amp Can not Reject This Ground Noise



Differential Amps Have Effective CMRR

- Differential Signal does not Need a Reference
- Ground and Other Noise Sources are Common to Both Inputs
  - CMRR of Differential Amp is Effective

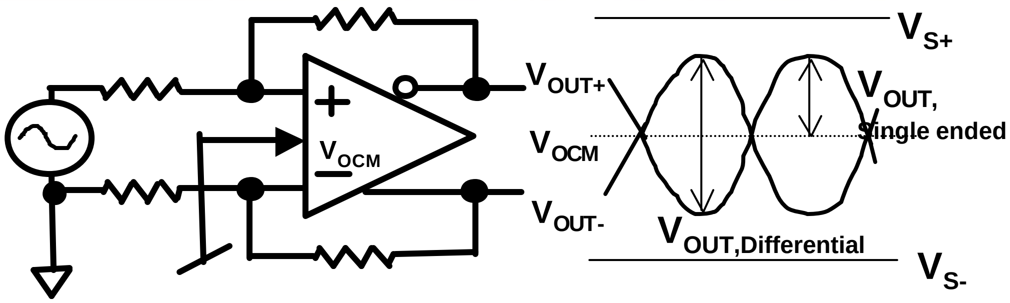


Why Differential Signal Processing is not More Common

- Differential Signals are Commonly used Today for ADC and Line Driving
- Differential Signaling is not Generally Considered for Other Uses Because:
  - Discrete Differential Designs can Be Difficult to Implement
    - Some Applications can not Tolerate the Higher Cost
  - Not Many Differential ICs are Available
    - Transformers must be Used
- As Speeds and Resolution Increase the Benefits of Differential Signaling Become More Necessary

Differential Input/Output
High-speed Amps
AD8131/2/8

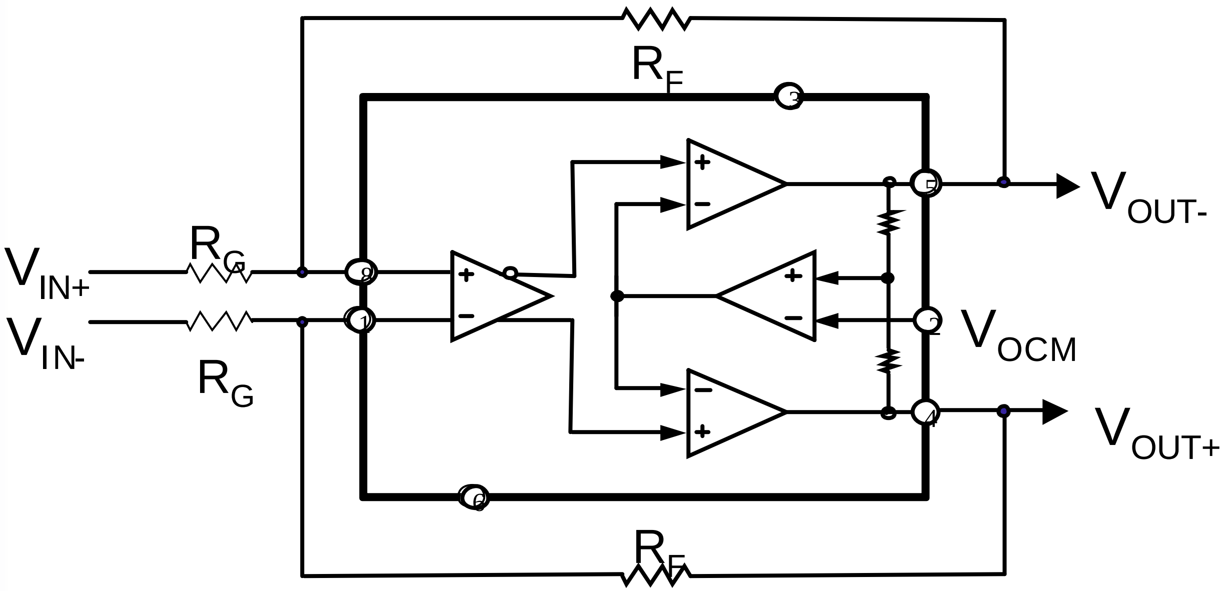
High Speed Differential Amps for Challenging Designs



- Differential Signal Processing Simplifies Circuit Design
  - Avoid Ground Noise
  - 2x Dynamic Range of Op Amps
  - Balanced Outputs Minimize EMI
  - High CMRR Reduces EMI Susceptibility
- High Speed ADC Driving
  - ADCs Perform Better when Driven Differentially
- Like a Voltage Feedback Op Amp:
  - Gain Set by Ratio of R_F/R_G
    - Signal Gain, Filtering, Level Shifting, Buffering / Driving

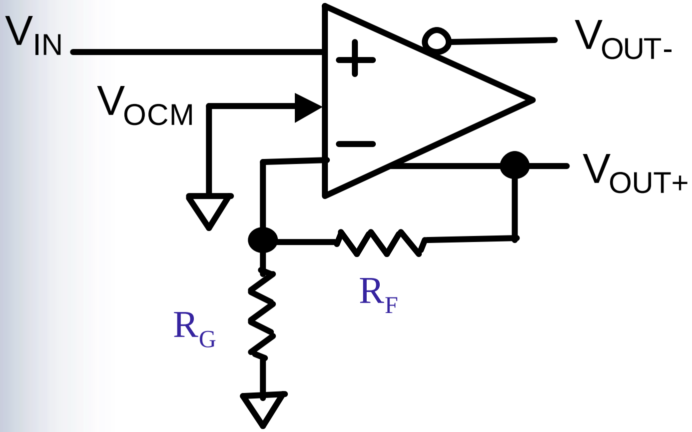
What's Inside the AD8131/2/8 Diff Amps?

- Internal CM Feedback forces Forces both outputs to be balanced,
  - Equal in amplitude 180° out of phase: $V_{OUT, CM} = (V_{OUT+} + V_{OUT-})/2)$
    - Balance is unaffected by R_F/R_G matching
- Differential feedback effectively creates 2 summing nodes
  - Forces Both Inputs to the same voltage when the loop is closed
  - High Input Z, Low Output Z

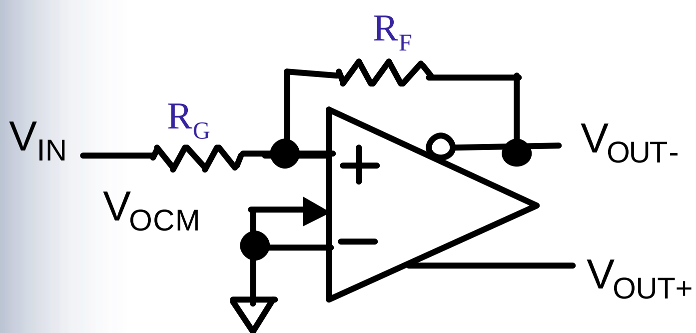


Understanding How They Work w/ Alternate Circuit Configurations

Like Non-inverting Op Amp



Like Inverting Op Amp



- 2 Feedback Loops
  - Differential feedback forces inputs to the same voltage
  - Common mode Feedback forces $V_{OUT-} = -V_{OUT+-}$
- Non-inverting example:
  - For $R_F = 0$
    - $V_{Out+} = V_{IN}$
    - Gain = 2
- Inverting example:
  - For $R_F = R_G$
  - High input Z summing node
    - $V_{out-} = -V_{IN}$
    - Gain = 2

More About the V_{OCM} Pin

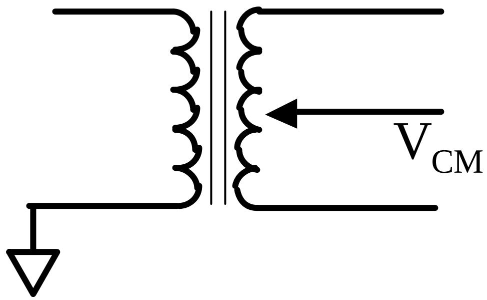
- V_{OCM} Pin separates our diff amps from other diff amp configurations
  - Creates Best Available Balance @ High Frequencies
  - Can be used with AC signal for Modulation as well as DC Reference Voltages
- Easy Level Shift
  - From Ground Referenced Signals (+/-5V supplies) to Single +5V Supply Signals for ADCs
  - Better Distortion in signal chain for +/-5V, than +5V
  - Connect to the ADC reference or any other reference voltage

AD8131/2/8 vs. Dual Op Amp Configurations

- Compared to Dual Op Amp Configuration for Differential Driving:
  - 2 Op Amps, G = +1 and G = -1
    - – Output Dynamics are Different at High Frequencies
      - ⌫Poor output balance; EMI emissions
  - No Easy Way to Change Common Mode Output Level
  - Distortion Products are Additive
    - – AD8131/2/8 even harmonics are Nulled by the Common Mode Feedback and Odd Harmonics are low by design

AD8131/2/8 vs. Transformers

- AD8131/2/8 are similar to Center-taped Transformers
  - Differential or Single-ended In with Differential Out
  - CM Output Adjustment

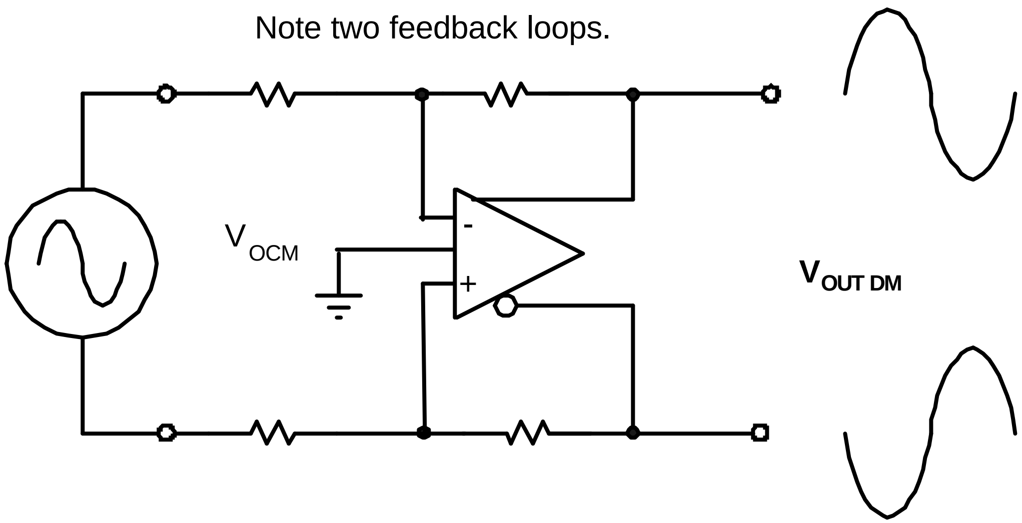


- AD8131/2/8 :
  - Bandwidth to DC
  - Does not require I/O impedance matching
  - Can have signal power gain
  - Smaller in size
  - Lower cost than most transformers
  - Has higher reliability

Using the AD8138 in Active Filters

- Op amps have inverting and non-inverting inputs available.
- AD8138 inputs are both inverting
  - Filter topologies must be inverting types.

Note two feedback loops.

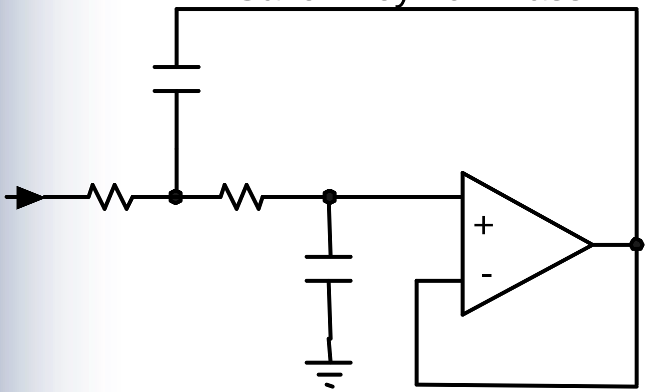


Filter Design

- Low-pass, High-pass and Band-pass Are Possible
  - Butterworth, Bessel and Chebyshev Filters can be Realized in MF filters
- MF filters are 2nd Order (conjugate pole pairs)
  - Higher order filters may be realized by stacking sections
  - Multiple Feedback Filter topologies provide a DC path for the input bias current.

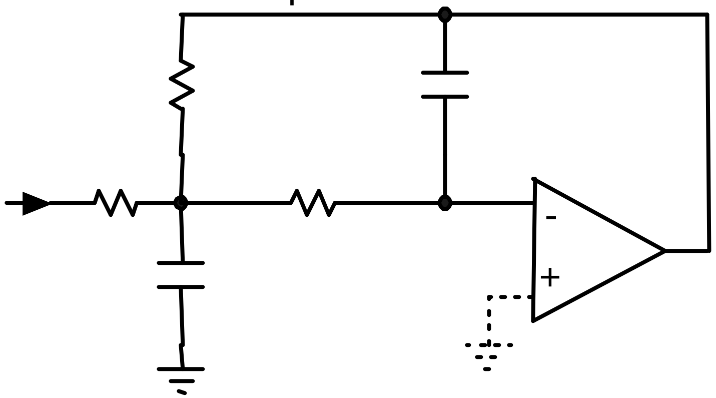
Not acceptable

Sallen Key Low Pass



Acceptable

Multiple Feedback Low Pass

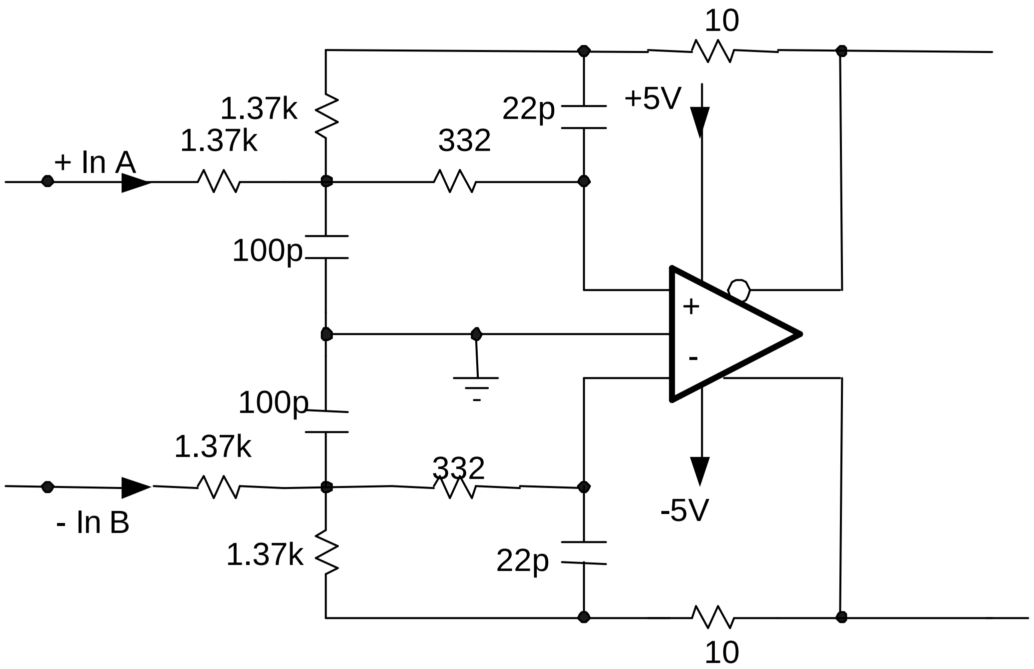


Differential Filter Characterization

- Low Pass, High pass and band-pass active filters were designed, built and tested
  - As shown in the following slides, theoretical and actual results closely agree.
- AD8138 needs Small resistor values (10-47 Ohms) in series with the feedback circuitry to prevent oscillation at approximately 300 MHz.
- AD8132 does not Require a small resistor
- Feedback capacitance greater than a few pF may result in high frequency de-stabilization of the AD8132/8.

Ex.: 2 Pole Low Pass Schematic

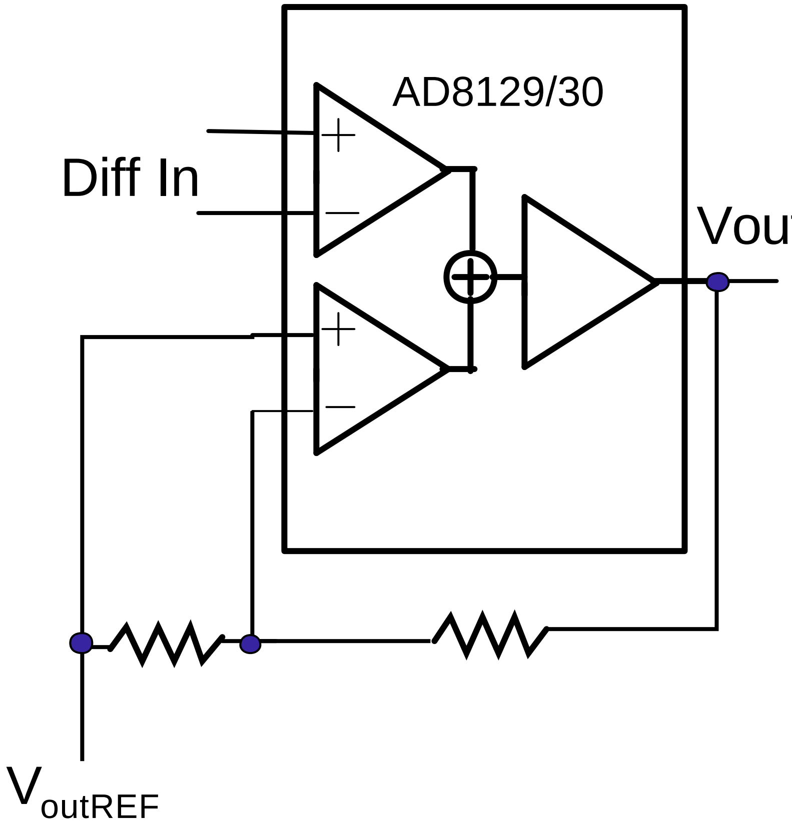
2 Pole Low Pass Butterworth
Anti-aliasing Filter, fc = 5 MHz



Differential Input to Single-ended Out Amps
AD8129/30

AD8129/30 Receivers

- Active Feedback Topology, Like the AD830
  - High CMRR @ High Freq
  - High Input Impedance
    - CMRR Insensitive to Input Z
  - Feedback network Independent of signal path
- Use as:
  - Differential Receiver
    - + & - Inputs have same Dynamic Response
  - Difference Amp
  - High Frequency InAmp

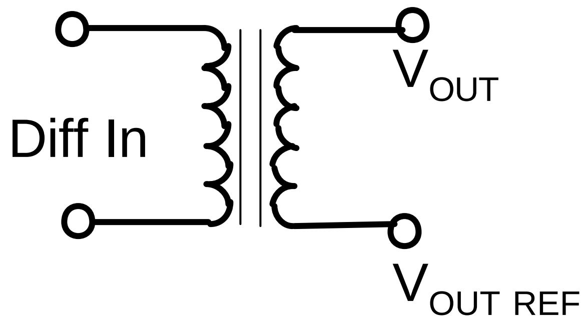


AD8129/30 vs. Op Amp Configurations

- **Compared to Single Op Amp Differential Amp Configuration for Receiver**
  - **Poor CMRR**
    - **Unbalanced Input Impedances**
    - **Requires resistor matching for good CMRR**
- **Compared to 3 Op Amp Receiver**
  - **Lots of parts and Design Time**
  - **Extra Amps in Signal path lowers BW**

AD8129/30 vs. Transformers

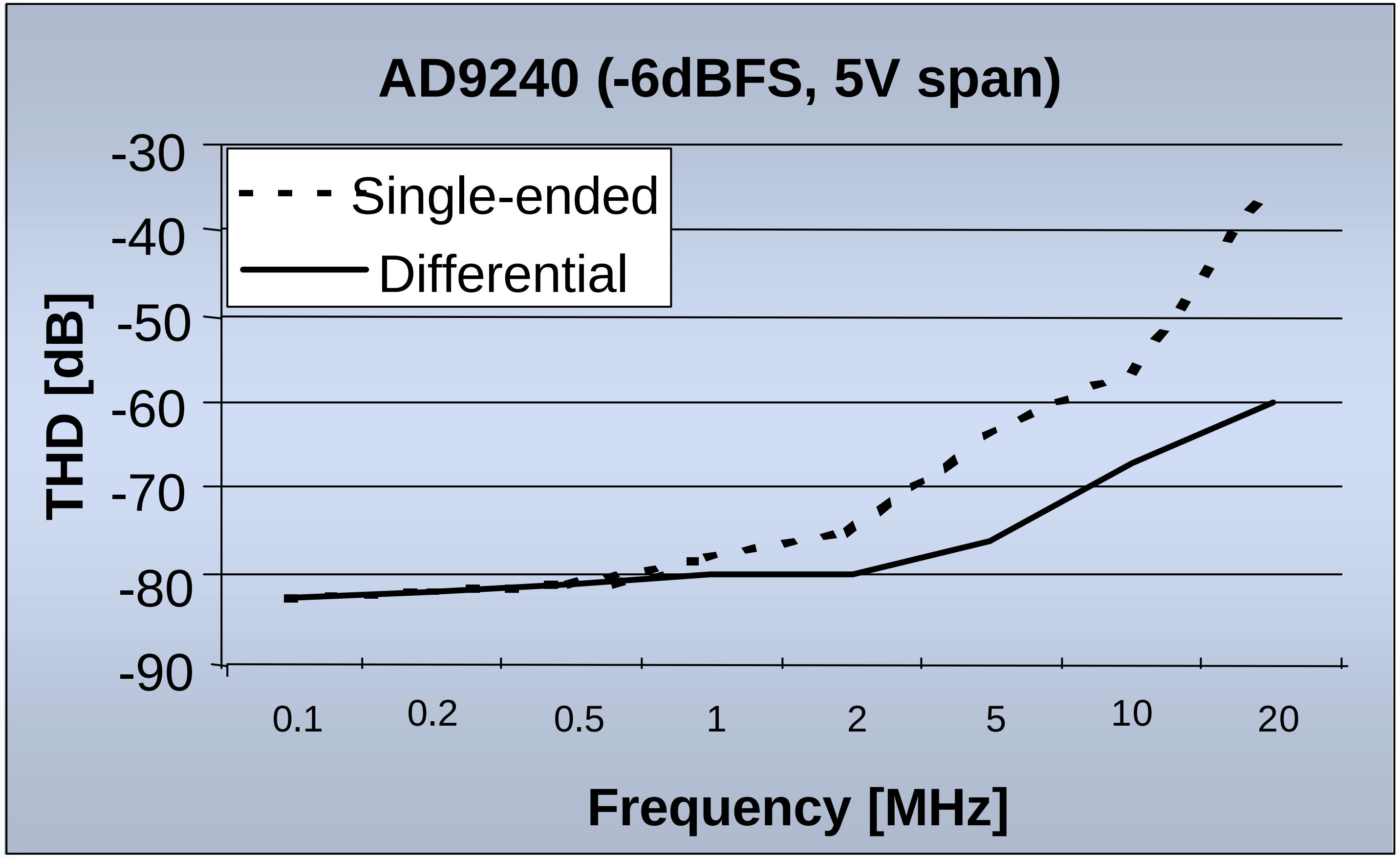
- **AD8129/30 are similar to Transformers**
  - **Differential In with Single-ended Out**
  - **Output Reference Adjustment**
- **AD8129/30 :**
  - **Bandwidth to DC**
  - **Can have signal power gain**
  - **Smaller in size**
  - **Lower cost than most transformers**
  - **Has higher reliability**



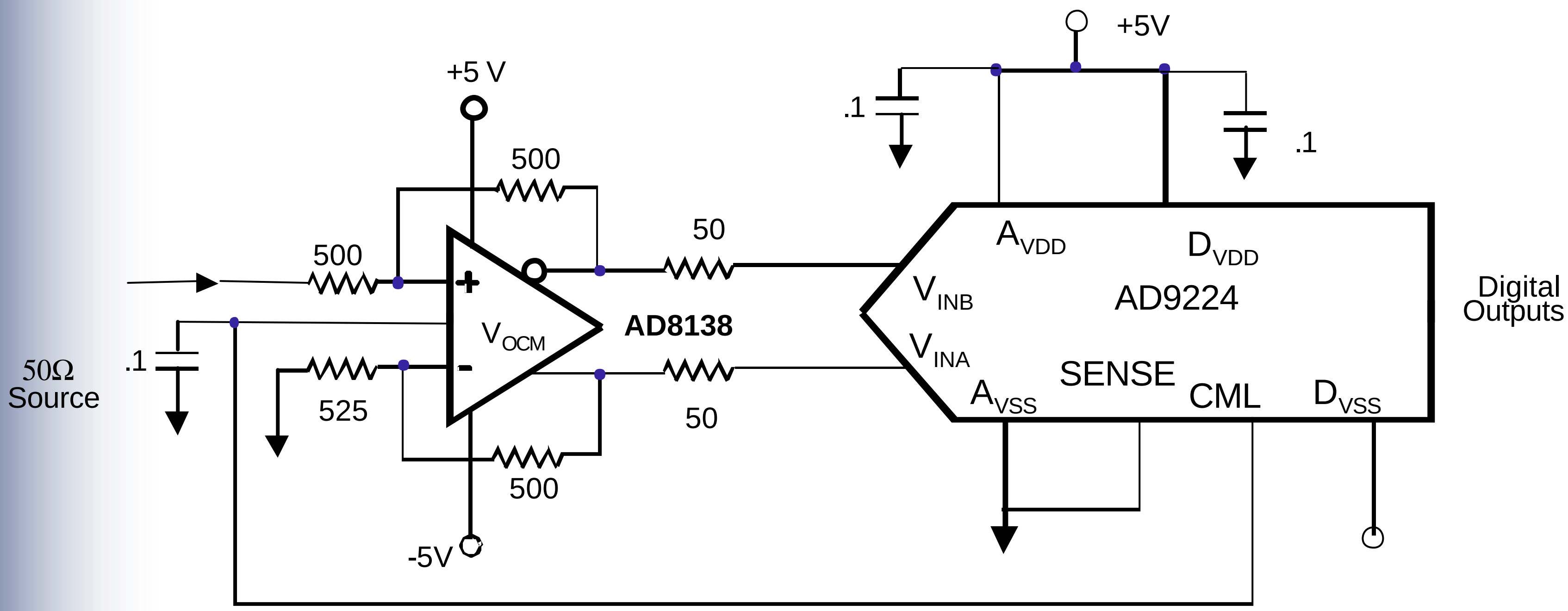
For Use with High-speed Converters

ADCs Perform Better when Driven Differentially

- Especially as Frequency Increases

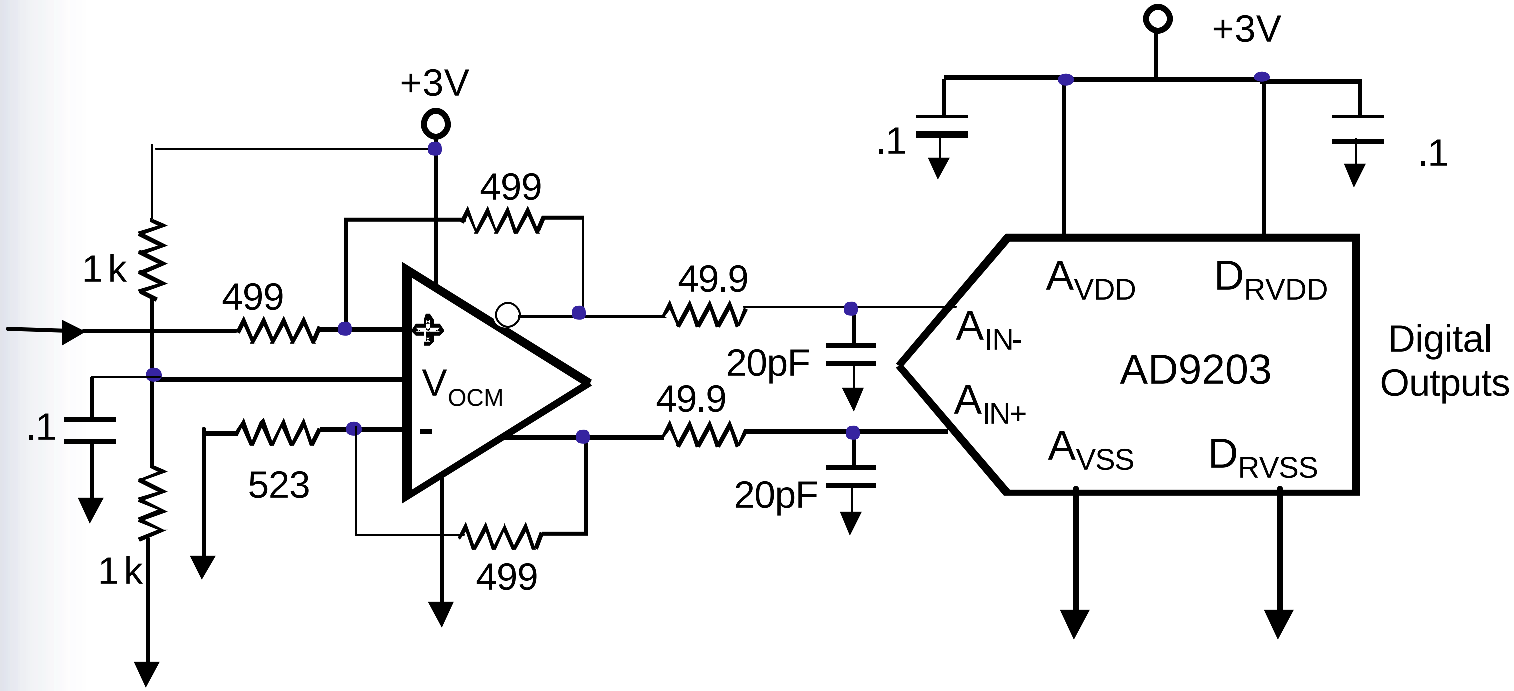


AD8138 Driving an AD9224 12-bit 40 MSPS A/D on +5V Supply



- **AD9224 Reference CML output drives V_{OCM} to set optimum CM output**
  - **Easy level shift using V_{OCM}**
- **The AD8138 provides low-distortion drive on +5V or +/-5V Supplies**

3V Circuit: AD8132 Driving an AD9203 10-bit 40 MSPS A/D

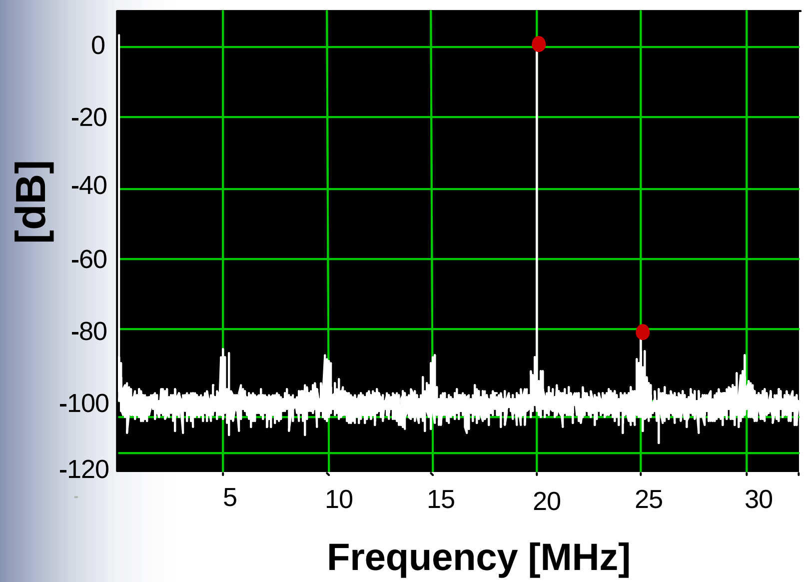


- AD8132 Provides +/-1V output swing on 3V supply with low distortion for low cost ADCs
- V_{OCM} Level Shifts from Ground-referenced input
- Resistor and capacitor between Amp and ADC needed to filter Switched-input current glitches

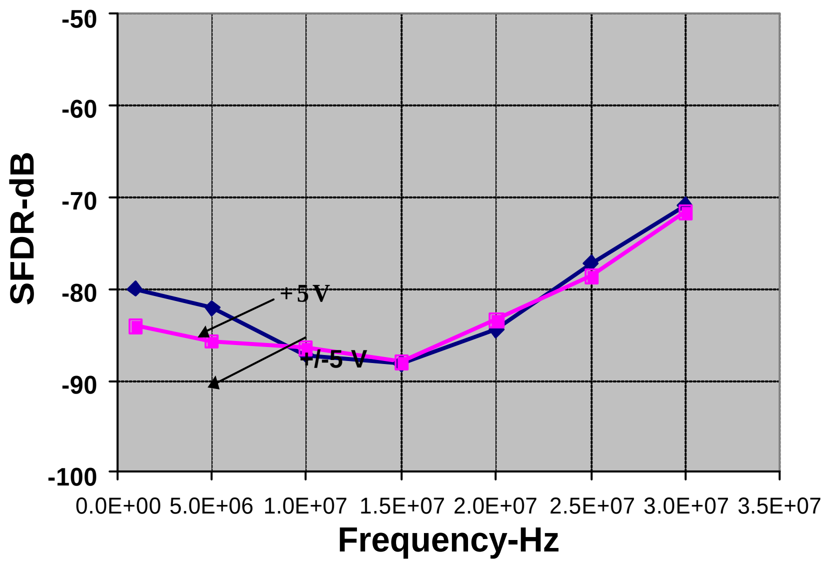
The AD8138 is the World's Best Amplifier for Driving High-speed ADCs

- > -80dB SFDR using the AD8138 to drive the AD9226

1Vp-p signal @ 20MHz



SFDR over frequency

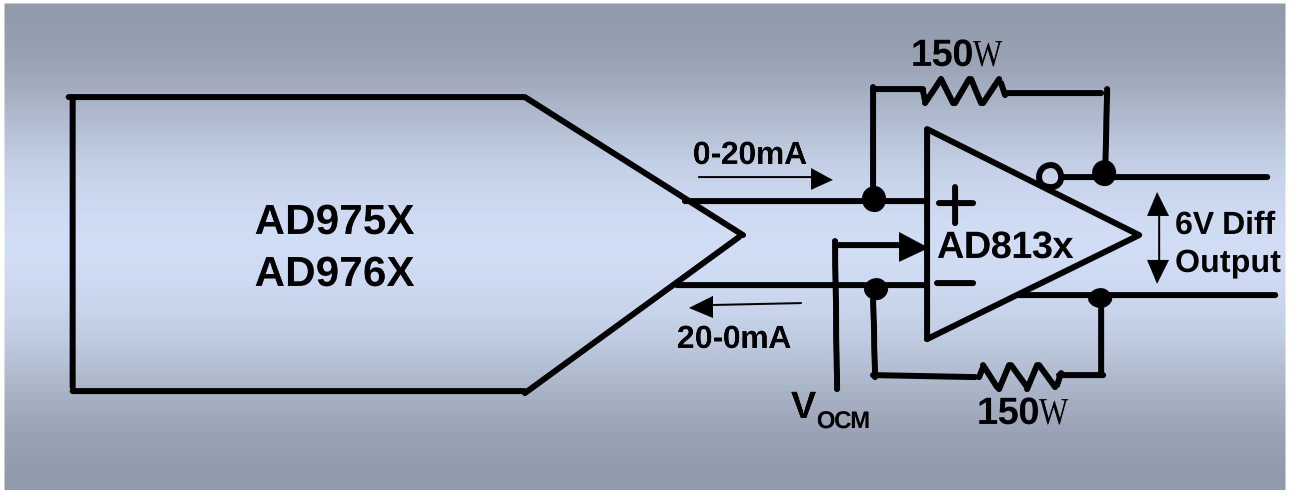


Diff amps to Help Reduce Clock Jitter

- Some ADCs have Differential Clock Inputs to Minimize Ground Noise Effects on Jitter
  - Ground Noise is only one source of jitter which decreases the performance of the fastest ADCs
- As Discussed before, With Differential Signals the Ground Noise becomes Common Mode
  - AD8131/2/8 can be used to send the clock signal from its source into the ADC
  - Isolating Analog and Digital Grounds
  - Minimizing Radiated EMI

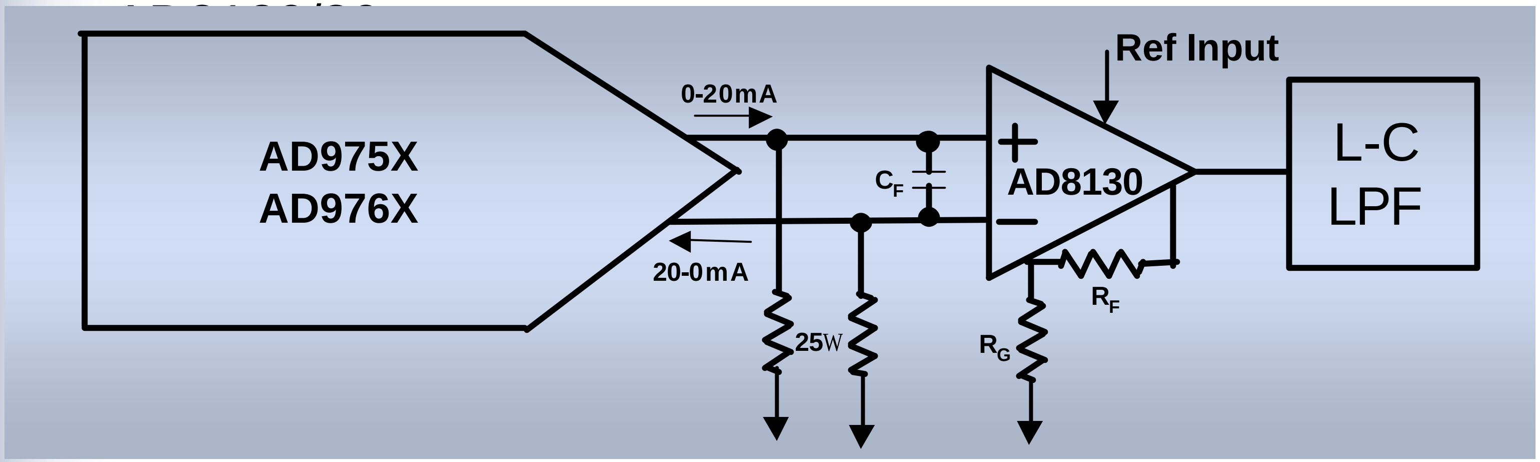
Buffered Differential Out for 12-16 bit High-speed DACs

- "Virtual GND" Reduces Effect of DAC's Nonlinear Output Impedance
  - To Achieve Larger Output Power without having a large compliance voltage on the DAC Output
  - When Level Shifting is Needed use V_{OCM}



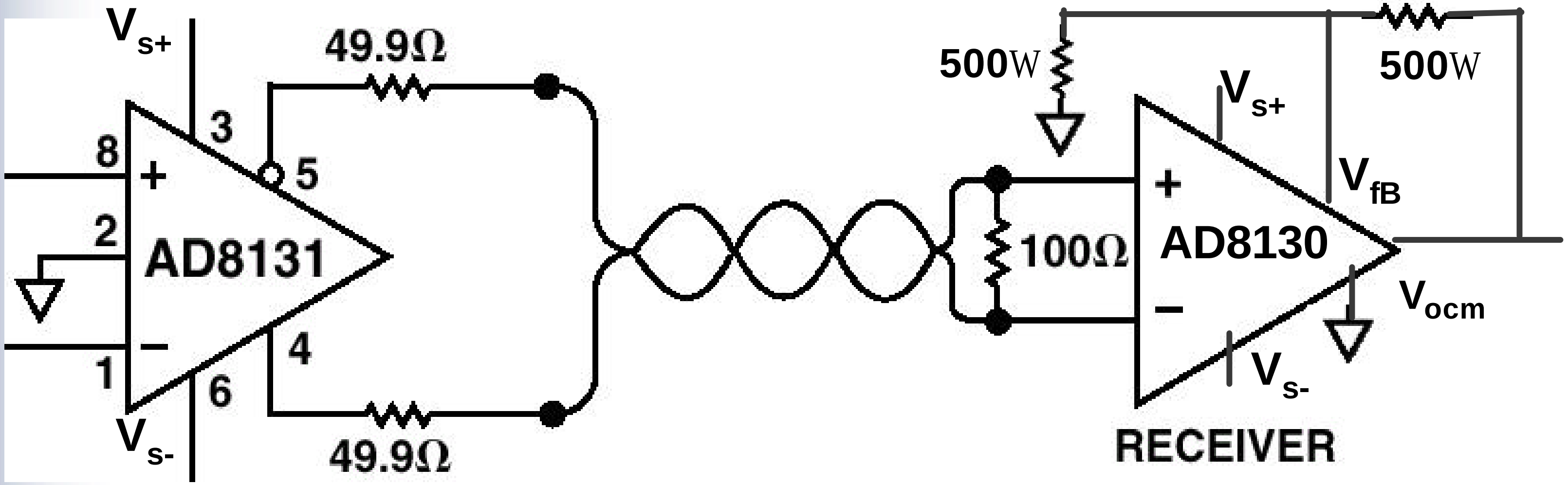
Differential to Singled-end Buffer for 12-16 bit High-speed DACs

- AD8129/30 can be used to Isolate the reactive load of the filter from the DAC output.
  - Filter cap may be needed to reduce excessive slewrate on the amp input to improve amp settling
- To Achieve Larger Output Power without having a large compliance voltage on the DAC Output
  - When Level Shifting is Needed use Ref input of the



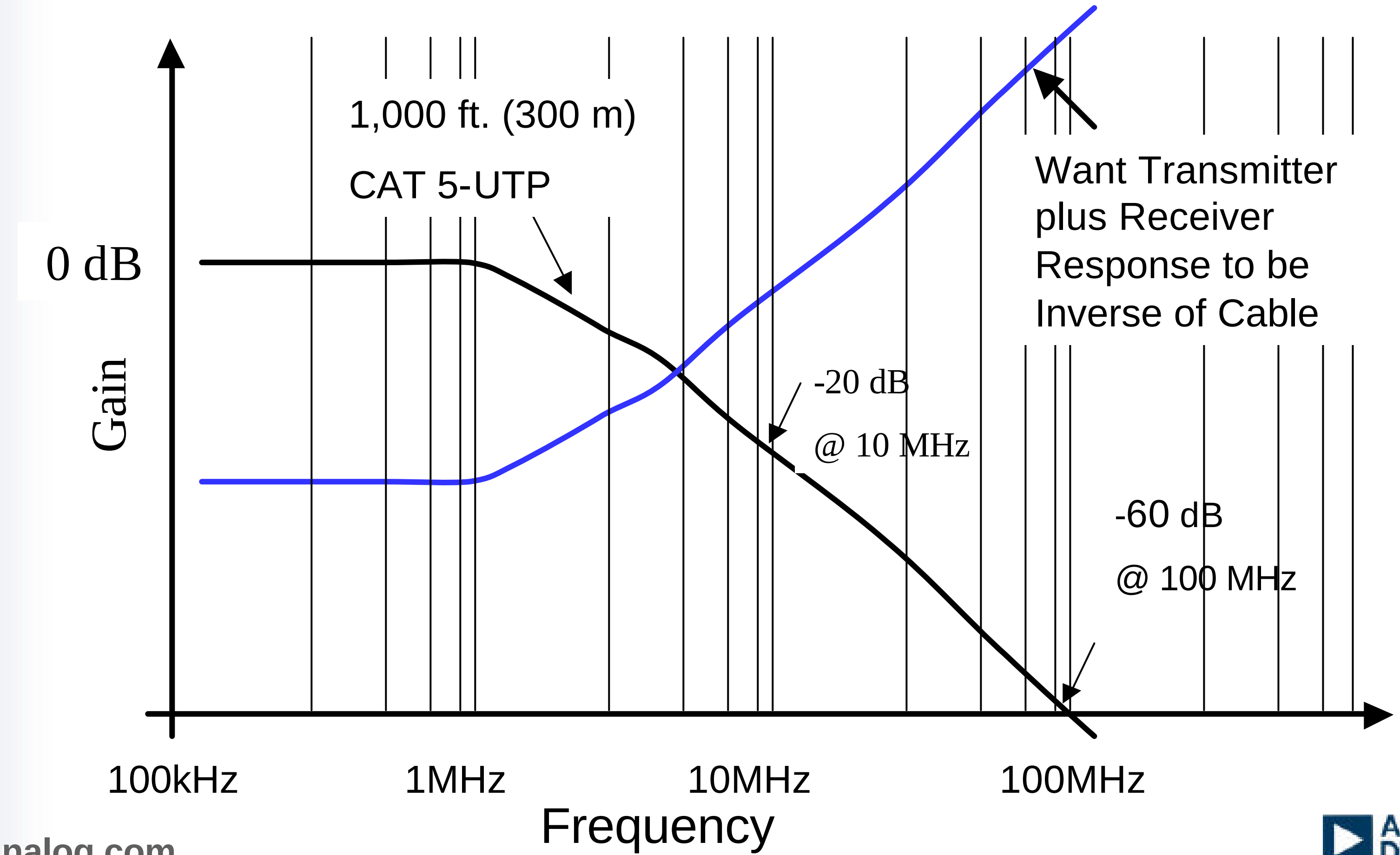
For Driving and Receiving High-speed Signals

Differential Driver and Receiver



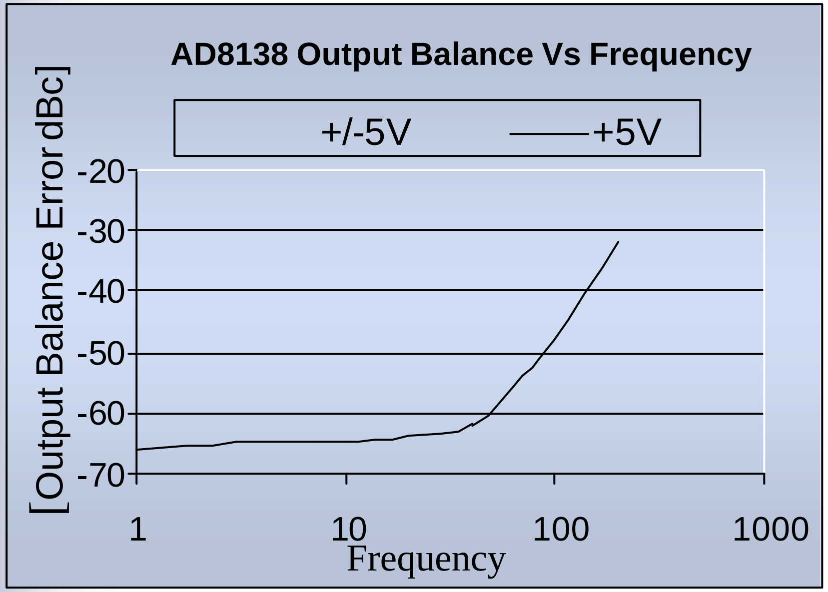
- Balanced Driver Minimizes EMI Generation
- High CMRR Receiver Minimizes EMI Pick-up

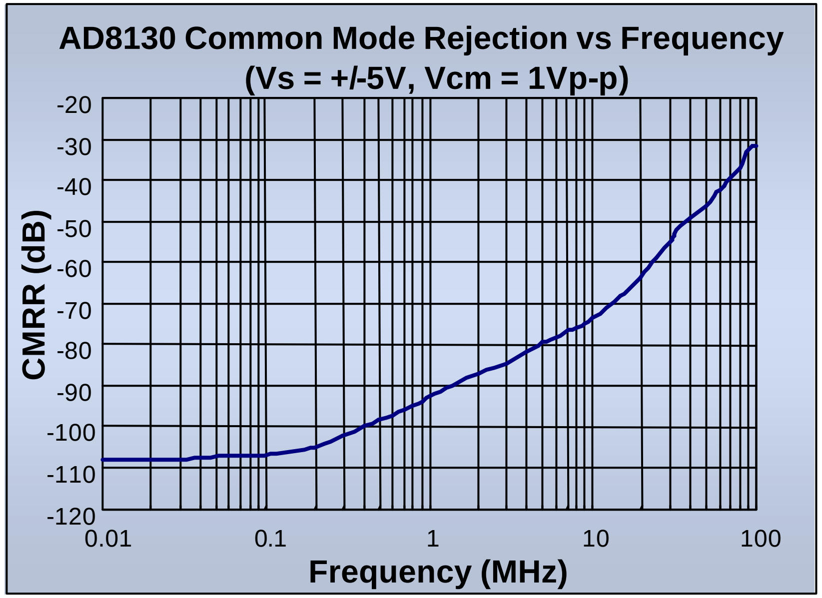
Cable Driving Challenge



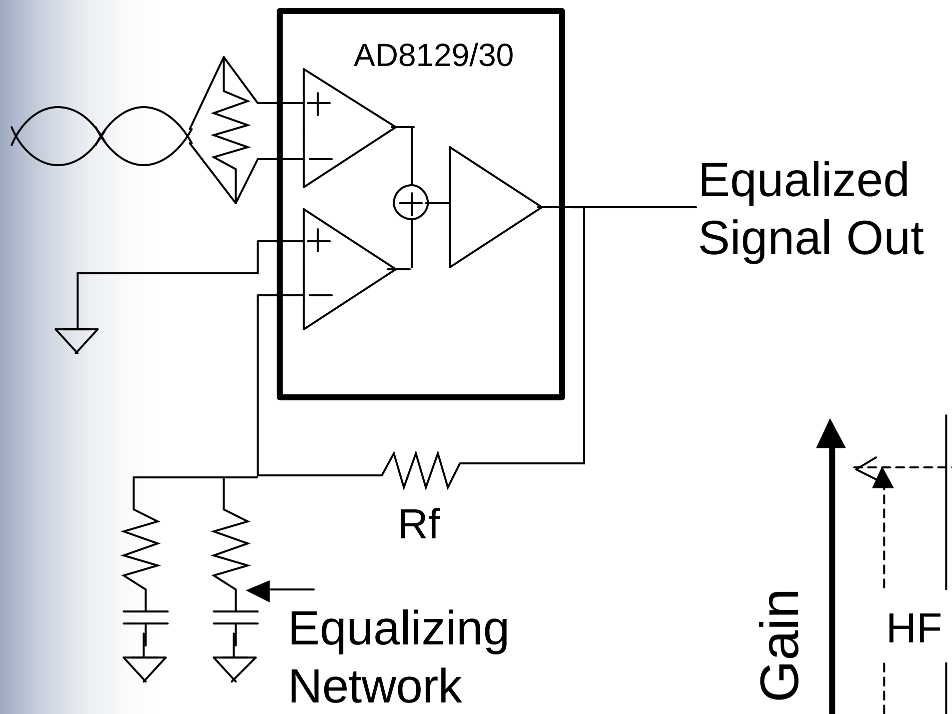
Drive / Receive Requirements

- **Driver**
  - **Balance needed to minimize radiated EMI**
  - **Simple to use, no Z matching required**
  - **High BW to transmit boosted signal**
- **Receiver**
  - **CMRR needed to reject CM Noise**
  - **Feedback network independent of receive section**
  - **High BW for equalization boost**

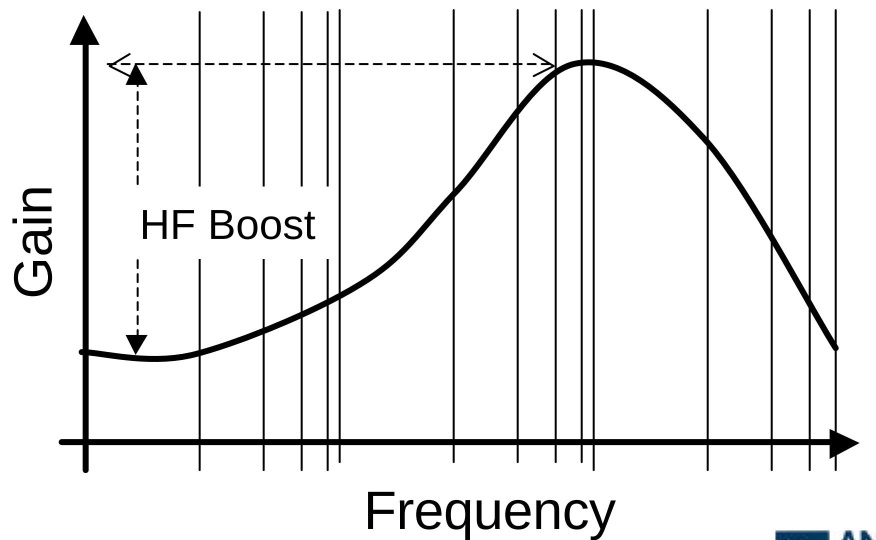




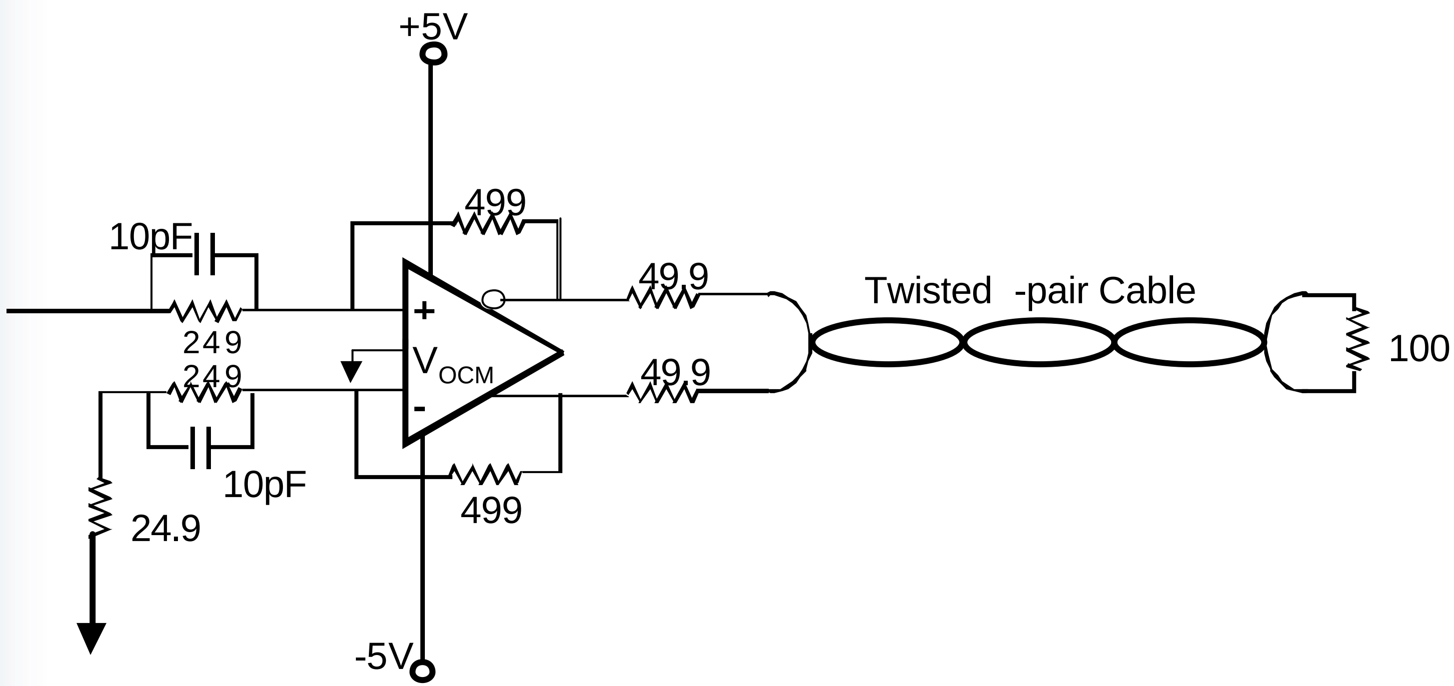
Receive-Side Equalization



- **Receiver Line equalization**
  - **40dB or more of gain can be achieved at high frequency**
  - **Feedback network zeros set the gain**
  - **AD8129 has more GBWP and Lower noise**

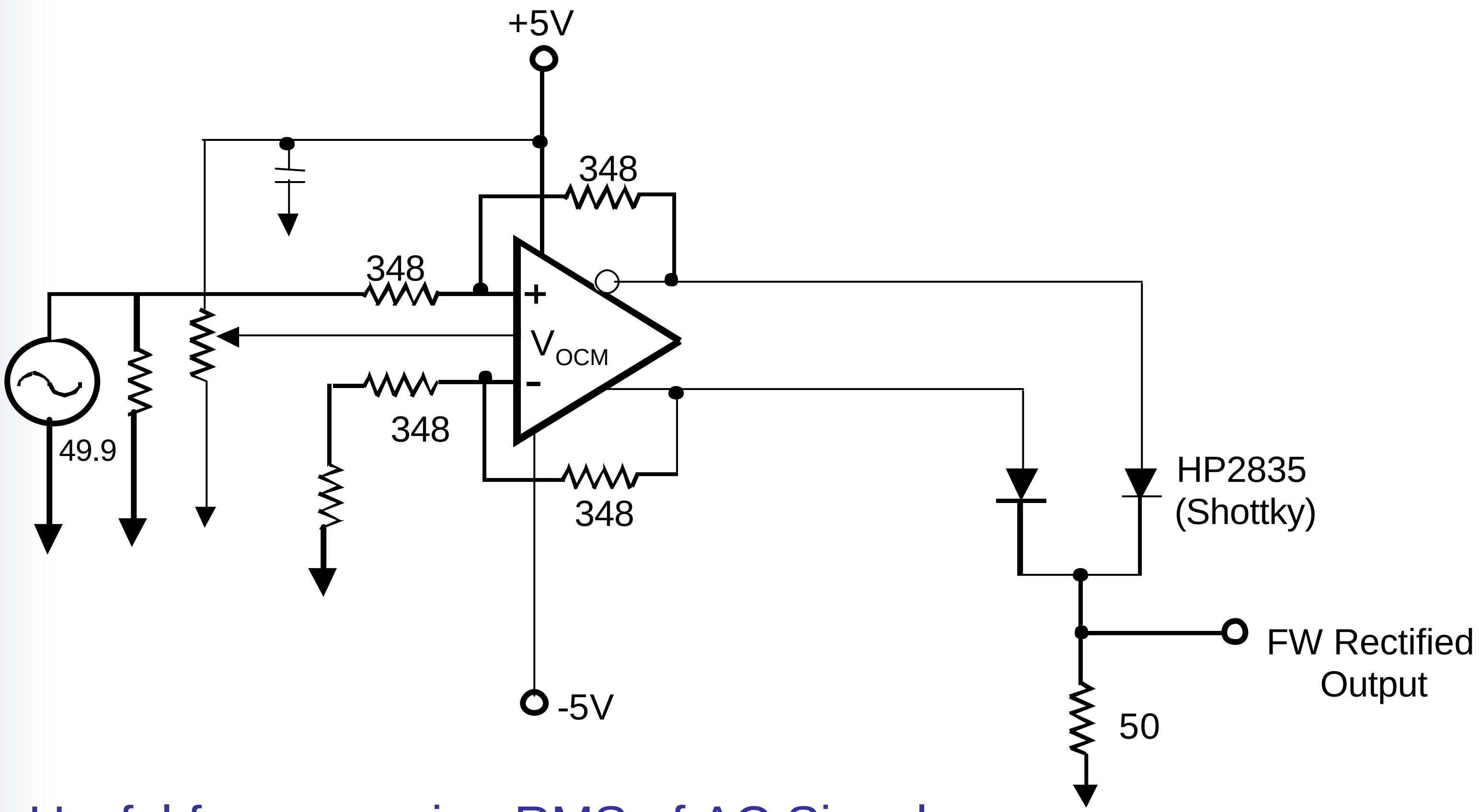


Drive Side High Frequency Boost



- Integrator on input adds zero to boost signal @ high frequency
- For Equalization when Driving Long Cables
  - Gain Limited by Output swing capability

AD8132 Makes Simple Very High Speed Full-wave Rectifier



- Useful for measuring RMS of AC Signals
- Operates to greater than 300 MHz

ADI Multi-Purpose Differential Amp Family

Part #	AD8131	AD8138	AD8132	AD8129	AD8130
	Differential-to-Differential Driver			Differential-to-Single Ended Receiver	
Features	Fixed Gain=2x	Adjustable Gain / Feedback		10x stable	1x stable
Bandwidth	400MHz	310MHz	350MHz	200MHz	270MHz
Slew Rate	2000V/µs	1150V/µs	1200V/µs	1060V/µs	1090V/µs
Position	Line Driver	Best ADC Driver	Low Cost Gen Purp	Diff-to-S.E. converter	Diff-to-S.E. converter

ANALOG DEVICES

High-Speed Amplifiers (HSA)

Fast FETs™

The NEW Standard for JFET Amplifiers

- Very Easy to Use
- Negligible I_{bias} and I_{noise}
- R-R output
- Wide supply range
- Low Supply Current
- Low Price

Fast FETs™
Low-Cost High-Speed AD8033/4

- AD8033/4
  - 75MHz Bandwidth
  - 80V/μs Slew Rate
  - 3.2mA/Amp Typical Supply Current
  - Rail-to-Rail output
  - Wide Supply Range 5-24V
  - Very Low Pricing
    - $1.19 @ 1K - AD8033 (Single)
    - $1.59 @ 1K - AD8034 (Dual)
  - Part Status
    - Final Silicon
    - Release Qtr
      - AD8033 (3Q02)
      - AD8034 (2Q02)

Fast FETs™

High-Performance High-Speed AD8065/6

- AD8065/66
  - 140MHz Bandwidth
  - 160V/µs Slew Rate
  - 7 nV/vHz Noise
  - 6.5mA/Amp Typical supply current
  - Rail-to-Rail output
  - Low offset voltage and drift
  - Wide Supply Range 5-24V
  - Price @ 1K
    - $1.59 - AD8065 (Single)
    - $2.29 - AD8066 (Dual)
  - Part Status
    - Final Silicon
    - Release Qtr
      - AD8065 (2Q02)
      - AD8066 (3Q02)

Ultra Low-Distortion and Noise Amplifier AD8007/8

- Extremely Low SFDR
  - -96dB@5MHz
  - -86dB@20MHz
  - -55dB@70MHz
- Low Noise
  - 2.6 nV/√Hz
  - 22 pA/√Hz
- High Speed
  - 600MHz Bandwidth
  - 1000V/µs Slew Rate
- Low Power
  - 9mA/Amp Typical supply current
- Pricing @ 1k
  - $1.19 - AD8007
  - $1.99 - AD8008
- Part Status
  - Final Silicon
  - Release Qtr
    - AD8007 (3Q02)
    - AD8008 (1Q03)

Low-Power High-Speed Amplifier AD8038/9

- Low Power
  - 1.1mA/Amp Typical supply current
- High Speed
  - 315MHz Bandwidth
  - 425V/μs Slew Rate
- Low Noise
  - 250pA/√Hz
  - 7nV/√Hz
- Low SFDR
  - -86dB @ 1MHz
  - -77dB @ 5MHz
- Price @ 1K
  - $0.85 - AD8038
  - $1.20 - AD8039
- Part Status
  - Final Silicon
  - Release Qtr
    - AD8038 (2Q02)
    - AD8039 (1Q02)

Summary of New Products

Generic	Description	Samples	Release
AD8033	*Fast FETs*™ Low-Cost High-Speed (single)	1Q02	3Q02
AD8034	*Fast FETs*™ Low-Cost High-Speed (dual)	Now	2Q02
AD8065	*Fast FETs*™ High-Performance High-Speed (single)	Now	2Q02
AD8066	*Fast FETs*™ High-Performance High-Speed (dual)	1Q02	3Q02
AD8007	Ultra Low-Distortion and Noise (single)	Now	3Q02
AD8008	Ultra Low-Distortion and Noise (dual)	1Q02	1Q03
AD8038	Low-Power High-Speed (single)	1Q02	2Q01
AD8039	Low-Power High-Speed (dual)	Now	1Q01