# *Designing Microphone Preamplifiers*

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129th AES Convention
San Francisco CA, November 2010

THAT Corporation

# The Tutorial Overview

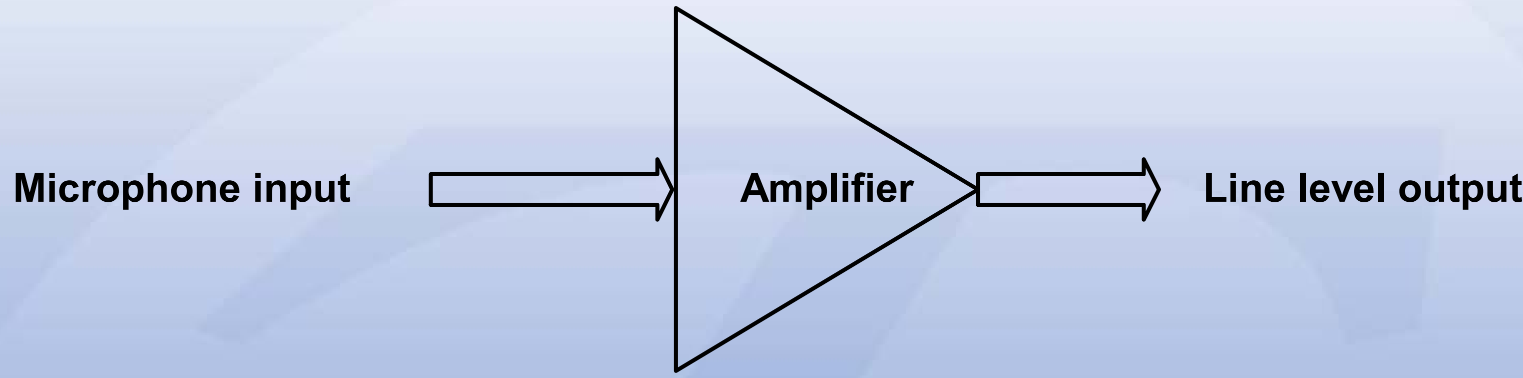
***Section 1***

***Support Circuitry***

***Section 2***

***The Amplifier***

# Simple Block Diagram




**Microphone signal levels vary widely due to:**

- **Microphone sensitivity**
- **Source SPL**
- **Proximity to source**

**Line level outputs are somewhat more constrained:**

- **“Standard” maximum operating levels include 24, 18, 15 dBu**
- **A/D converter input levels are approximately 8 dBu or 2 Vrms differential**

# Typical Requirements

**Gain**

- **Up to 40 dB covers the majority of close-mic'd applications**
- **Some situations require more than 70 dB**
- **Variability of input levels requires adjustable gain over a very wide range**

**Phantom Power**

- **Required for many microphones**
- **Standardized in IEC EN 61938**
  - **48 Volts +/- 4V at up to 10 mA per microphone**
- **On / off control**

**Input Pad**

- **Can allow higher input signal levels, at the expense of noise**
- **May be required depending on minimum gain and supply rails**
- **20 dB is common**

**Resistant to common mode noise and RFI**

**Reliable**

# Preamplifier Technologies

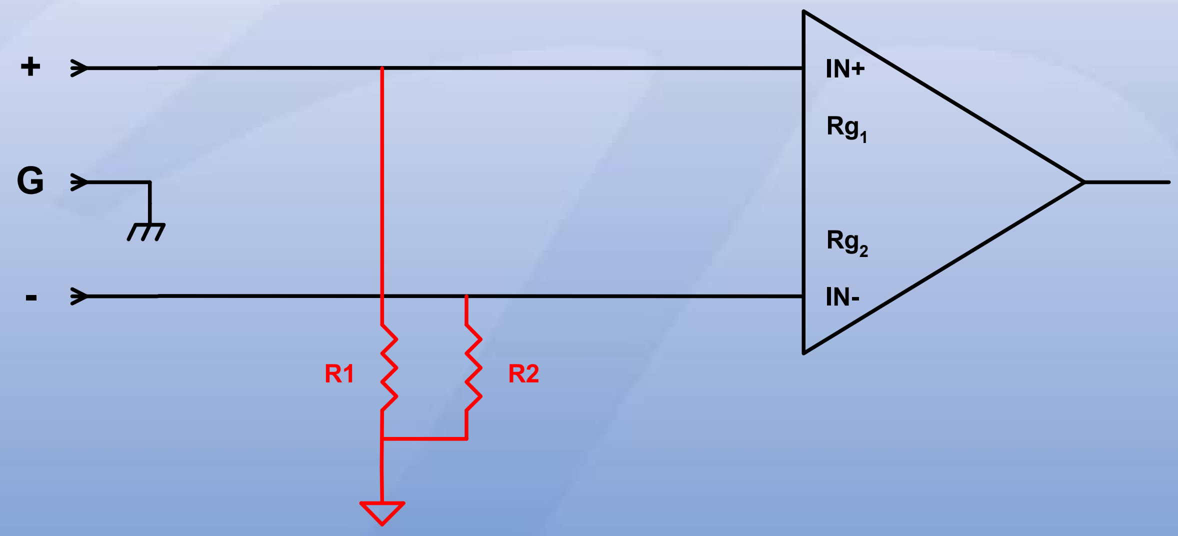
**Transformer-Coupled Vacuum Tube**
- **Robust**
- **Colorful**
- **Costly**

**Transformer-Coupled Solid State**
- **Also Robust**
- **Performance can be excellent**
- **Cost can be high**

**Transformerless Solid State**
- **More vulnerable**
- **Performance can be excellent**
- **Cost ranges from very low to high**

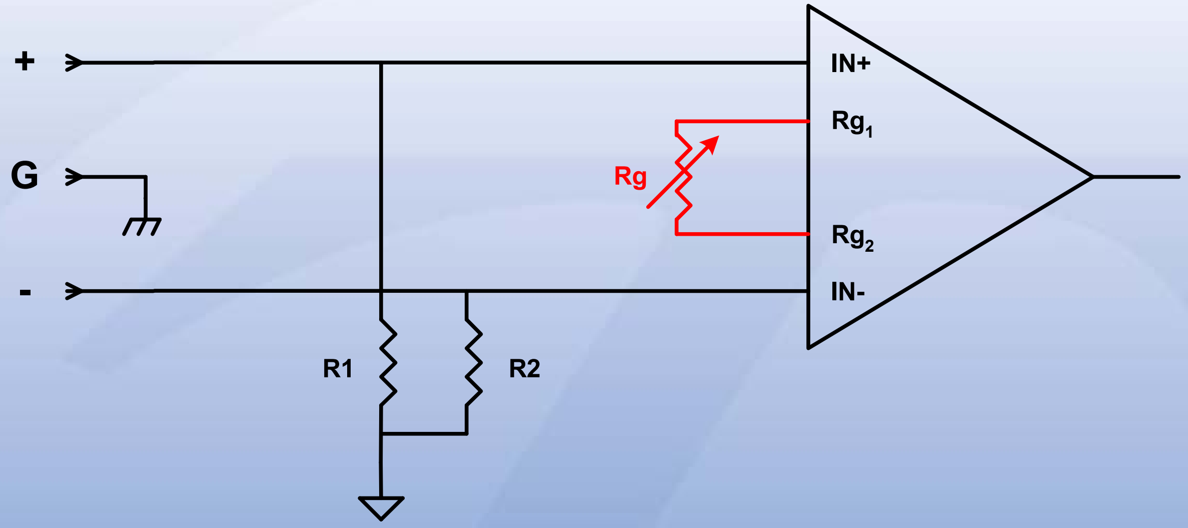
**Transformerless solid state designs are the focus today**

# Amplifier Input Bias Current




**Must provide a DC current path to supply the amplifier input bias current**

# Gain Control




The amplifier is often designed to vary gain using a single variable resistor ($R_g$)

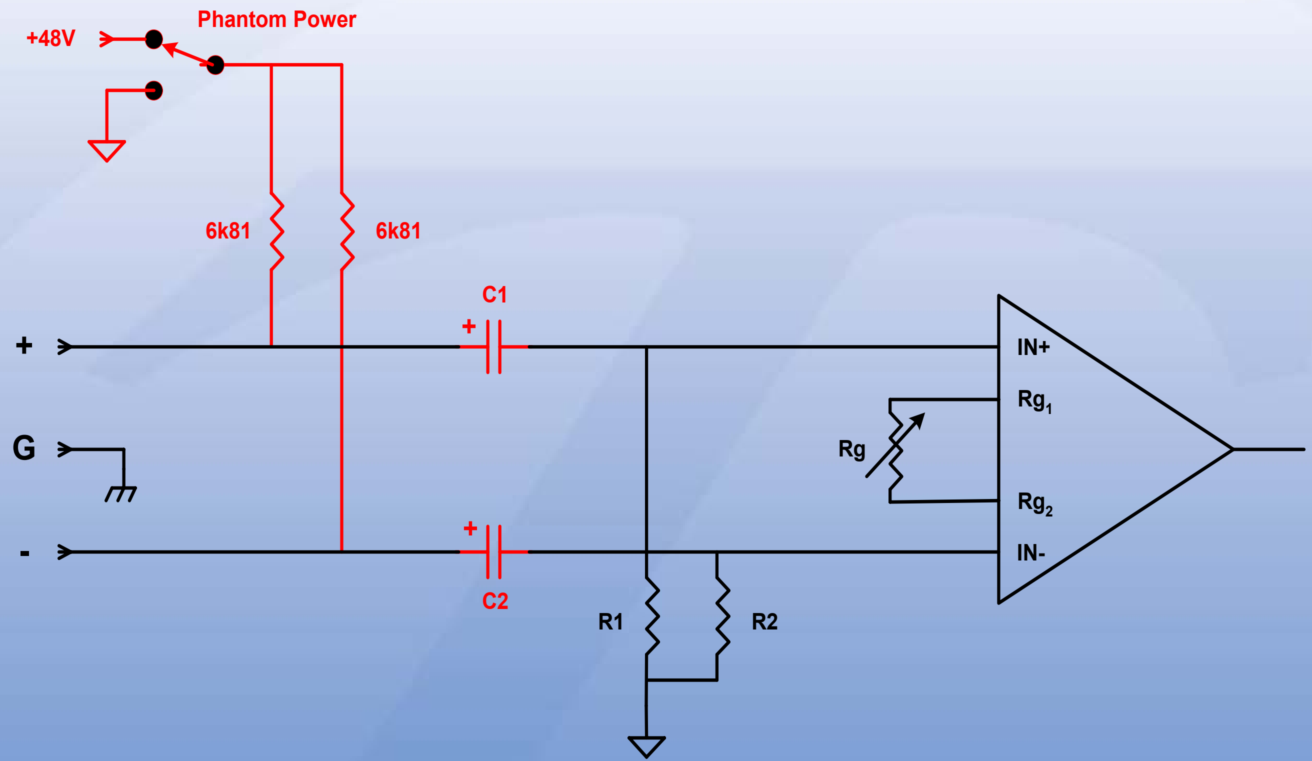
Manually controlled options

- Potentiometer with continuous control over a defined range
- Switched resistor network with a fixed number of steps and gain settings

Digitally controlled options

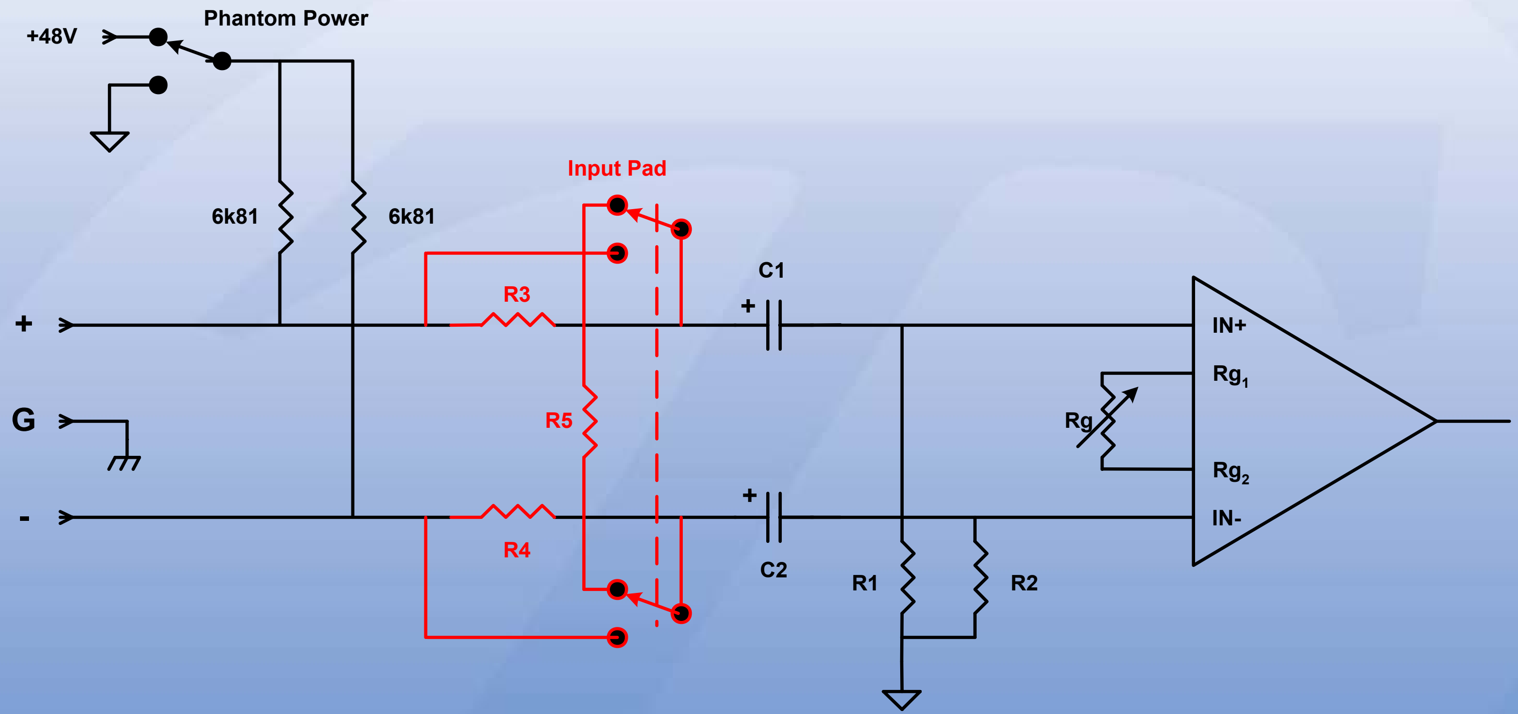
- Digitally switched resistor network with a predetermined number of steps
- Switches are either relays or silicon devices
- Both discrete and integrated circuit solutions are available

# Phantom Power



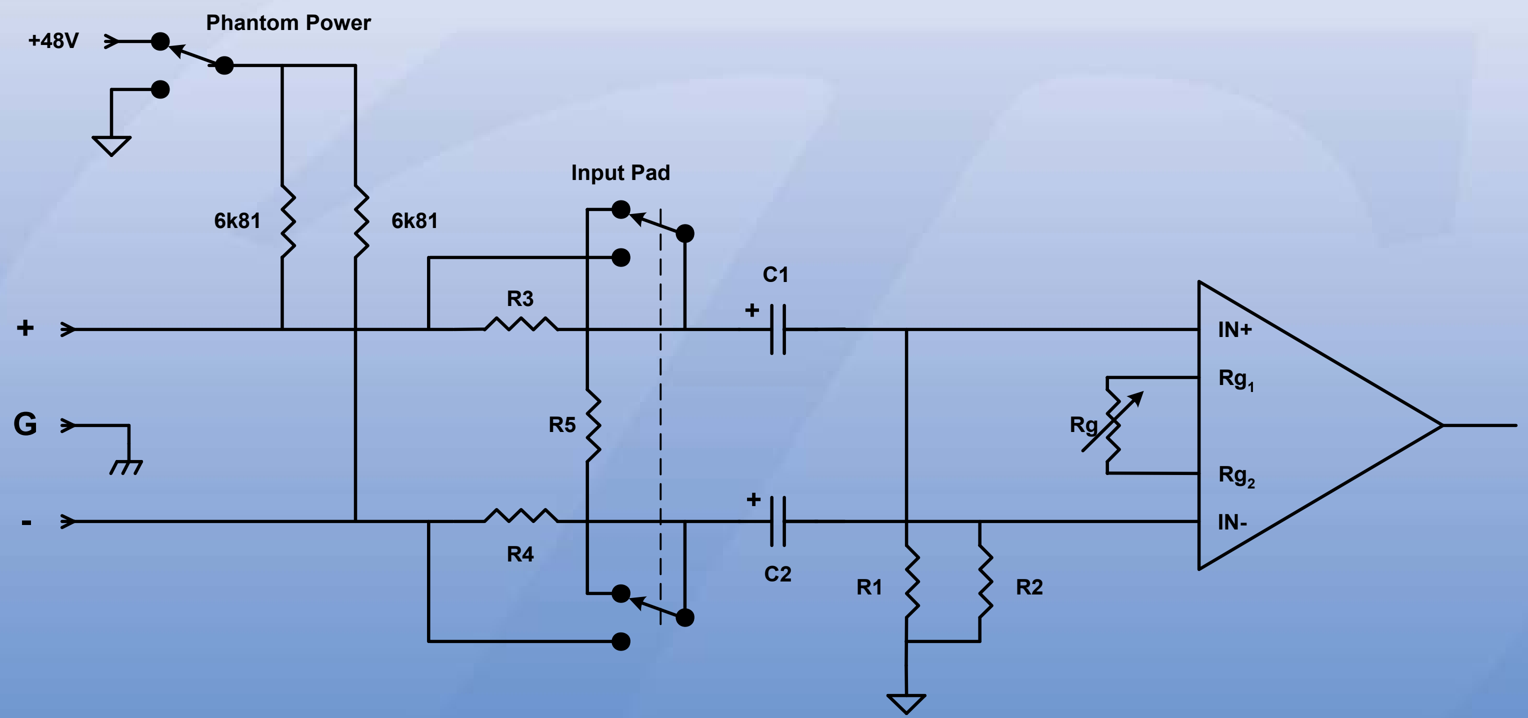

- C1 and C2 required to block the 48 V from the amplifier inputs
- 6.81k series resistors are specified in the standards for 48V phantom power
- On/Off is available via a
  - Simple mechanical switch in manual applications
  - Relay or silicon switch in digitally controlled systems

# Input Pad




- Input pad is simply a signal attenuator prior to the amplifier
- This is a differential-only pad, it does not attenuate common-mode signals

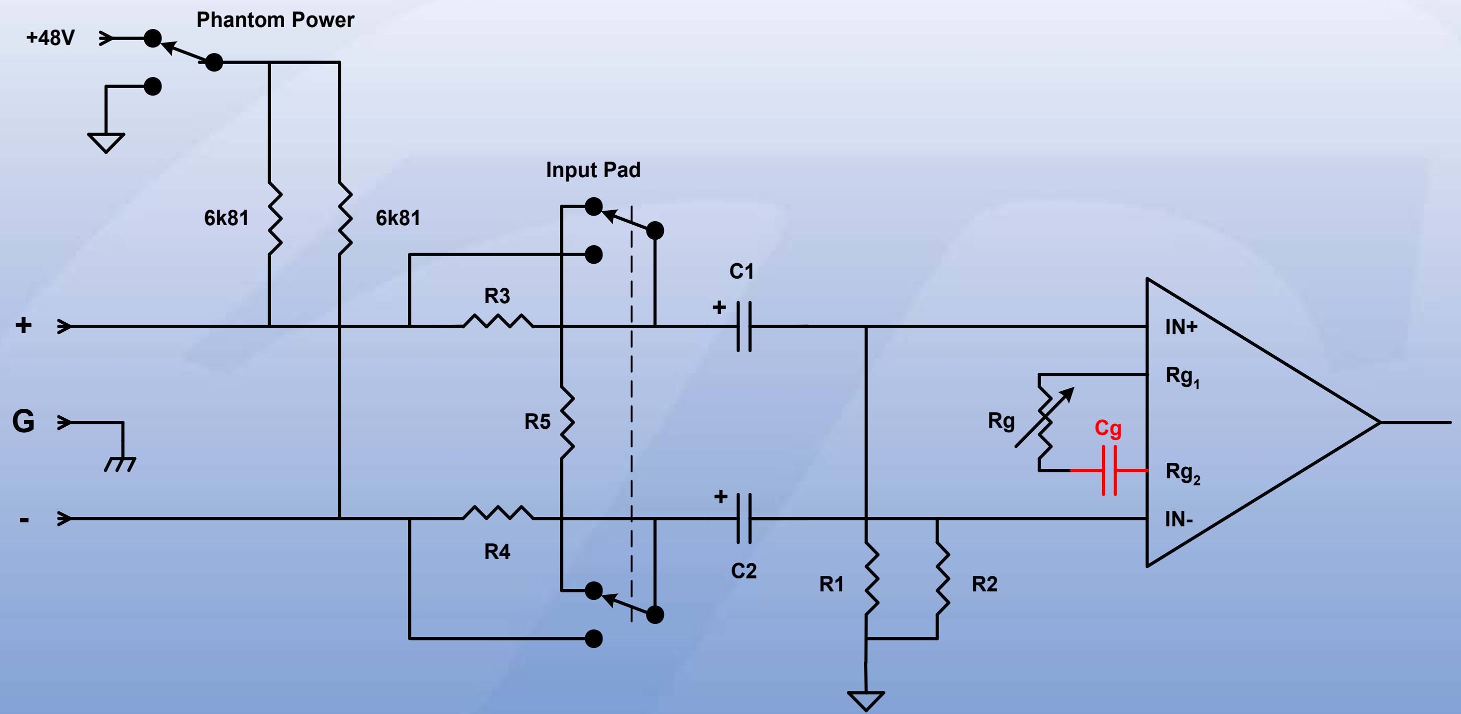
# “Complete” Microphone Preamp



*It would be nice to say “that’s all there is” but………*

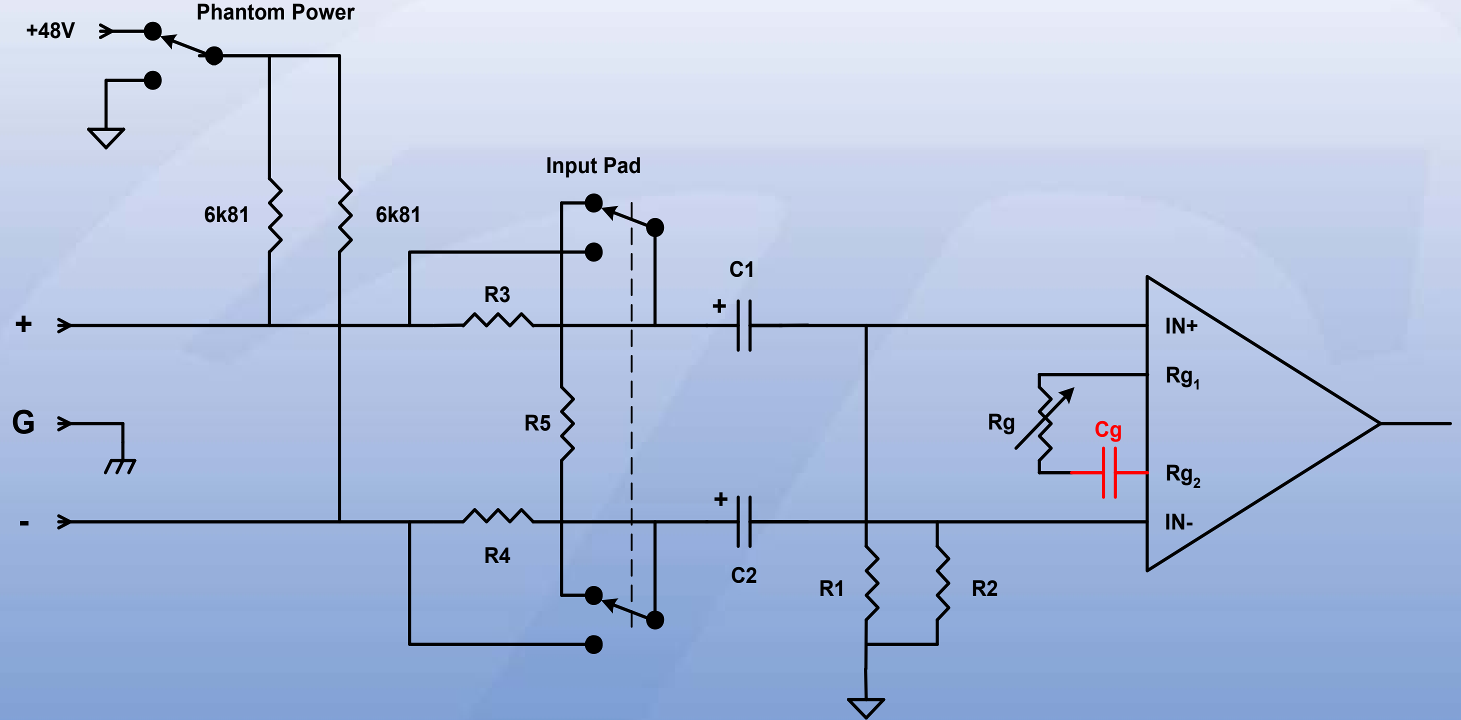
*there are gremlins are in the details!!*

# DC Offset Changes



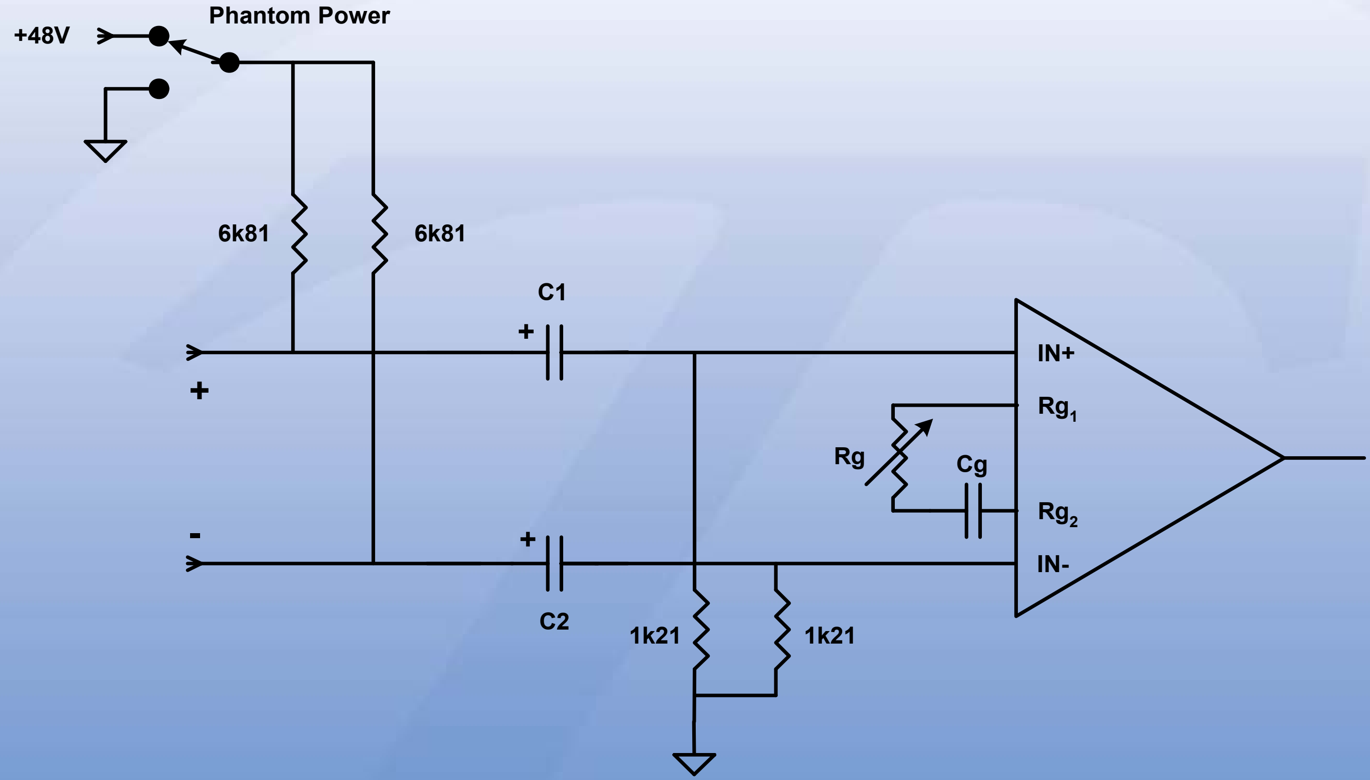

- Changes in gain can result in the DC offset changes at the output of the amplifier
- 2 solutions are available
  - Adding a capacitor (Cg) sets the DC gain to a fixed value and avoids these offset changes
  - A servo-amplifier can also be effective, but we don't have time to discuss them today

# Trade-offs with Cg



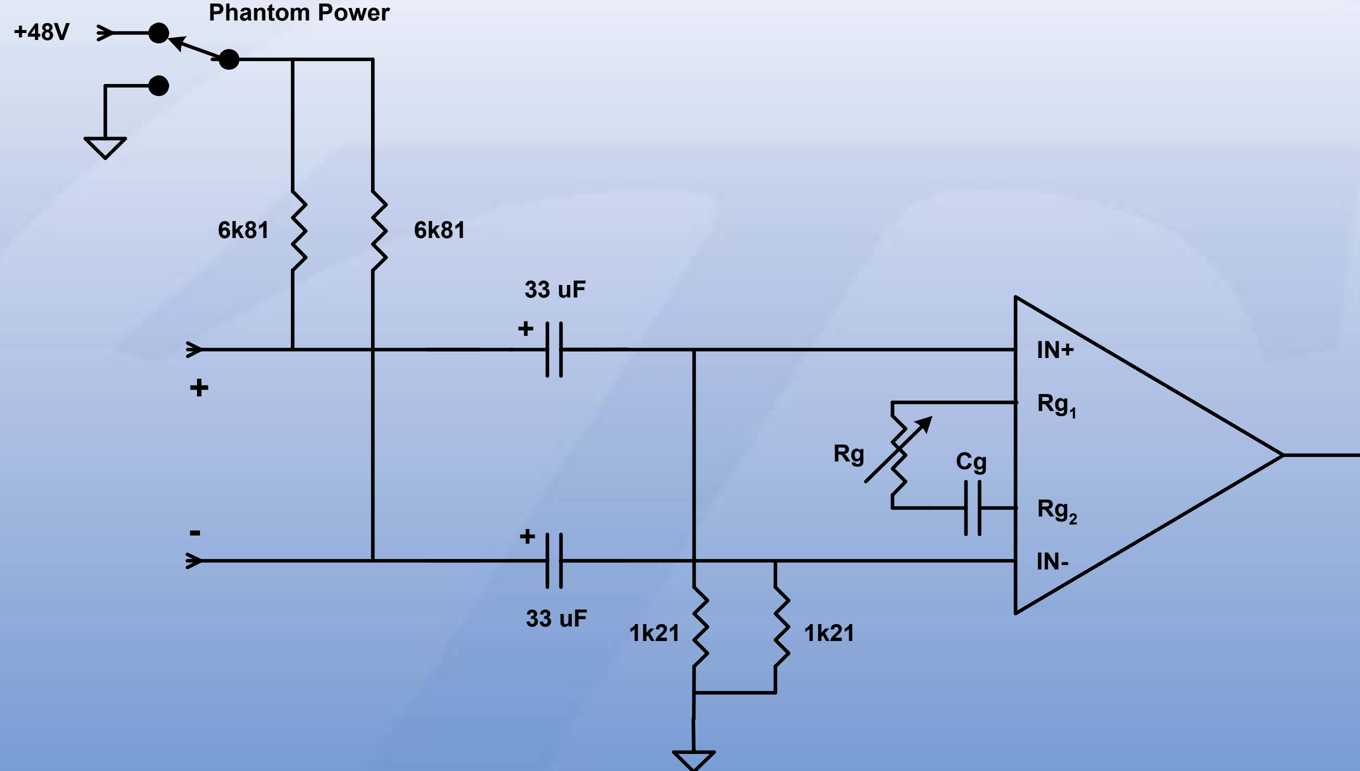

- Rg and Cg create a high-pass filter in the signal path
- Rg can vary from <5 to >10k ohms
- Cg must have a very large capacitance to avoid low frequency audio attenuation
  - Worst at highest gain

# Resistor Value Selection



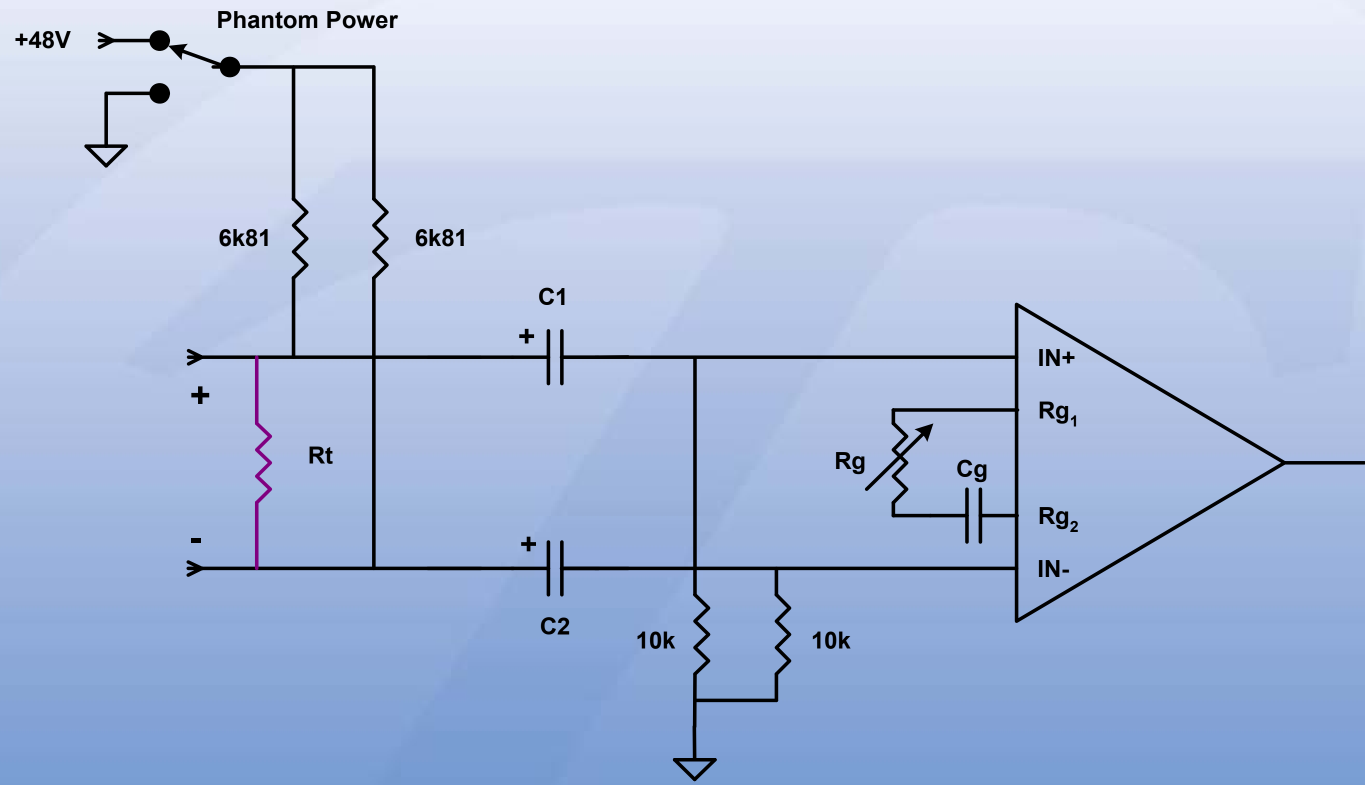

- Microphone are commonly specified for 2 to 3 kohm loads
- Differential input impedance is (R1 II 6.81k) + (R2 II 6.81k)
- Therefore, suitable values for R1 & R2 are between 1172 and 1924 ohms

# Capacitor Value Selection



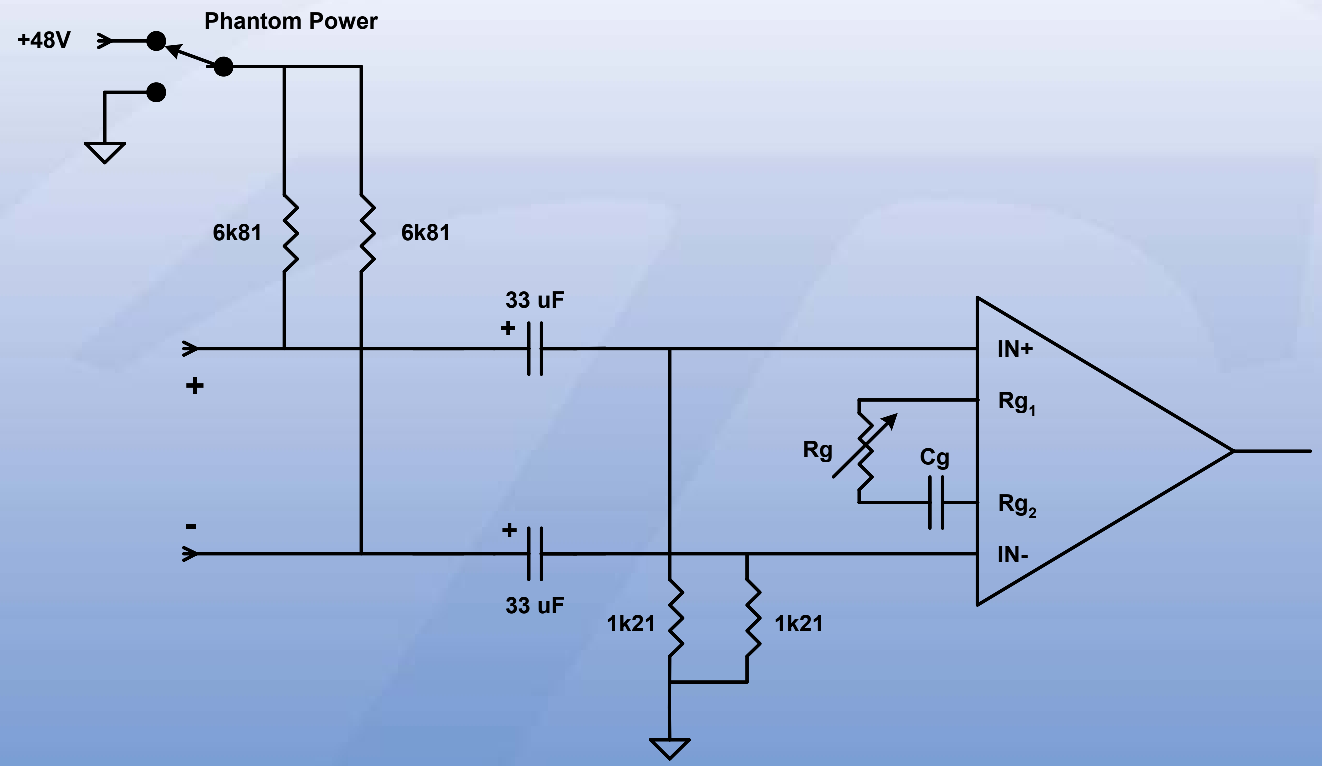

- High-pass filter corner frequency is set by the blocking capacitor and bias resistor and is equal to 1 / (2 x pi x R x C)
- For a 5 Hz corner frequency, the minimum values for C1 & C2 are 26 uF
- The next largest standard value is 33 uF
- Results in a nominal corner frequency of about 4 Hz

# Alternative Resistor-Capacitor Value Selection



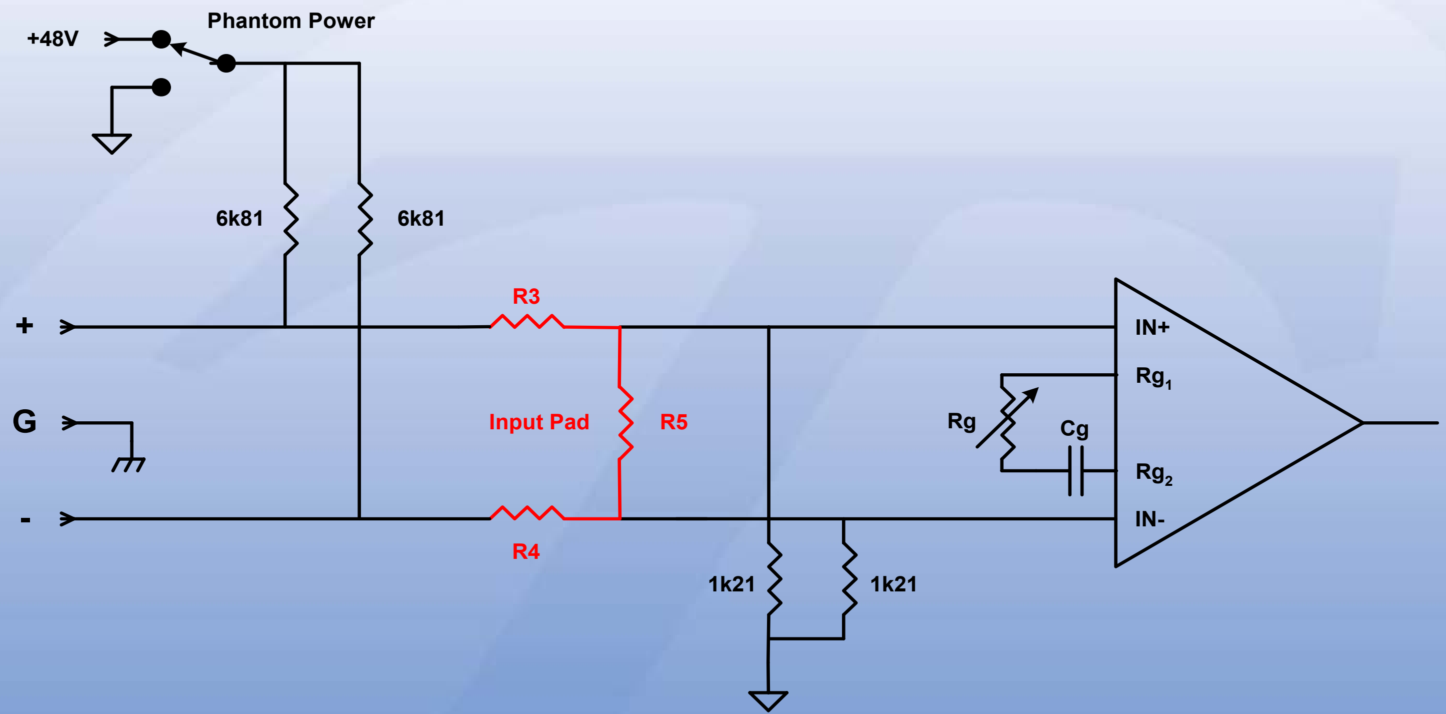

- C1 and C2 can be made smaller if bias resistors are made larger
- Rin is defined by Rt
- However, C1 and C2 convert 1/f noise to 1/f^2 noise
- 10k resistors contribute thermal noise and current noise*R

# Common Mode Rejection (CMRR)



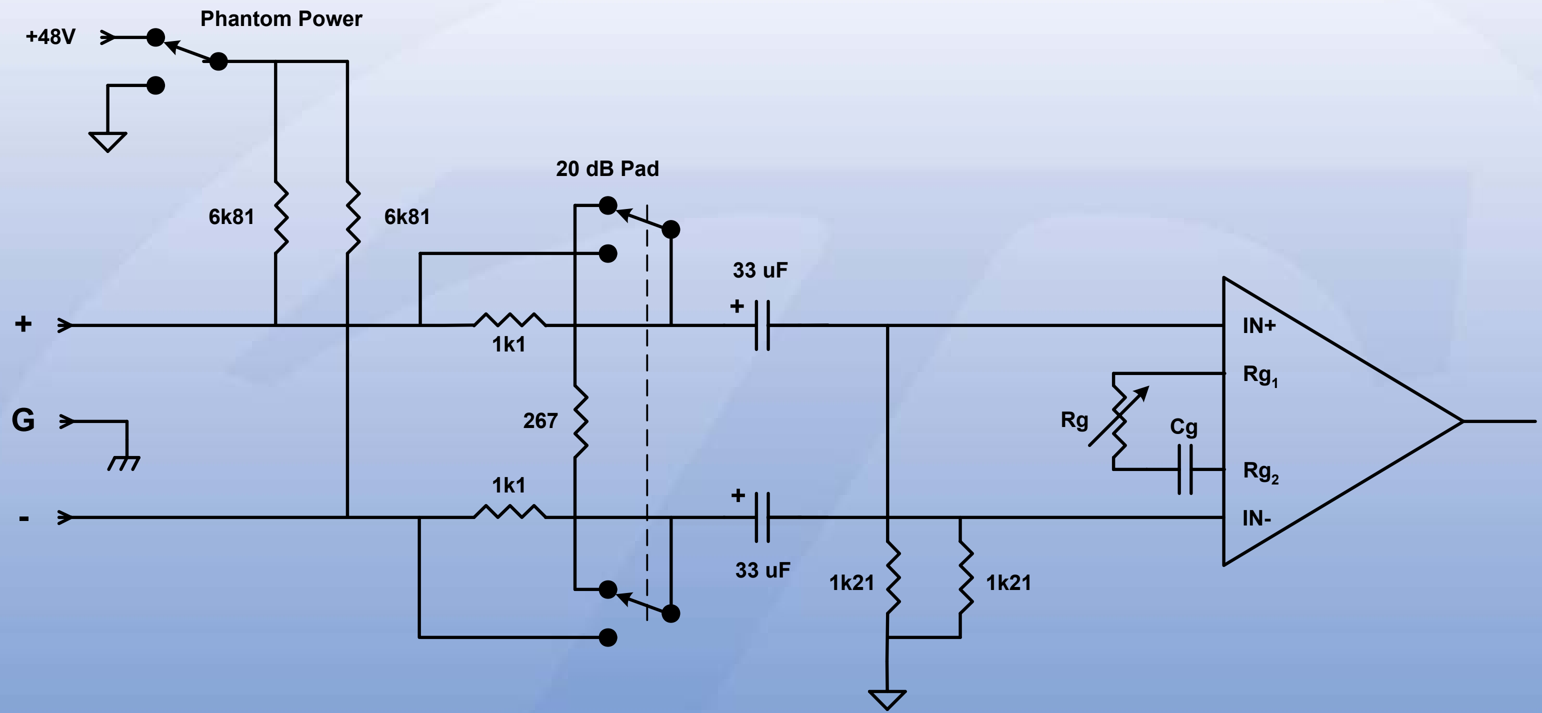

- Common-mode to differential conversion results from mismatches in:
  - 6.81 k resistors
  - 1.21 k resistors
- Low frequency CMRR affected by capacitor mismatch

# U-Pad Attenuator



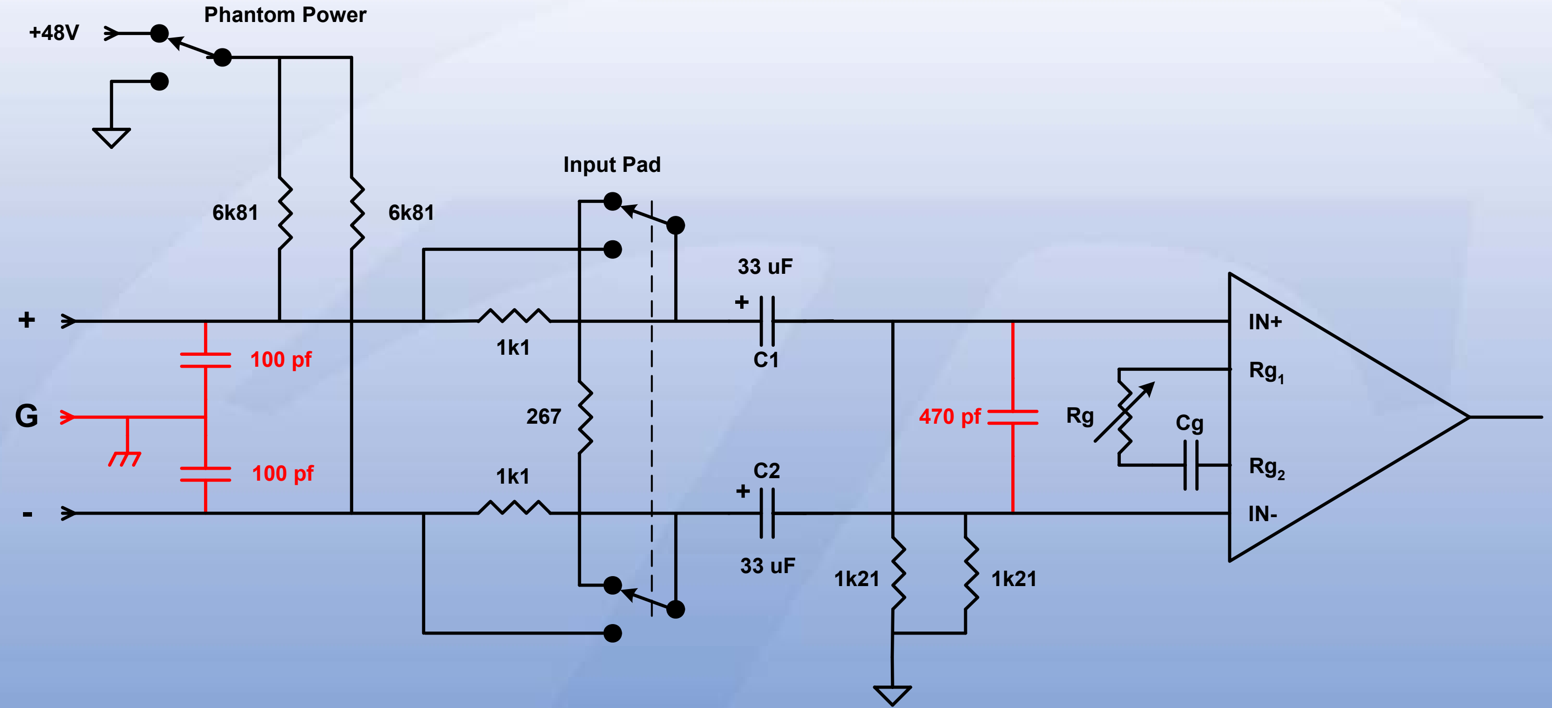

- $Z_{IN}$ with and without pad can be closely matched
- Can be designed for any attenuation
  - 20dB is typical
- Noise performance is degraded
- Better noise, less headroom with less attenuation

# Example -20 dB Input Pad




- $Z_{IN}$ with and without pad is approximately 2k
- 20 dB Attenuation
- Pad output impedance is approximately 240 ohms
- See THAT Design Note DN-140 for details and alternatives

# RFI Protection




- RFI protection is required in any practical design
- 100 pf caps at the input connector attenuate differential and common-mode RFI
- 470 pf cap at amplifier input pins reduces differential high frequencies from both internal and external sources

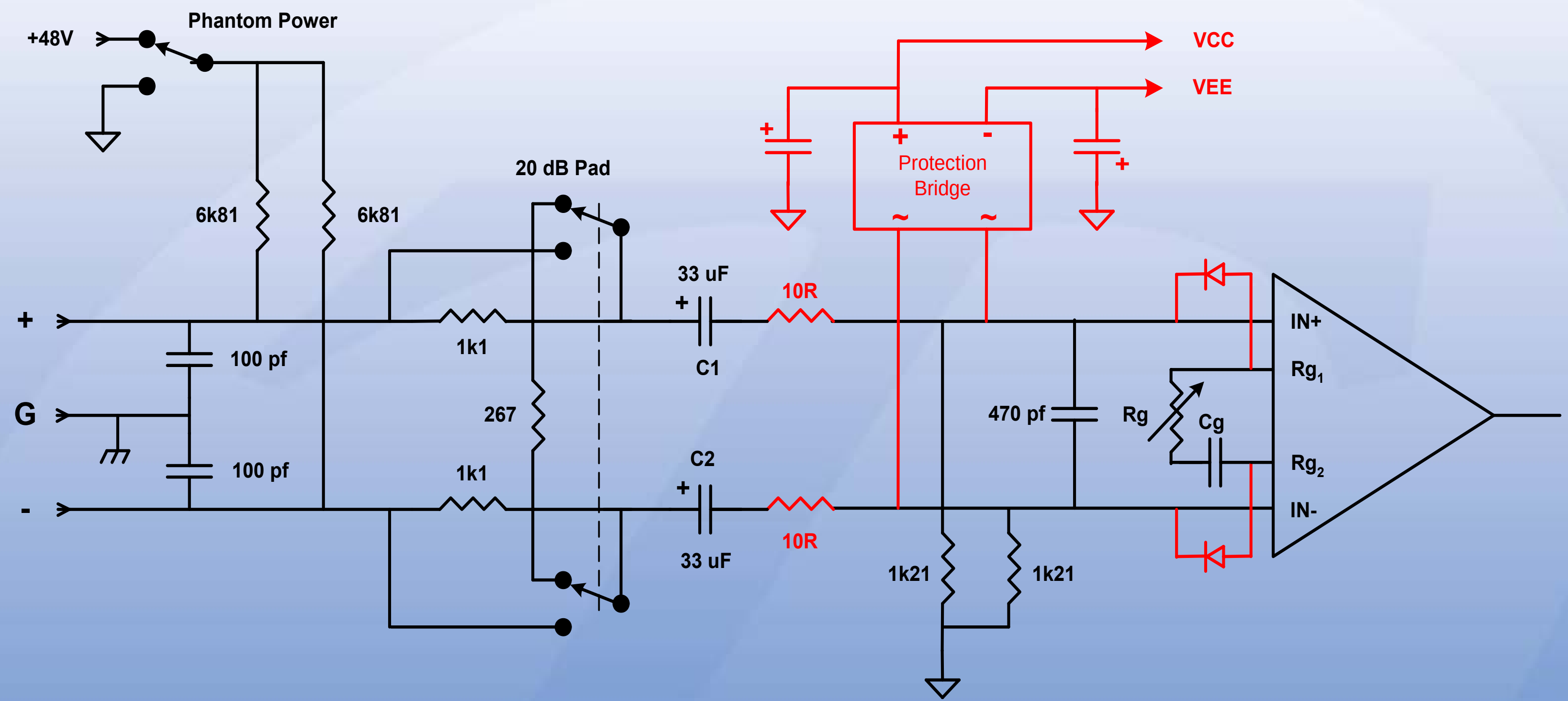
# Phantom Power Faults

- **Shorting input pins to ground with phantom turned on**
  - **33uF coupling caps C1 & C2 start charged to 48V**
  - **Positive end of C1, C2 connect to ground**
  - **Negative end of C1, C2 driven to -48V!**

- **The shorting sequence can vary**
  - **“Single-ended”: One input to ground**
  - **“Common-mode”: both inputs to ground simultaneously**
  - **“Differential”: One input to ground, then the other**
  - **Differential is worst**

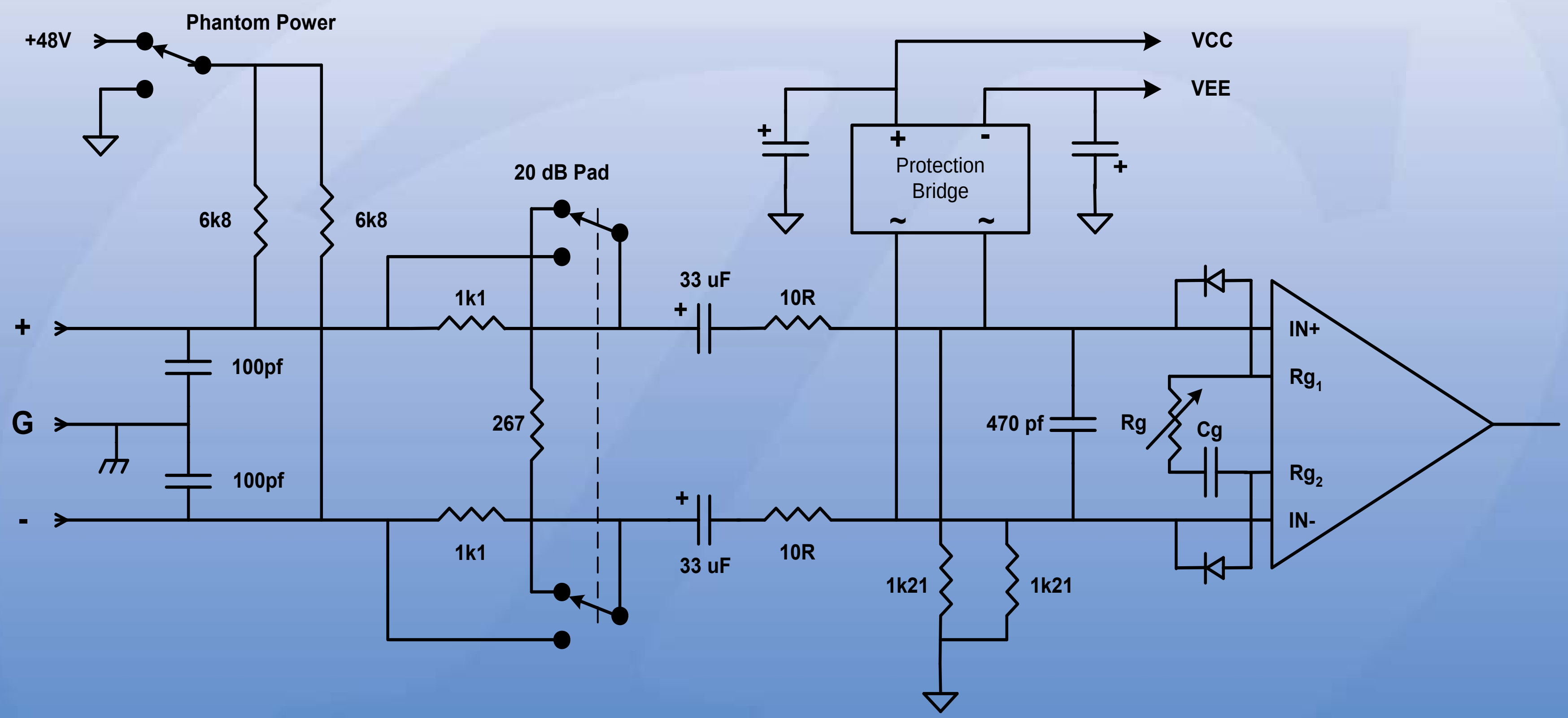
- **Big currents flow as C1, C2 discharge**
  - **Currents over 3 *amperes* flow in the capacitors**

# Phantom Fault Protection




- **Limit the current with small value resistors**
- **Direct fault currents away from the amplifier inputs**
  - **Input diodes provide a conduction path which bypasses the amplifier**
  - **This current varies with gain setting**
- **Diode bridge directs fault current to rails**
  - **Consider impact on supply rails**
  - **Minimize supply transient with capacitance**

# Complete Microphone Preamp



# References and Additional Information

- THAT Corp *"THAT 1510/1512"* data sheet
- THAT Corp *"THAT 1570 & 5171"* data sheets,
- THAT Corp *"Design Note 140"*
- THAT Corp *"Design Note 138"*
- THAT Corp *"Analog Secrets Your Mother Never Told You"*
- THAT Corp *"More Analog Secrets Your Mother Never Told You"*
- *"The 48 Volt Phantom Menace Returns"* Audio Engineering Society Preprint from the 127$^{th}$ AES Convention, Oct 2009
- *"The 48 Volt Phantom Menace"* Audio Engineering Society Preprint from the 110$^{th}$ AES Convention, May 2001

**All THAT Corp references are available at thatcorp.com**

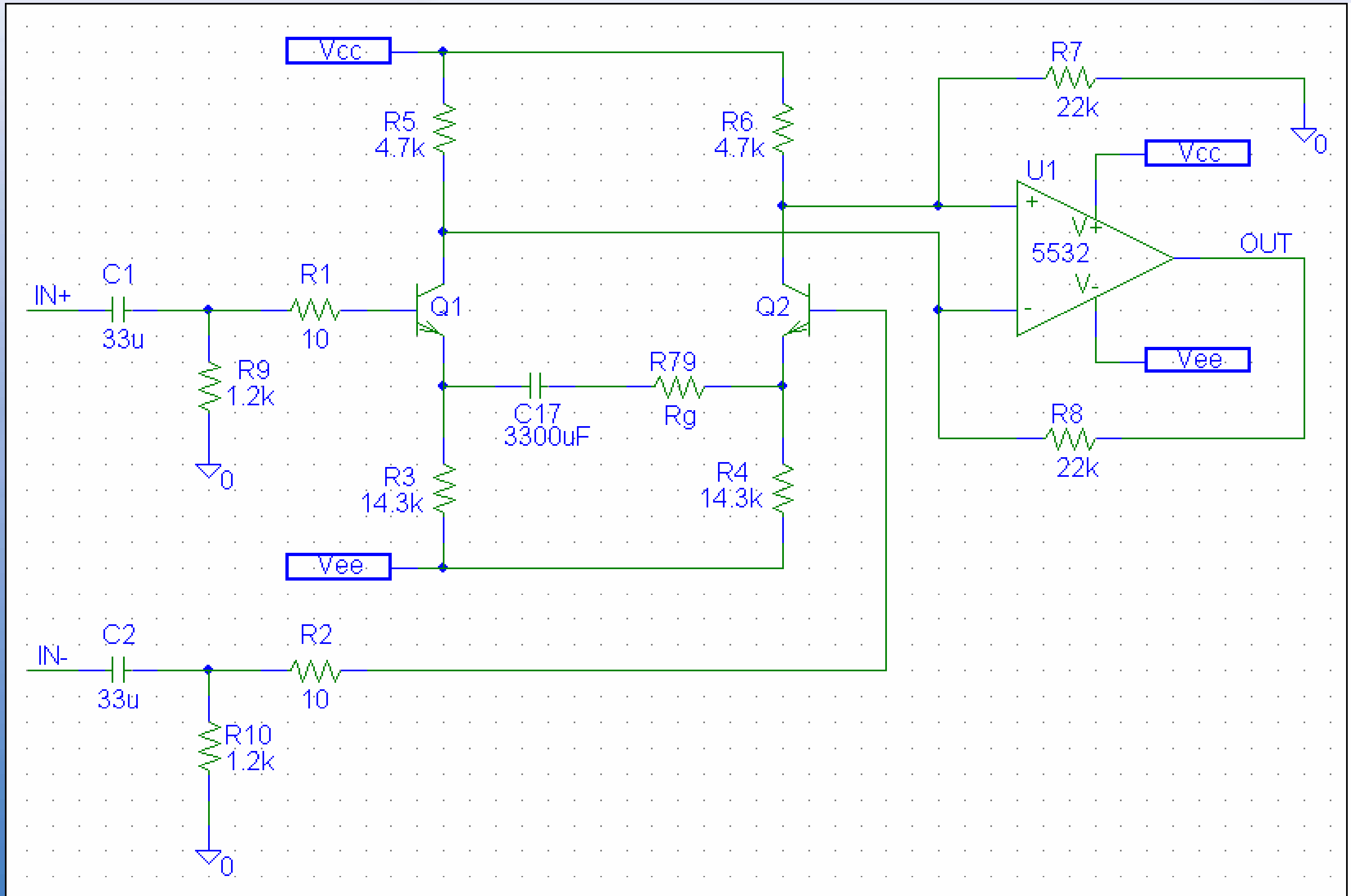
# *Amplifier Topologies*

***What's inside the triangle?***

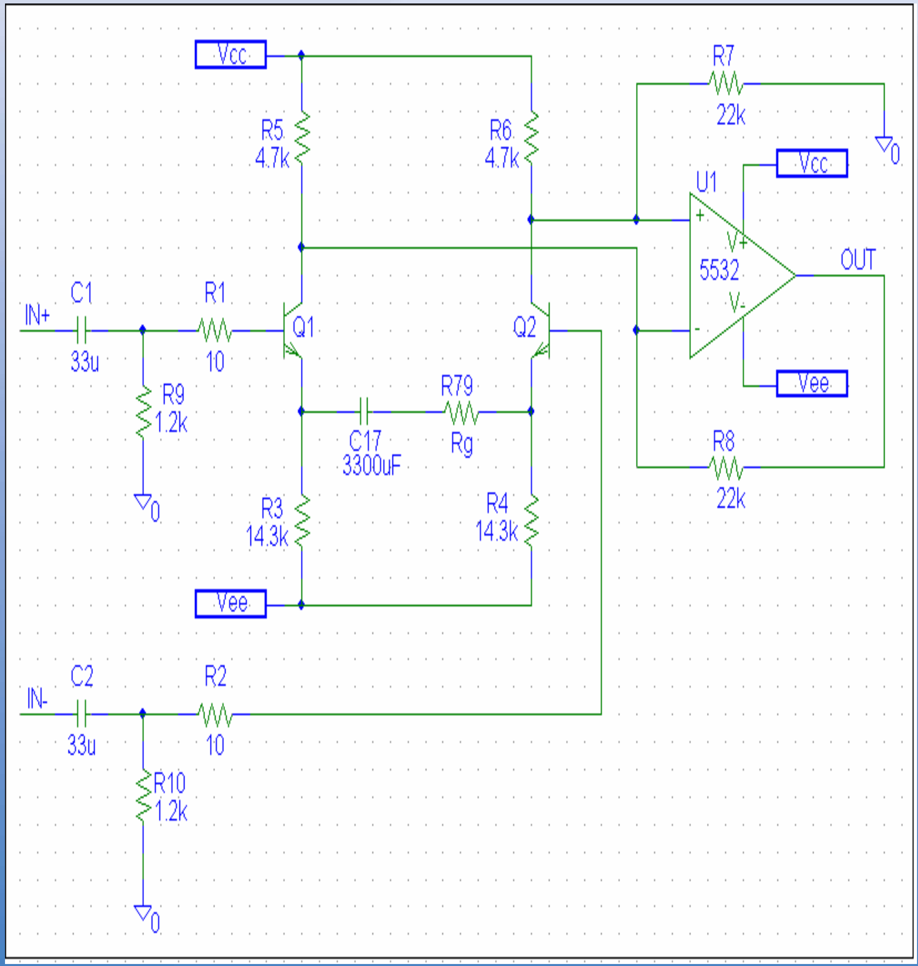
# Scope

- We will concentrate on topologies that allow a wide range of gain with a single control.
- The goal is to balance the requirements for low distortion and low noise at both ends of the gain range.

# Simple Mic Preamp Schematic



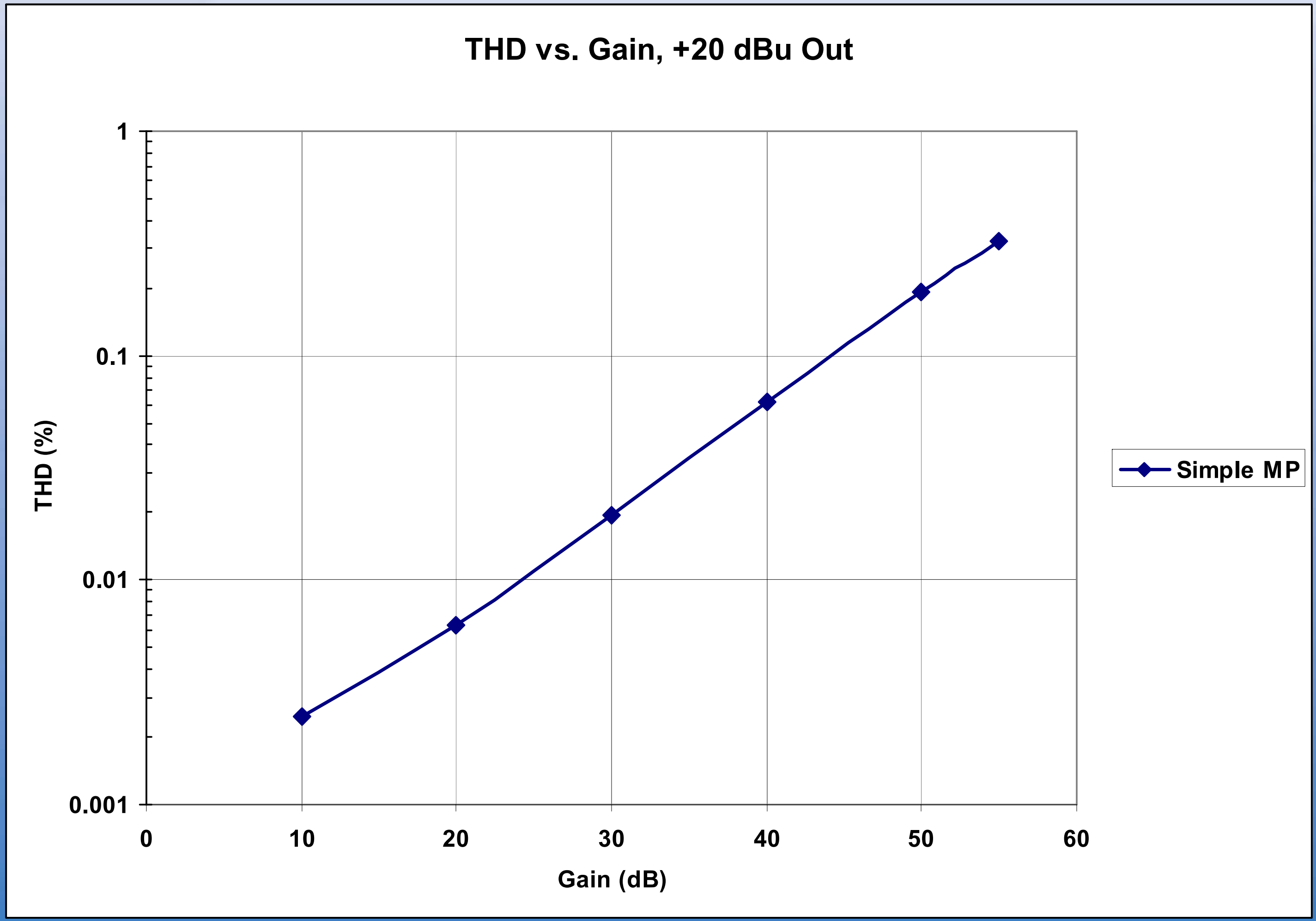
# Simple Mic Preamp



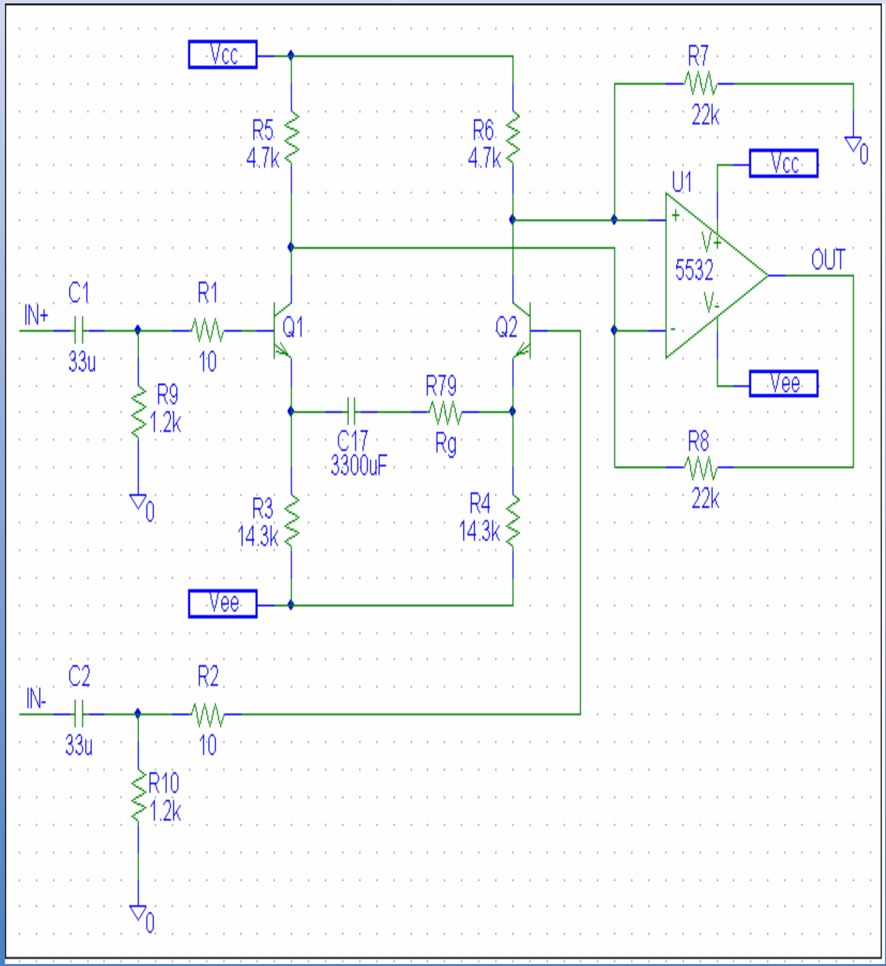

- Ic = 1 mA per input transistor, set by $(|V_{EE}| - V_{BE})/14.3k$
- Diff Gain = $22k/(r_e + R_g/2||14.3k)$
- where $r_e = 1/g_m = KT/qI_C = 26$ ohms
- But – "$r_e$" is current dependent!
- Minimum gain = 22k/14.3k = 3.7 dB

# Simple Mic Pre THD Performance

## THD vs. Gain, 1 kHz, +20 dBu Out

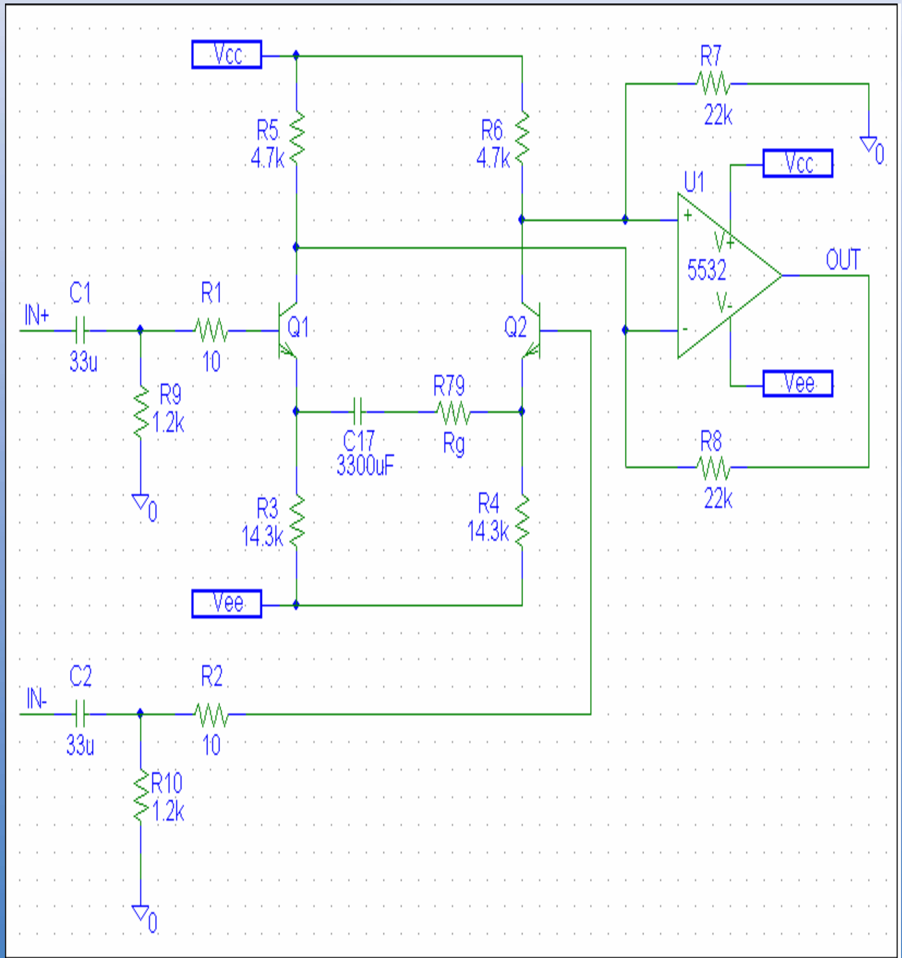


# High-Gain Noise Sources of Simple Mic Preamp



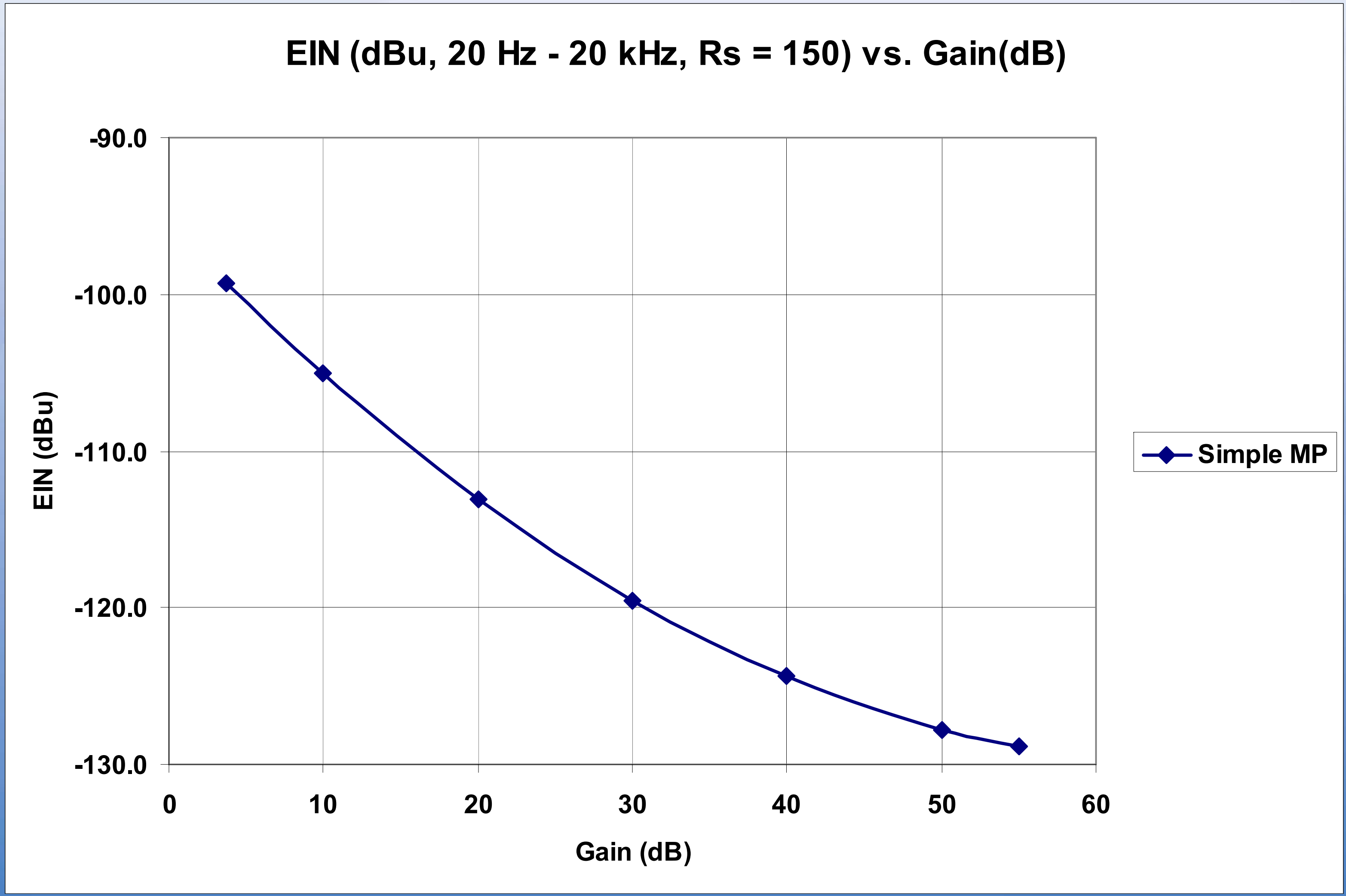

- Input noise at high gains dominated by:
- $Q_1$, $Q_2$ $I_C$ Shot Noise (RTI) = $\frac{\sqrt{2qI_C}}{g_m} = \sqrt{4kTr_e}$
- $Q_1$, $Q_2$ $r_b$ Thermal Noise = $\sqrt{8kTr_b}$
- $R_1$, $R_2$, $R_g$ Thermal Noise = $\sqrt{4kT(R_1+R_2+R_g)}$

# Low-Gain Noise Sources of Simple Mic Preamp

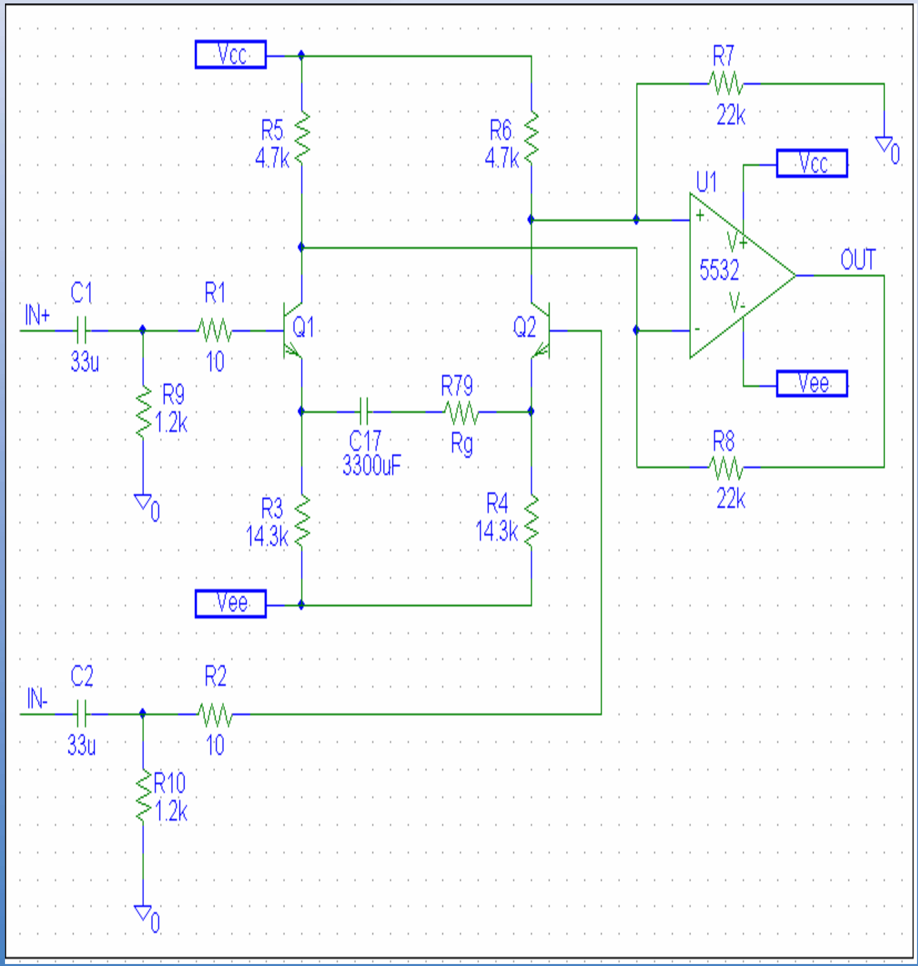



- Input noise at low gains dominated by:
- Thermal Noise of $R_5$ and $R_6$
- Thermal Noise of:
  $R_g \| (R_3 + R_4)$
- $Q_1$,$Q_2$ $I_B$ shot noise across $\frac{R_g \| (R_3 + R_4)}{2}$
- EIN of U1

# Noise Performance of Simple Mic Preamp



# CMRR Performance of Simple Mic Preamp

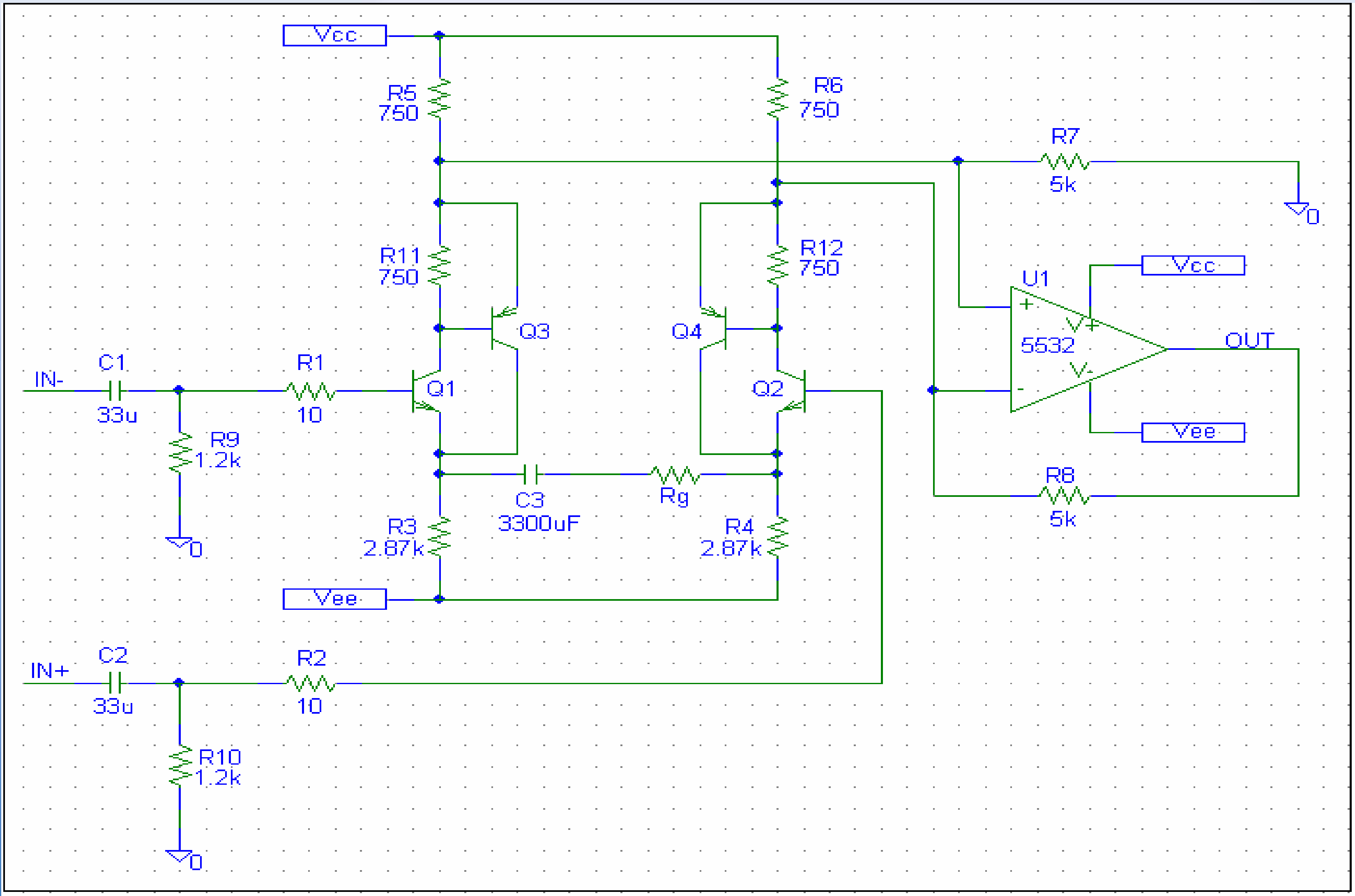



- CM to differential conversion can occur due to mismatches in:
- $R_3$ and $R_4$
- $R_5$ and $R_6$
- $R_7$ and $R_8$
- $R_9$ and $R_{10}$
- $Q_1$ and $Q_2$

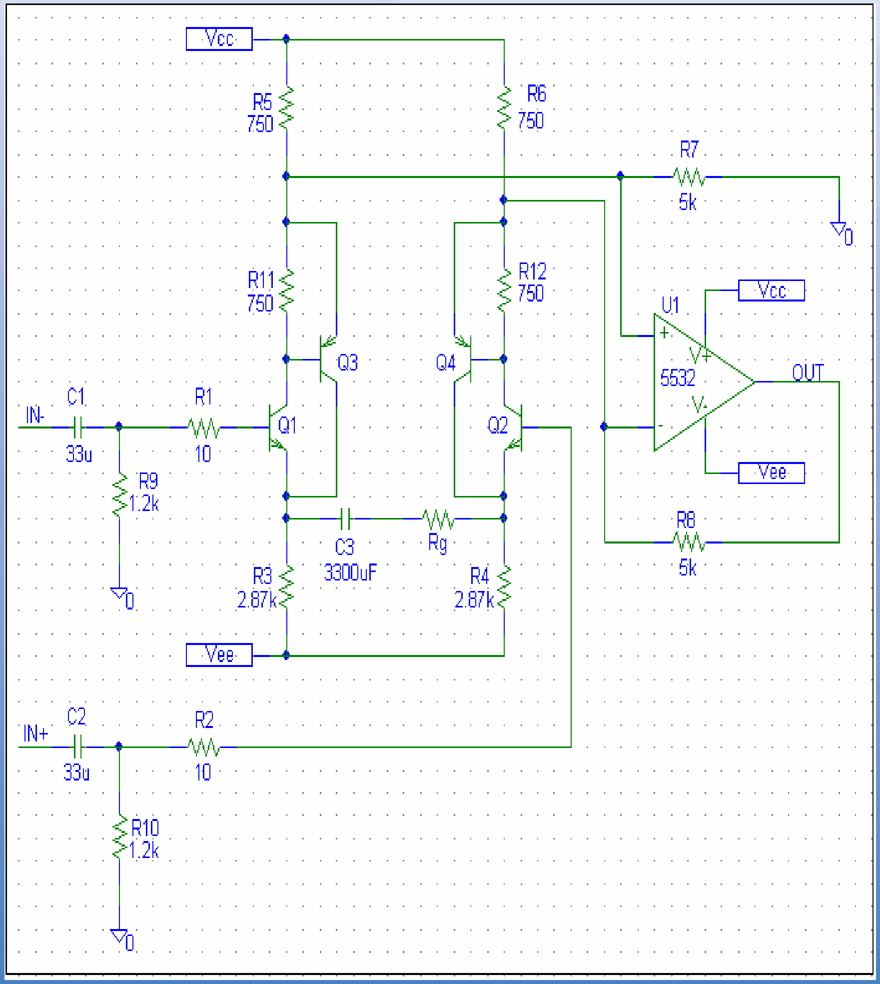
# Simple Mic Preamp

- 2 Transistors and 1 Opamp
- Very Low Cost
- Marginal Performance

# Complementary Feedback Pair Mic Preamp

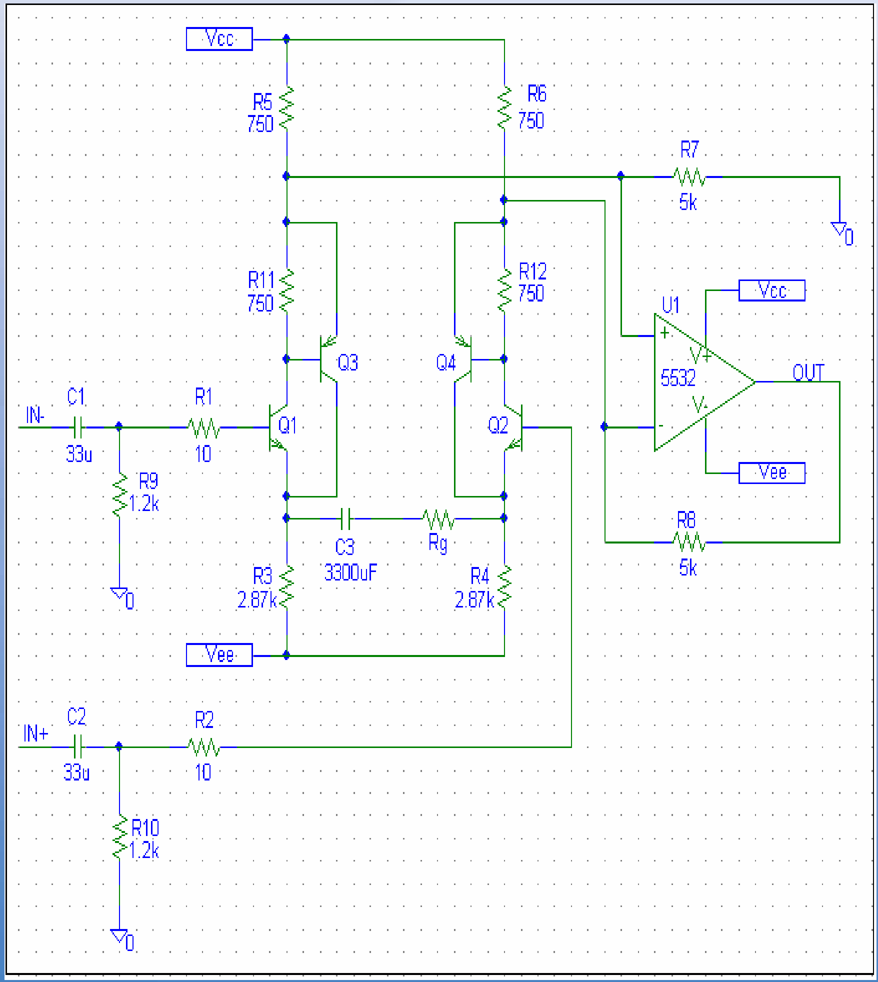


# CFP Mic Preamp




- Input devices are each a compound transistor (Complementary Feedback Pair)
- NPN Input Ic set by Vbe/750 ohms (1 mA each)
- NPN Ic + PNP Ic set by (|Vee|-Vbe)/2k87 (5 mA per side)

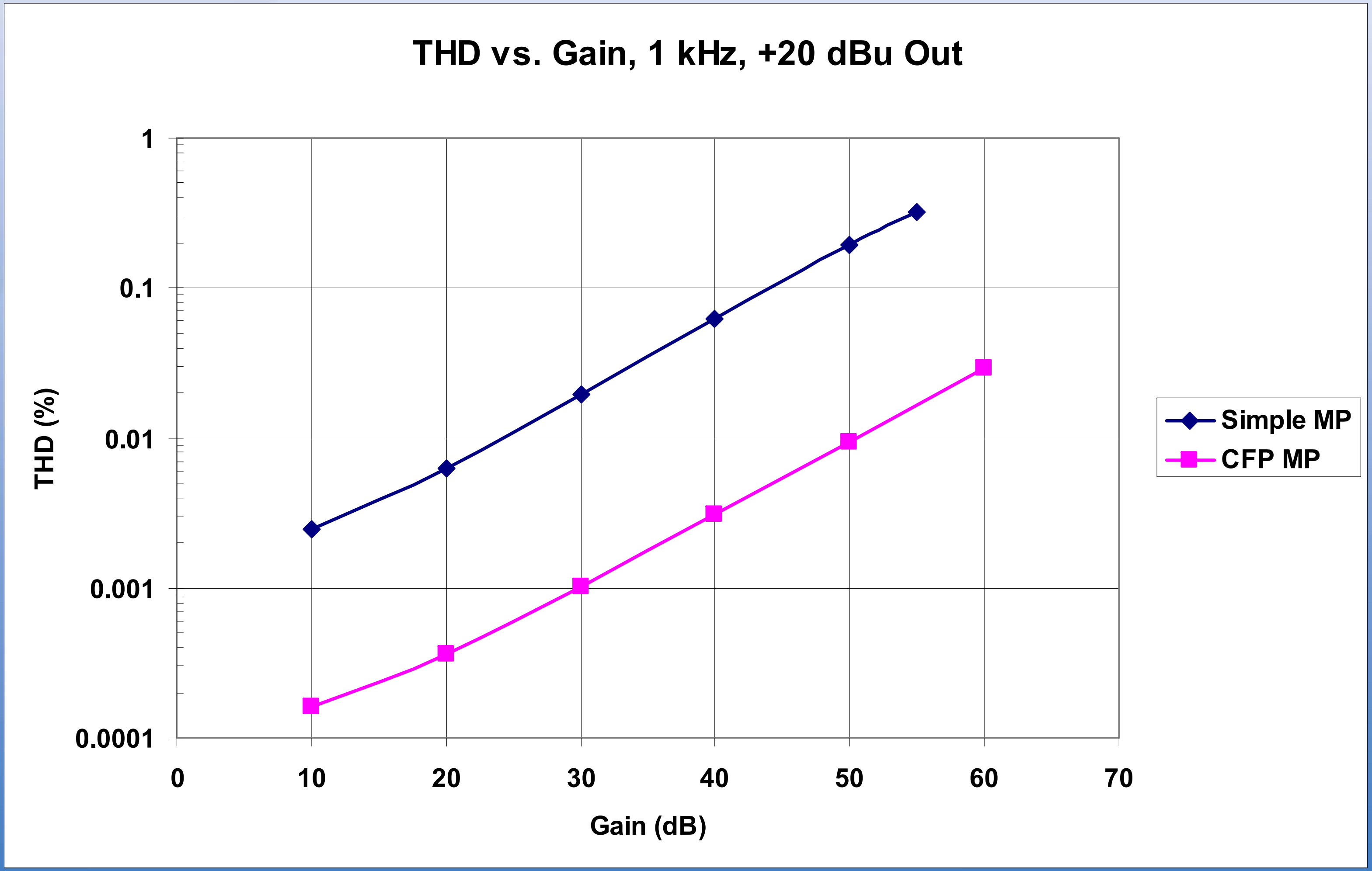
# CFP Mic Preamp



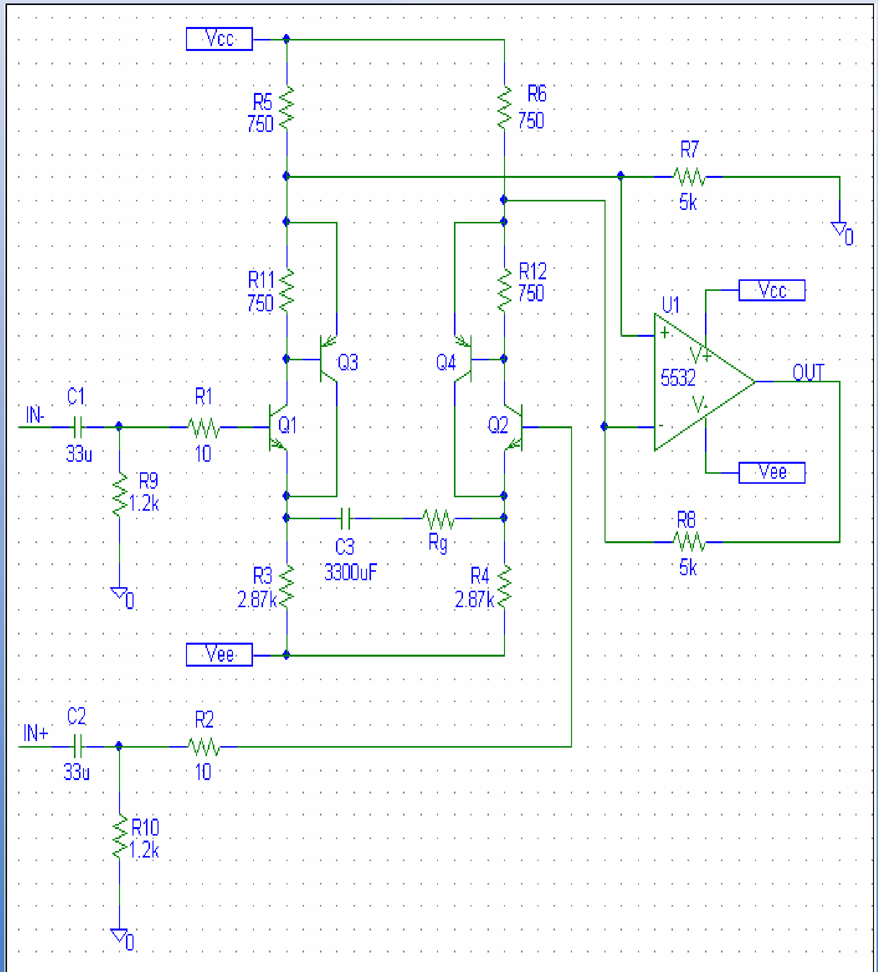

- Output impedance at NPN emitters is now: $r_o = \frac{1}{g_m(1+\beta_{PNP} \bullet \frac{R_{11}}{r_{\pi PNP}+R_{11}})}$
- Still current dependent, but much lower
- Gain = 5k/($r_e$/74 + Rg/2||2.87k)
- Minimum Gain = 5k/2.87k = 4.8 dB

# THD Performance of CFP Mic Preamp

## THD vs. Gain, 1 kHz, +20 dBu Out

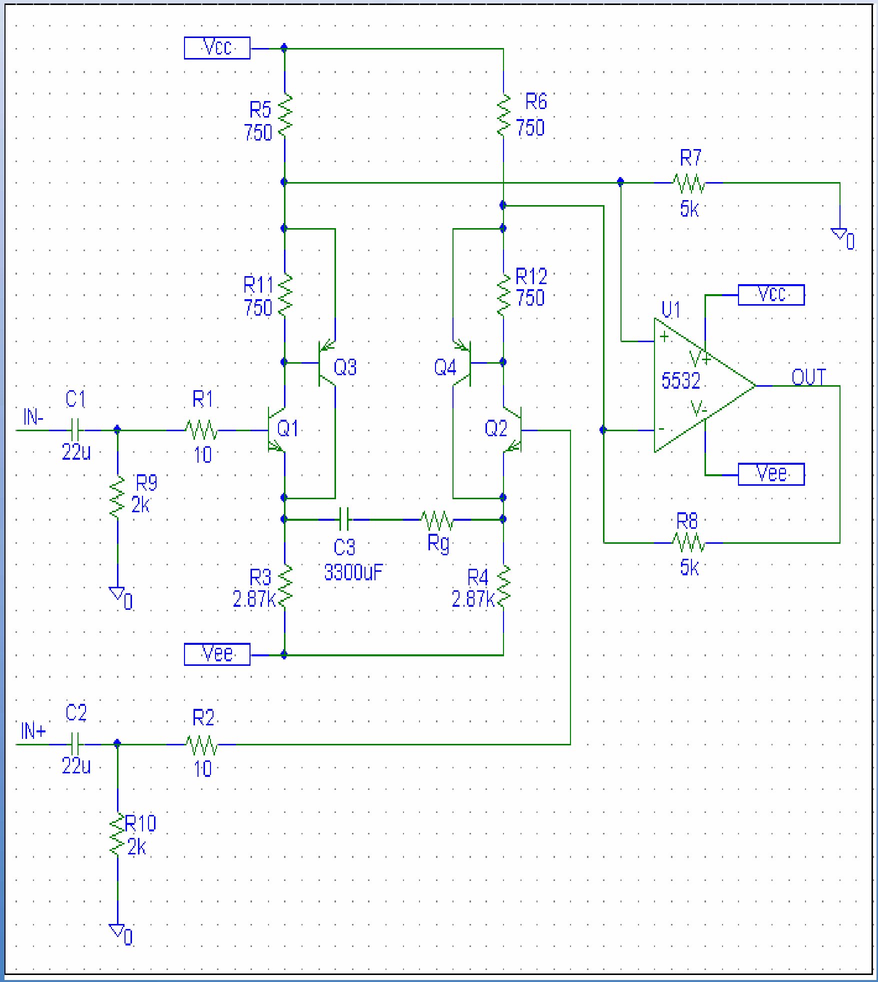


# High-Gain Noise Sources of CFP Mic Preamp



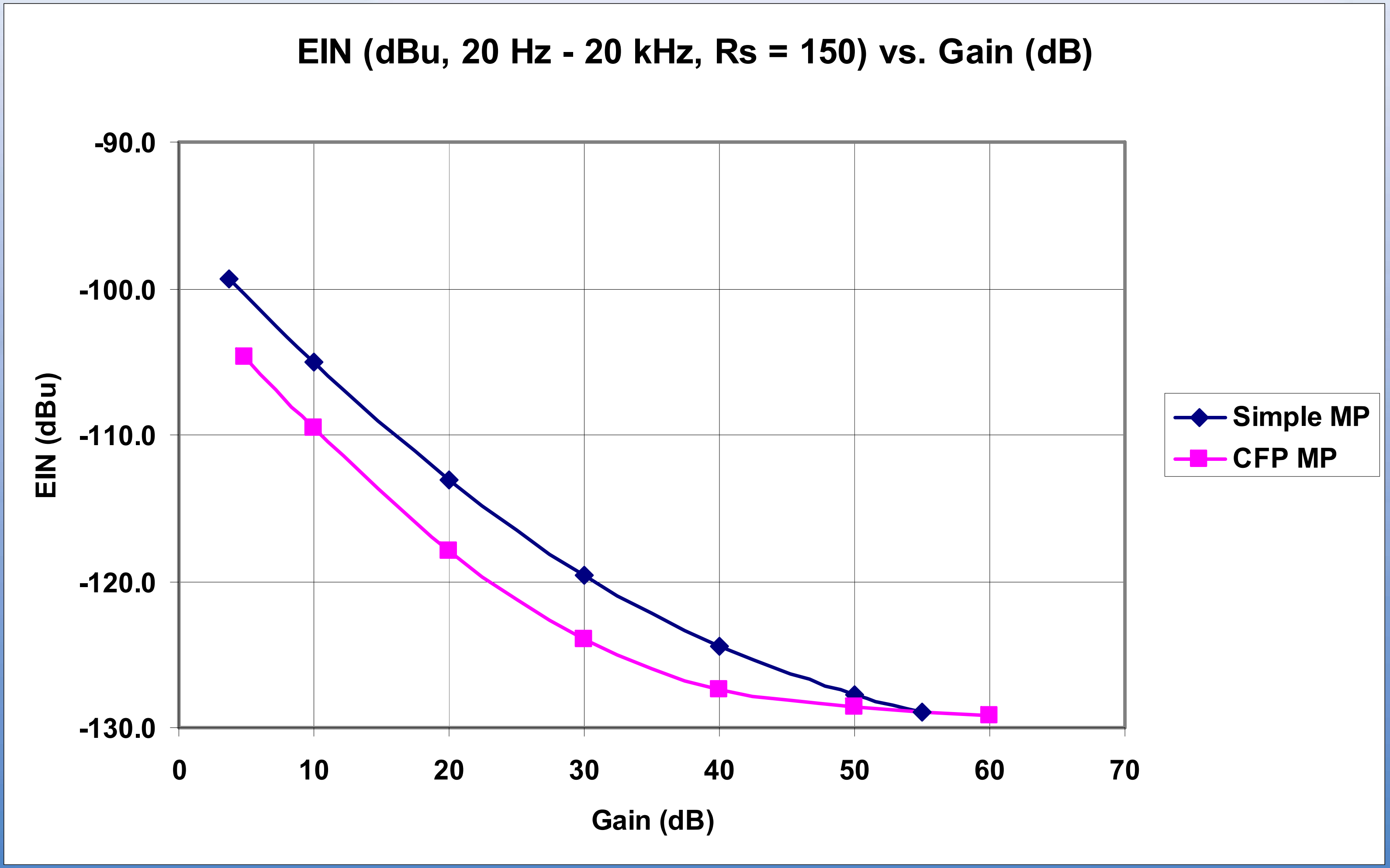

- Input noise at high gains dominated by:
- $Q_1$, $Q_2$ $I_C$ Shot Noise (RTI) = $\frac{2\sqrt{qI_C}}{g_m} = \sqrt{4kTr_e}$
- $Q_1$, $Q_2$ $r_b$ Thermal Noise = $\sqrt{8kTr_b}$
- $R_1$, $R_2$, $R_g$ Thermal Noise = $\sqrt{4kT(R_1+R_2+R_g)}$

# Low-Gain Noise Sources of CFP Mic Preamp

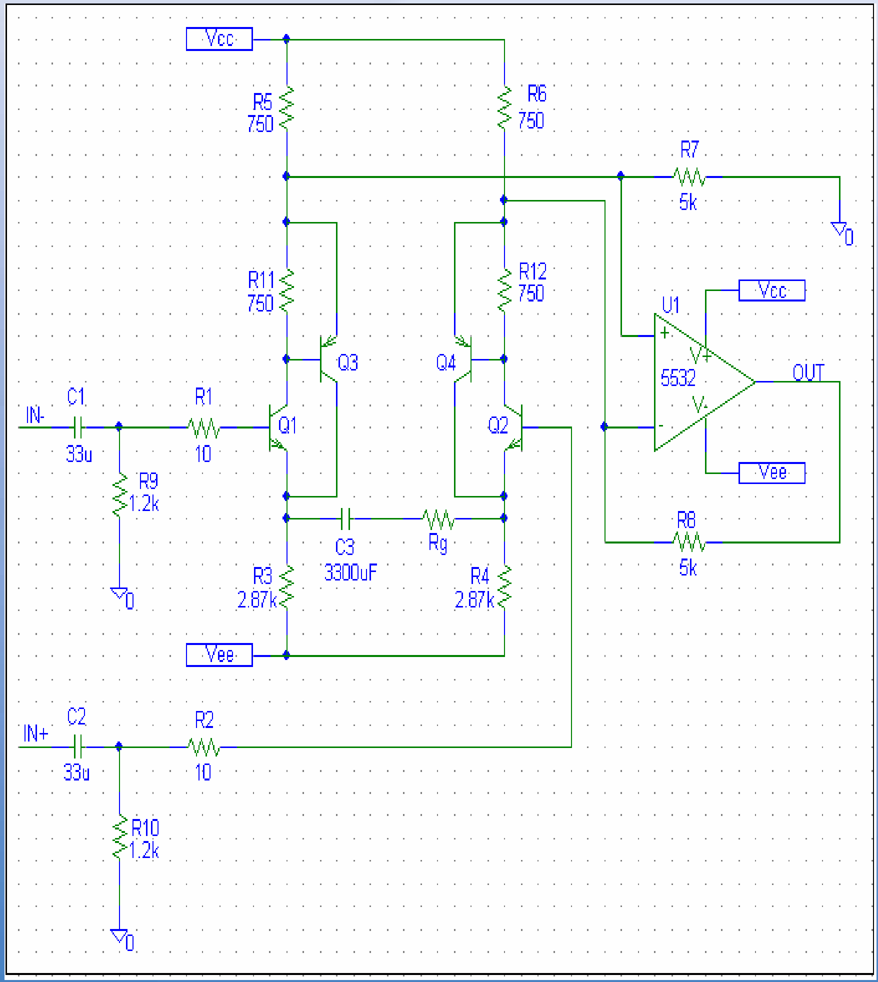



- Input noise at low gains dominated by:
- Thermal Noise of $R_5$ and $R_6$
- EIN of U1
- Thermal Noise of $R_g \| (R_3 + R_4)$
- $Q_1, Q_2$ $I_B$ shot noise across $\frac{R_g \| (R_3 + R_4)}{2}$

# Noise Performance of CFP Mic Preamp



# CMRR Performance of CFP Mic Preamp




- CM to Diff conversion can occur due to mismatches in:
- $R_3$ and $R_4$
- $R_5$ and $R_6$
- $R_7$ and $R_8$
- $R_9$ and $R_{10}$
- $R_{11}$ and $R_{12}$

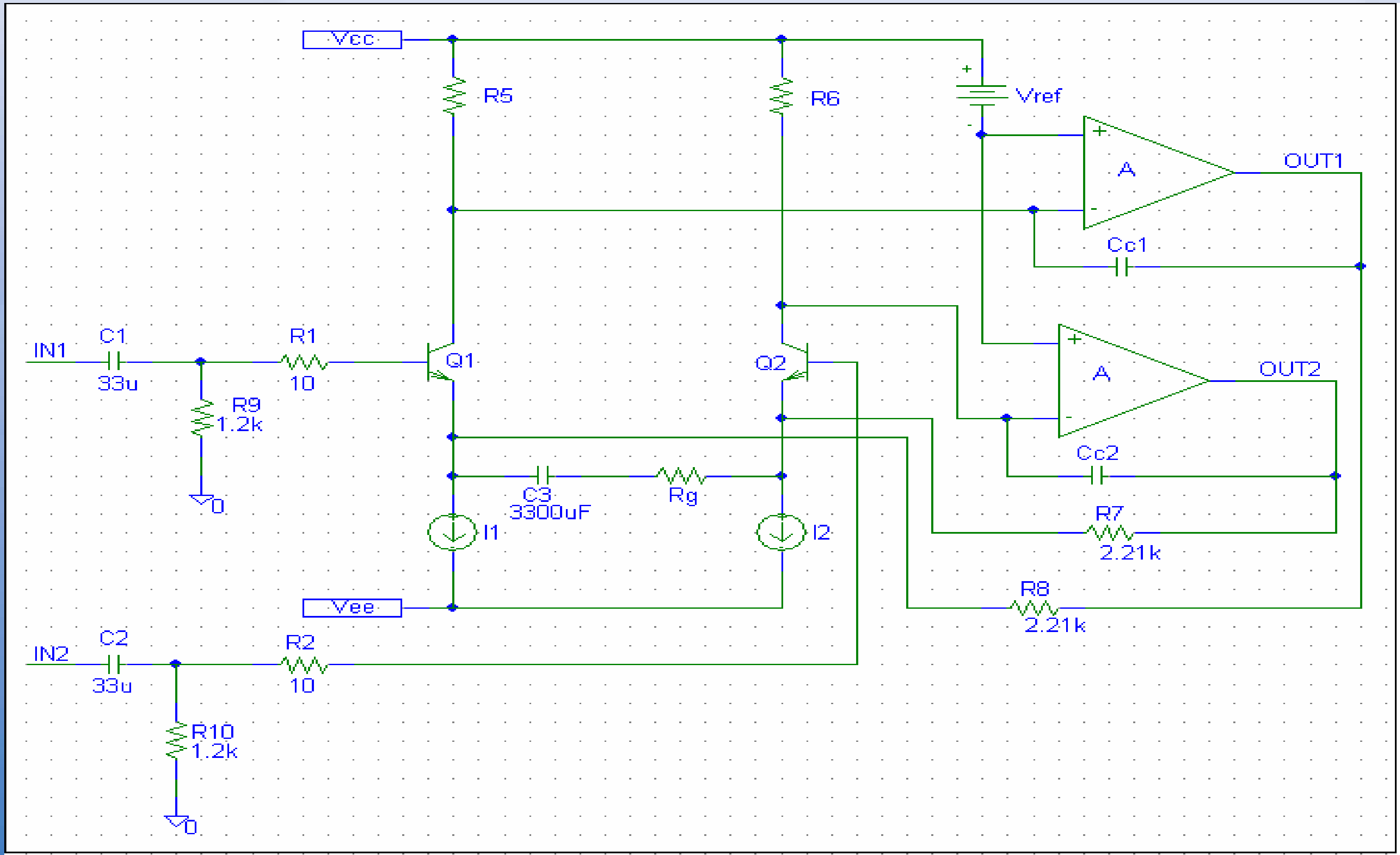
# CFP Mic Preamp

- Performance is improved over Simple Mic Preamp
- Distortion performance still not terrific at high gains
- Power consumption is high to get that performance
- Cost is modest

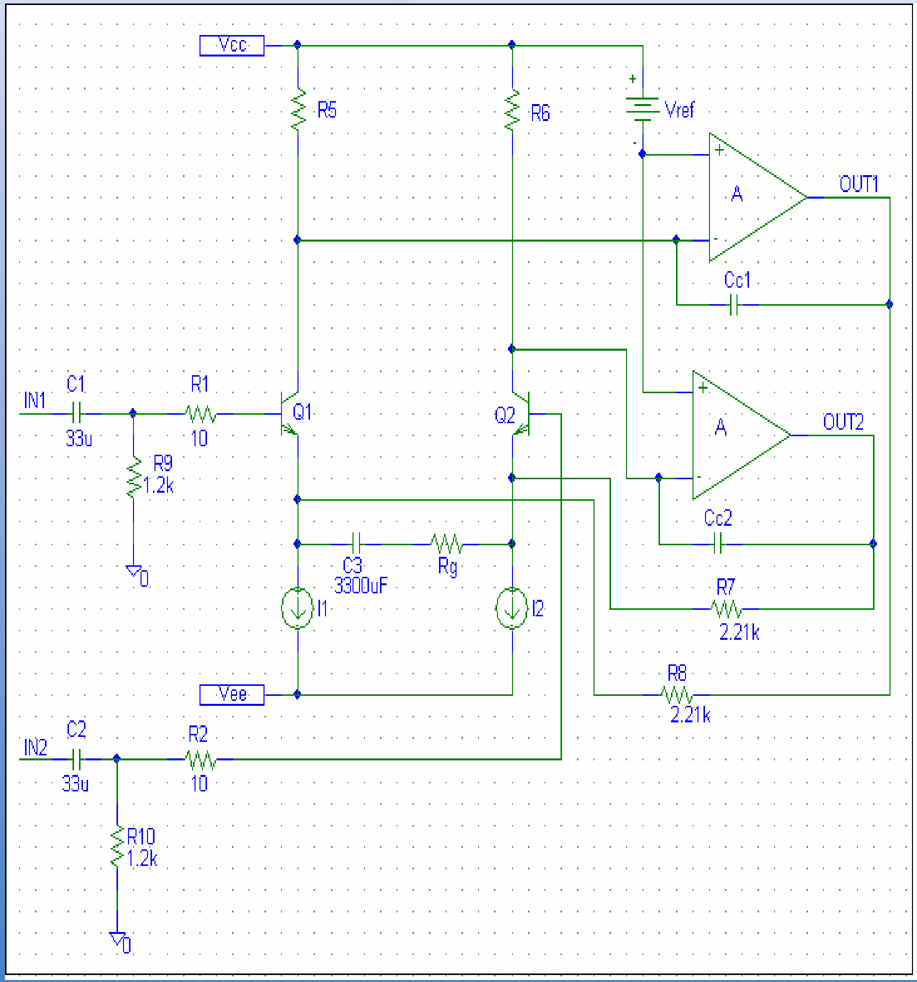
# Current Feedback Instrumentation Amp

- Topology used in most integrated mic preamp ICs including ADI - SSM2019, TI - INA103, INA163, INA217, THAT – 1510,1512, 1570 and possibly others
- Scott Wurcer – AD524 IEEE Paper 12/82
- Graeme Cohen AES Paper – “Double Balanced Microphone Amplifier” 9/84

# Basic CFIA Mic Preamp Schematic

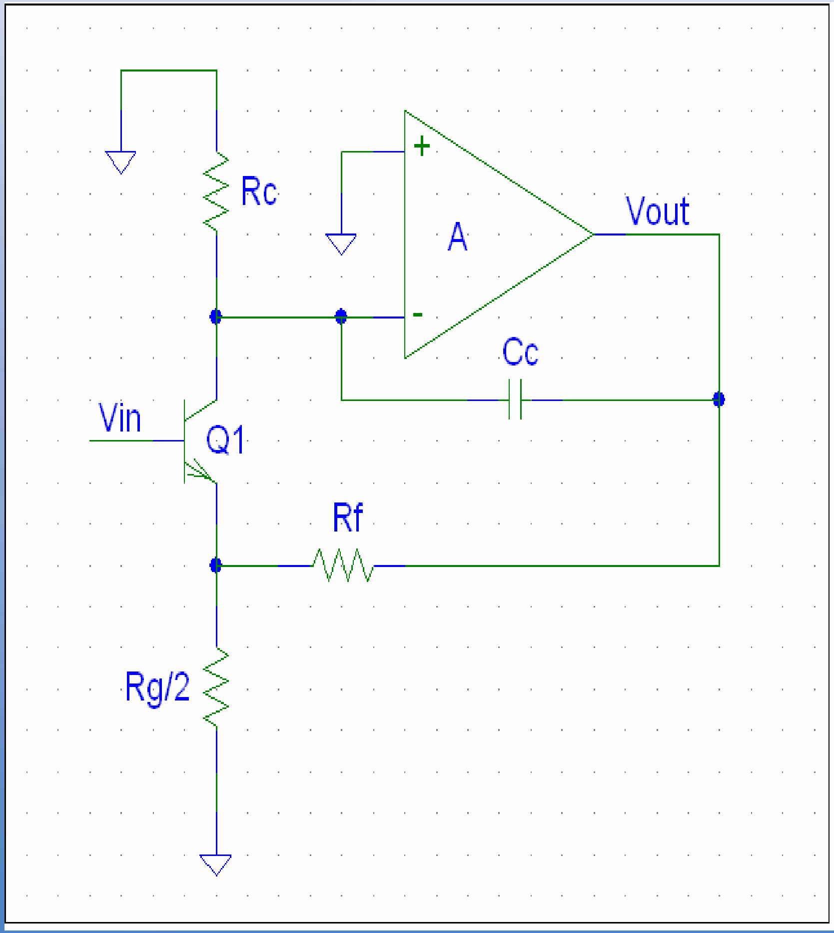


# Basic CFIA Mic Preamp



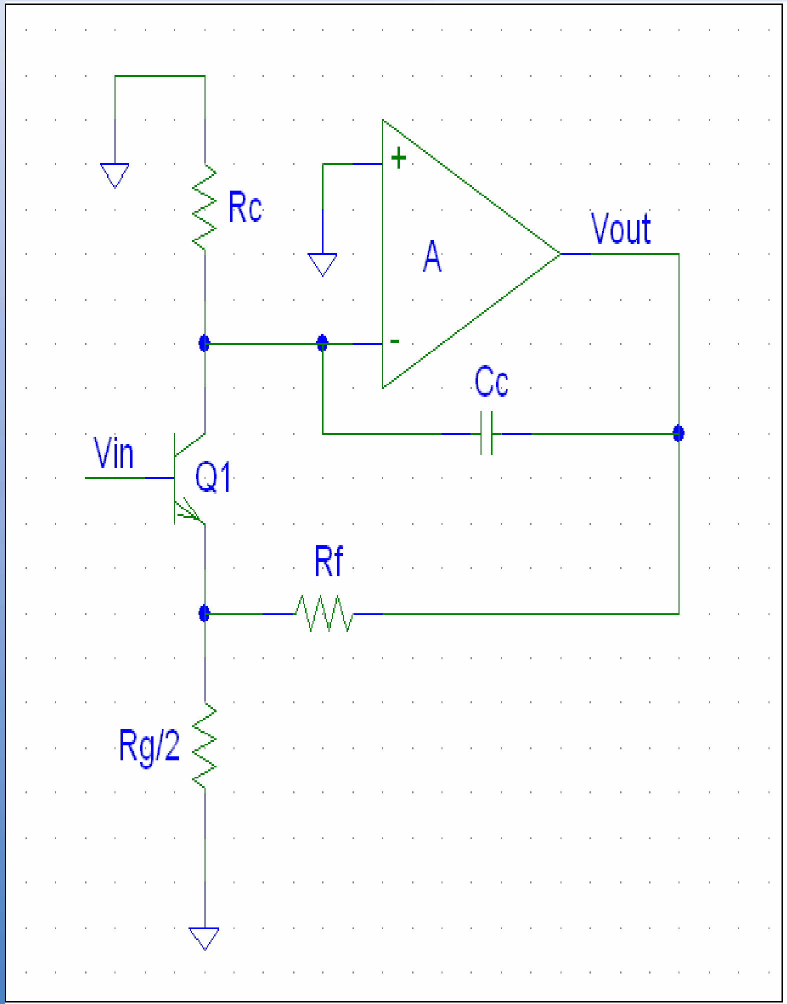

- Input Transistor Ic = Vref/$R_5$
- Current Sources $I_1$ and $I_2$ are for "bias current cancellation" only
- Gain = 1 + ($2R_7/R_g$)
- Min. gain = 0 dB

# What's "Current Feedback"?




- Closed loop bandwidth stays substantially constant with closed loop gain until $r_e$ becomes a significant factor
- Cc charging current is not limited

# "Half Circuit" of CFIA




$$\frac{V_{out}}{V_{in}} = \frac{\dfrac{R_C \bullet A}{\left[r_e + (R_F \| R_G/2)\right](R_C C_M S + 1)}}{1 + \dfrac{R_C \bullet A}{\left[r_e + (R_F \| R_G/2)\right](R_C C_M S + 1)} \bullet \dfrac{R_G}{2R_F + R_G}} = \frac{A}{1 + A\beta}$$

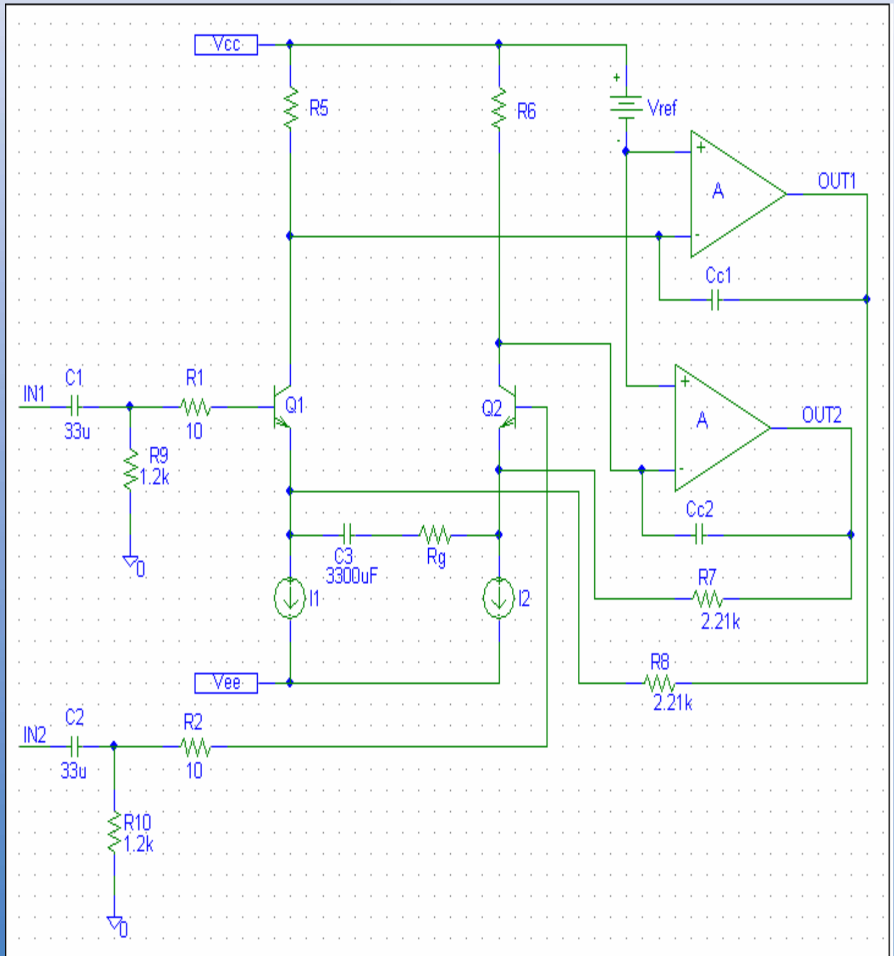
Where $C_M = C_C(A+1)$, $r_e = 1/gm$

For $r_e << (R_F \| R_G/2)$:

$$\frac{V_{out}}{V_{in}} = \frac{\dfrac{R_C \bullet A}{(R_F \| R_G/2)(R_C C_M S + 1)}}{1 + \dfrac{R_C \bullet A}{R_F(R_C C_M S + 1)}} = \frac{A}{1 + A\beta}$$

**Note that the loop transmission Aβ is independent of the closed loop gain if $r_e$ is much less than the feedback network impedance**

# High-Gain Noise Sources of CFIA Mic Preamp

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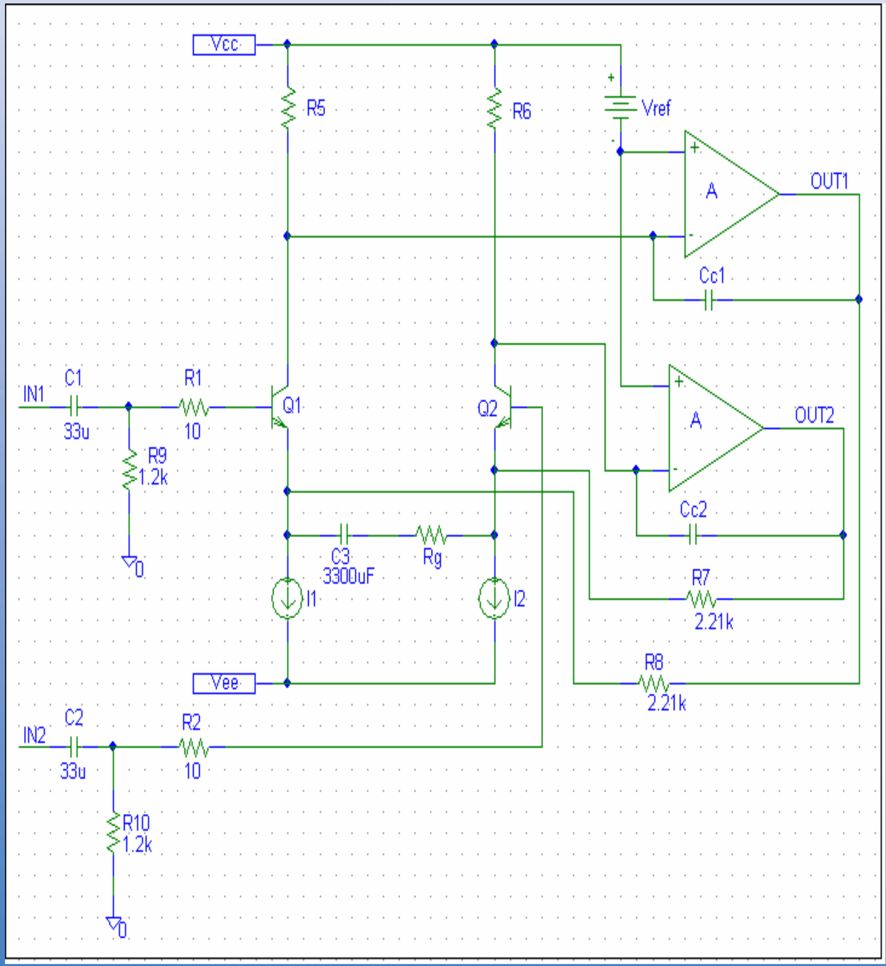
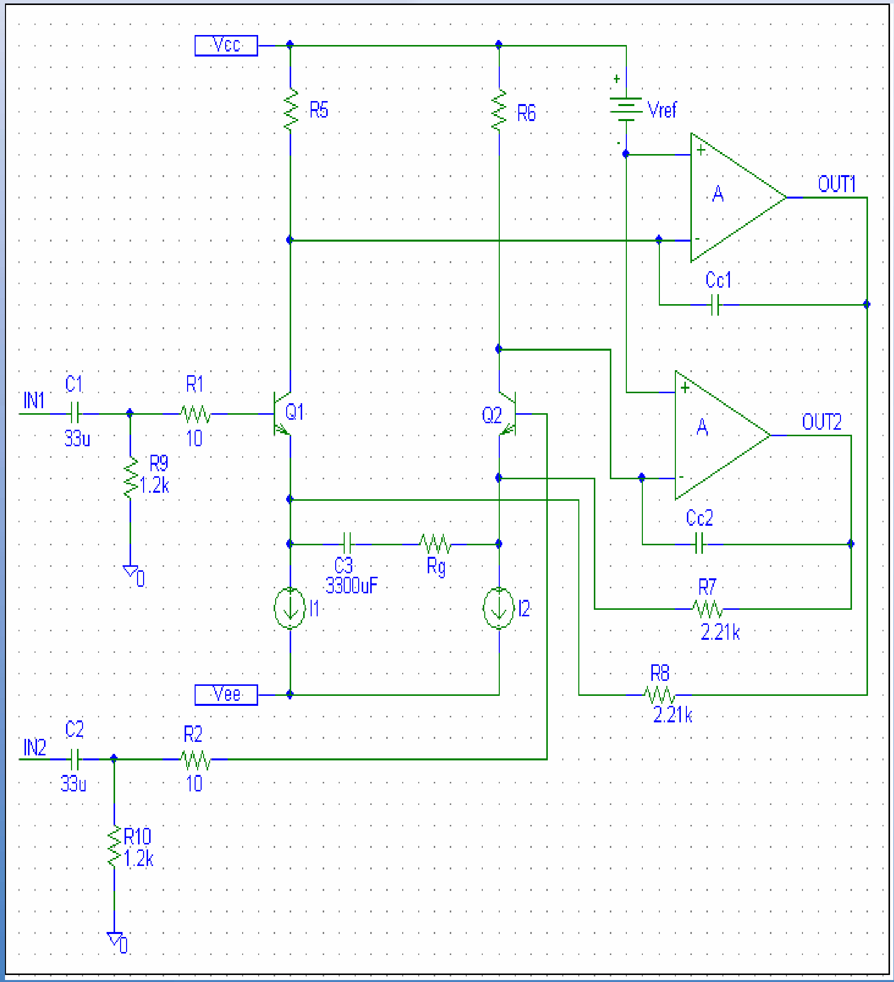
# Low-Gain Noise Sources of CFIA Mic Preamp



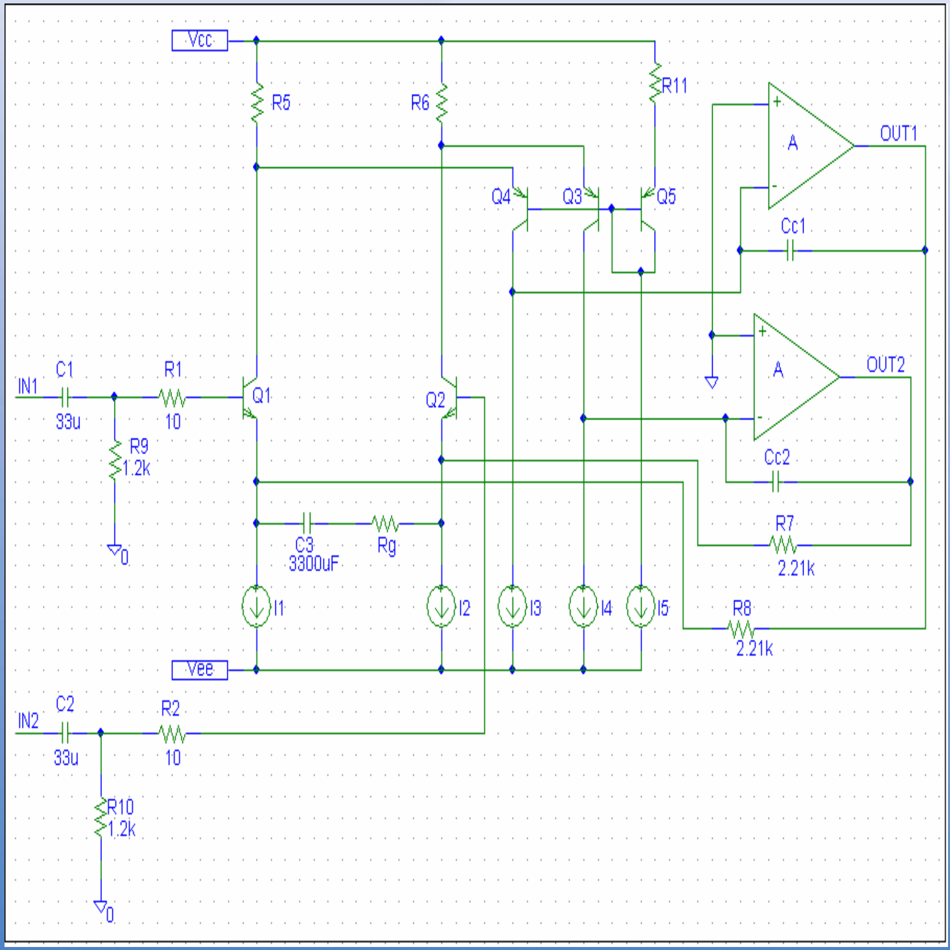

- Input noise at low gains dominated by:
- Thermal Noise of $R_5$, $R_6$
- Noise of $I_1$, $I_2$
- Thermal Noise of $R_g \| (R_7 + R_8)$
- $Q_1$,$Q_2$ $I_B$ shot noise across $\frac{R_g \| (R_7 + R_8)}{2}$
- EIN of U1, U2

# CMRR Performance of CFIA Mic Preamp



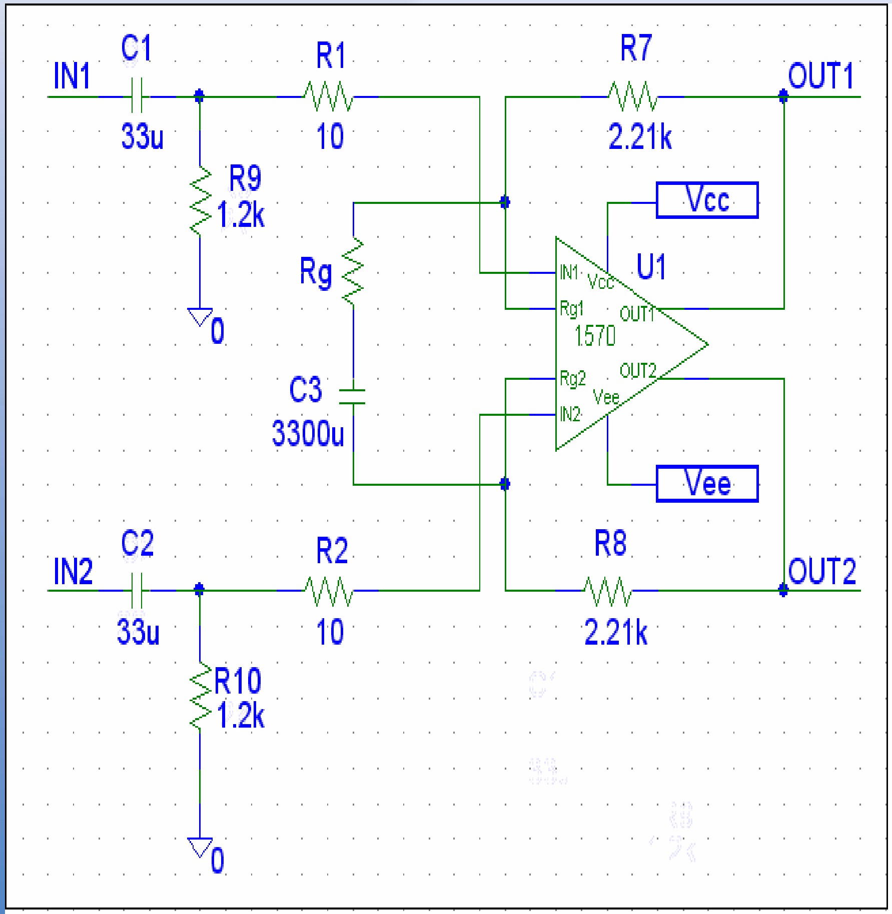

- Unity CM Gain to OUT1 – OUT2
- CMRR = Differential Gain
- CM to Diff conversion can occur due to mismatches in transistors

# Refinements to the CFIA



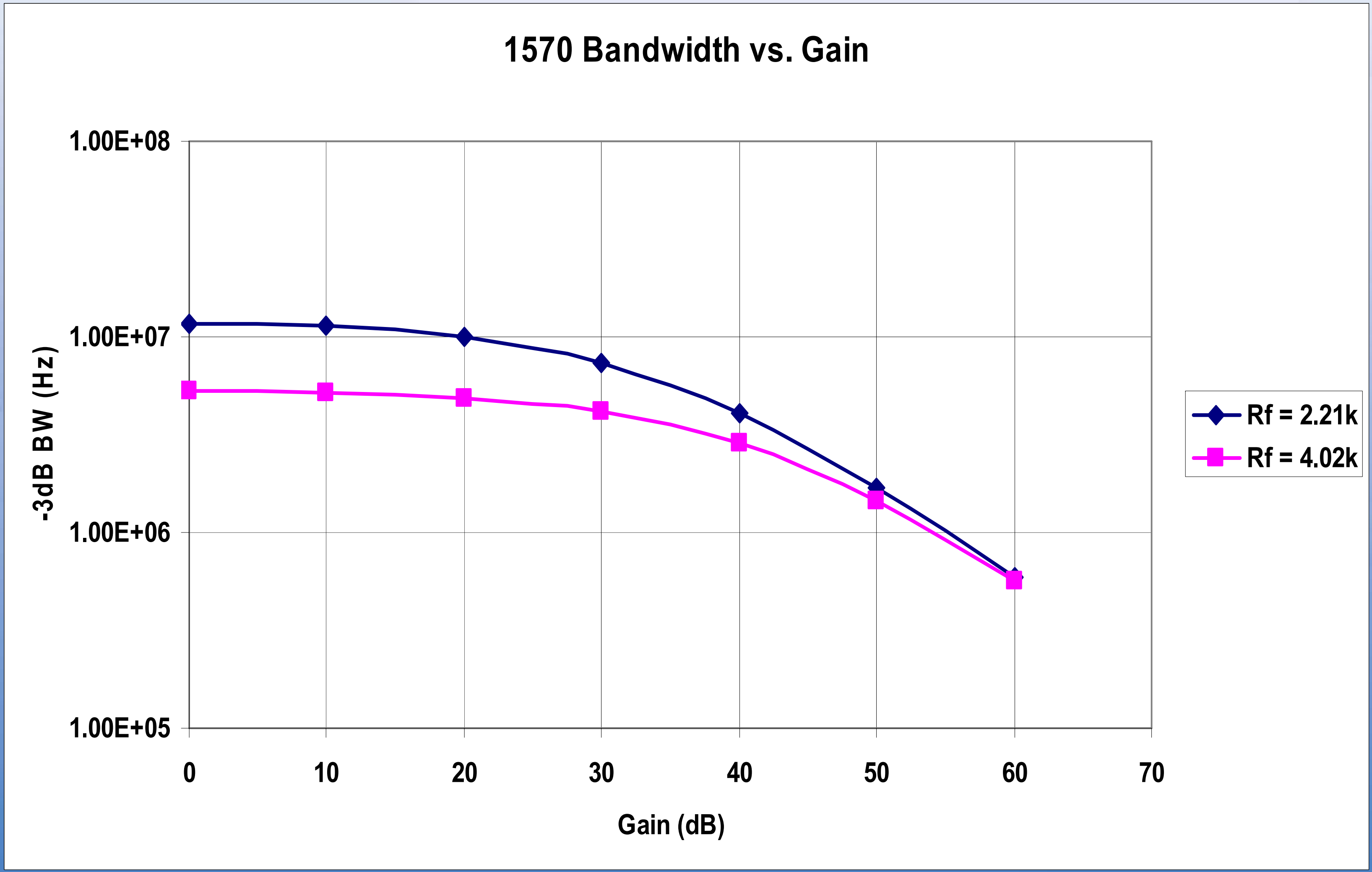

- Early effect and Ccb mismatch in the current source transistors can also contribute to THD at low gains
- Cascoding helps here at the expense of some input CM range
- A Folded Cascode can minimize the noise contribution of the integrator stages and $R_5$ and $R_6$ while minimizing the impact on input CM range
- At this level of complexity an IC makes sense and the good device matching helps performance

# A Real Example THAT's 1570 CFIA



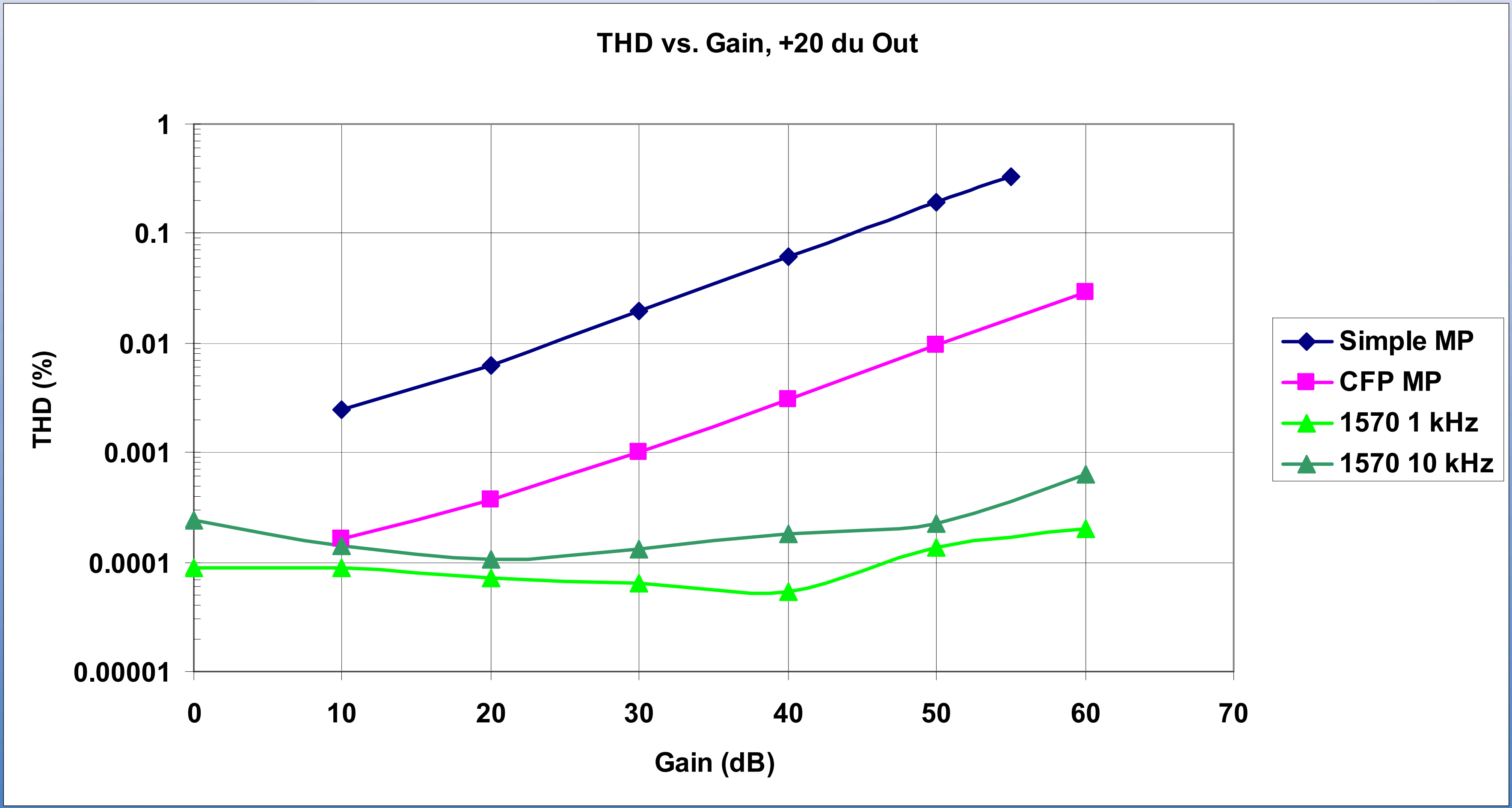

- An integrated circuit current-feedback instrumentation amplifier front end
- Utilizes the techniques described on the previous slide.
- Compensated for $R_F$ values down to 2 kohm

# 1570 Bandwidth vs. Gain

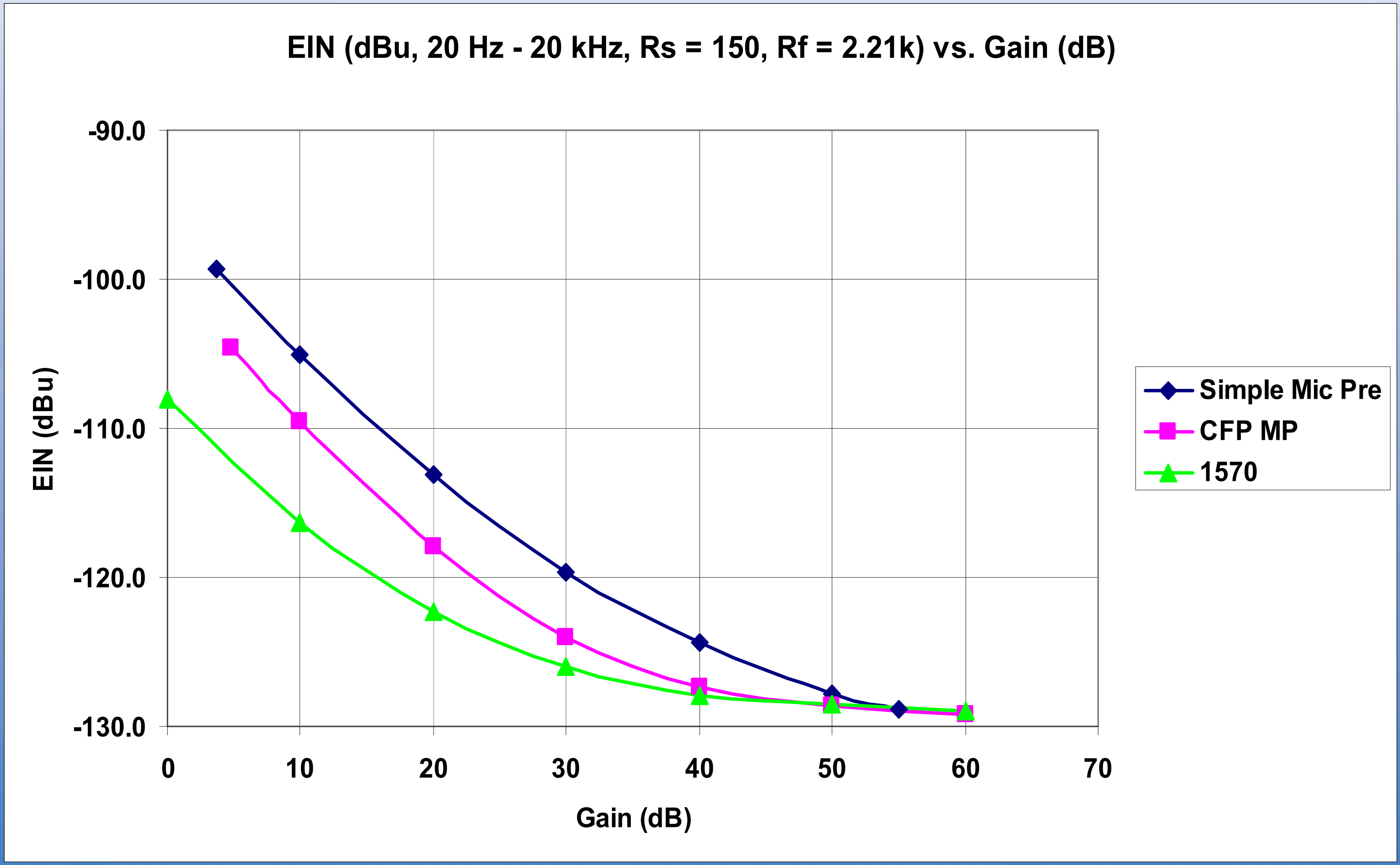


# THD Performance of 1570 Mic Preamp

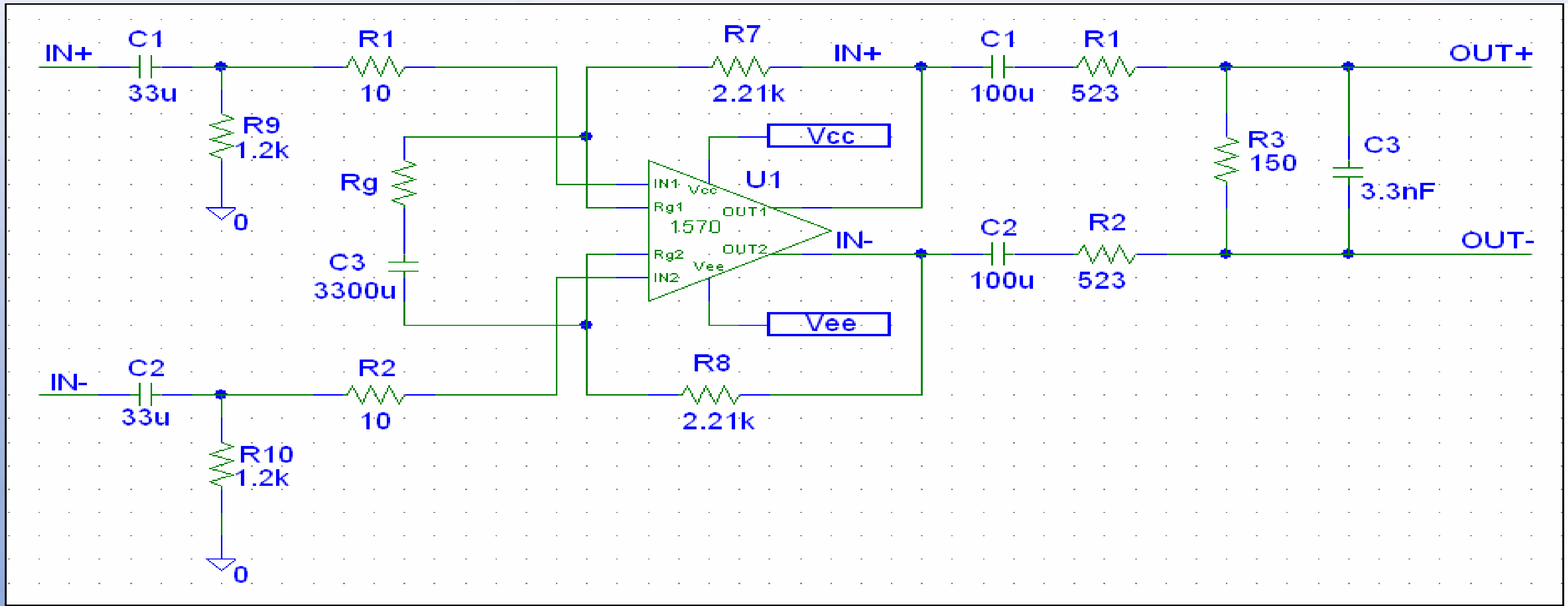
## THD vs. Gain, +20 dBu Out, Rf = 2.21k



# Noise Performance of 1570

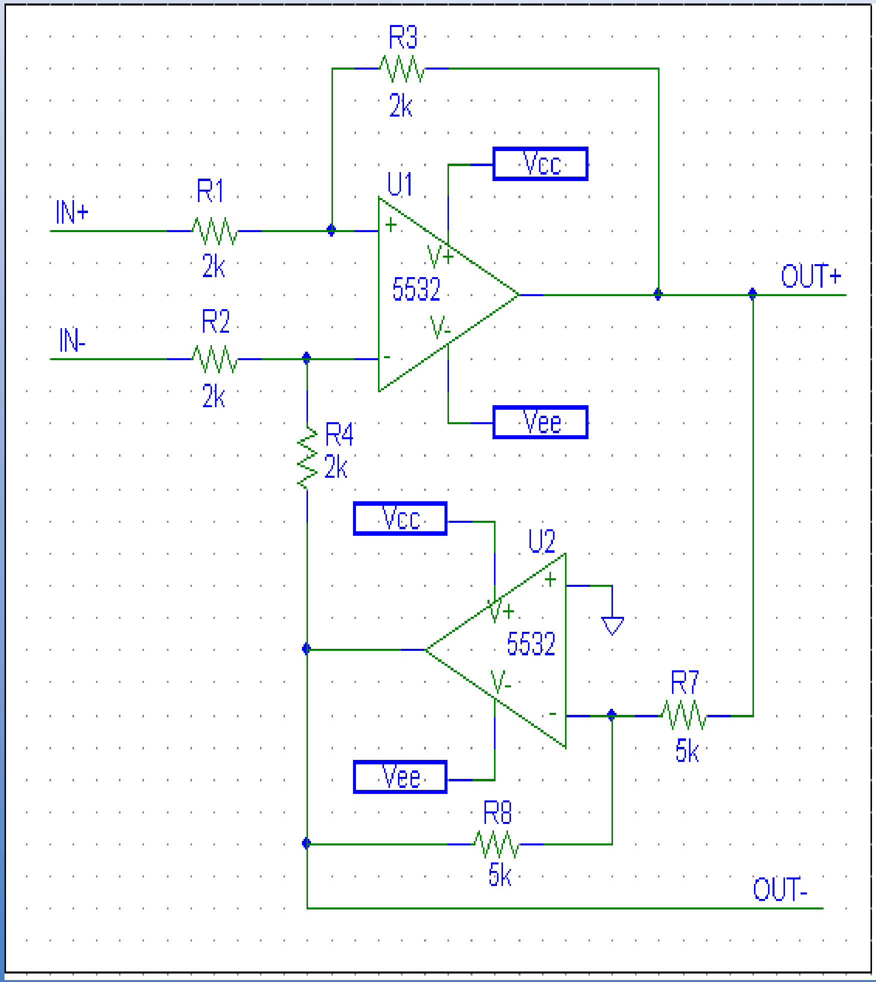


# Utilizing the Differential Output to Drive A/D Converters



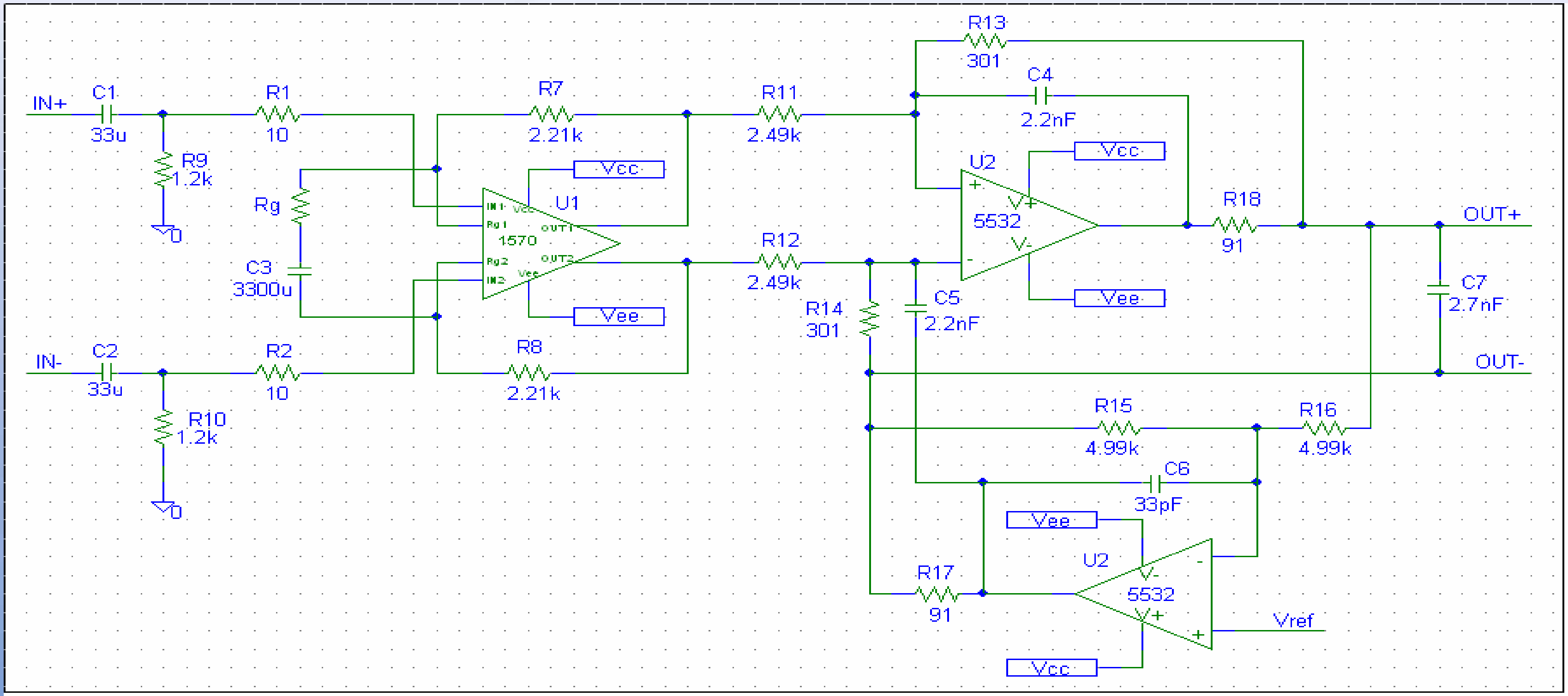

- The cheap and simple way:
- Rely on the A/D converter for CMRR at low gains
- Converter CM input range might be an issue as the pad does not attenuate CM signals

# Birt Circuit



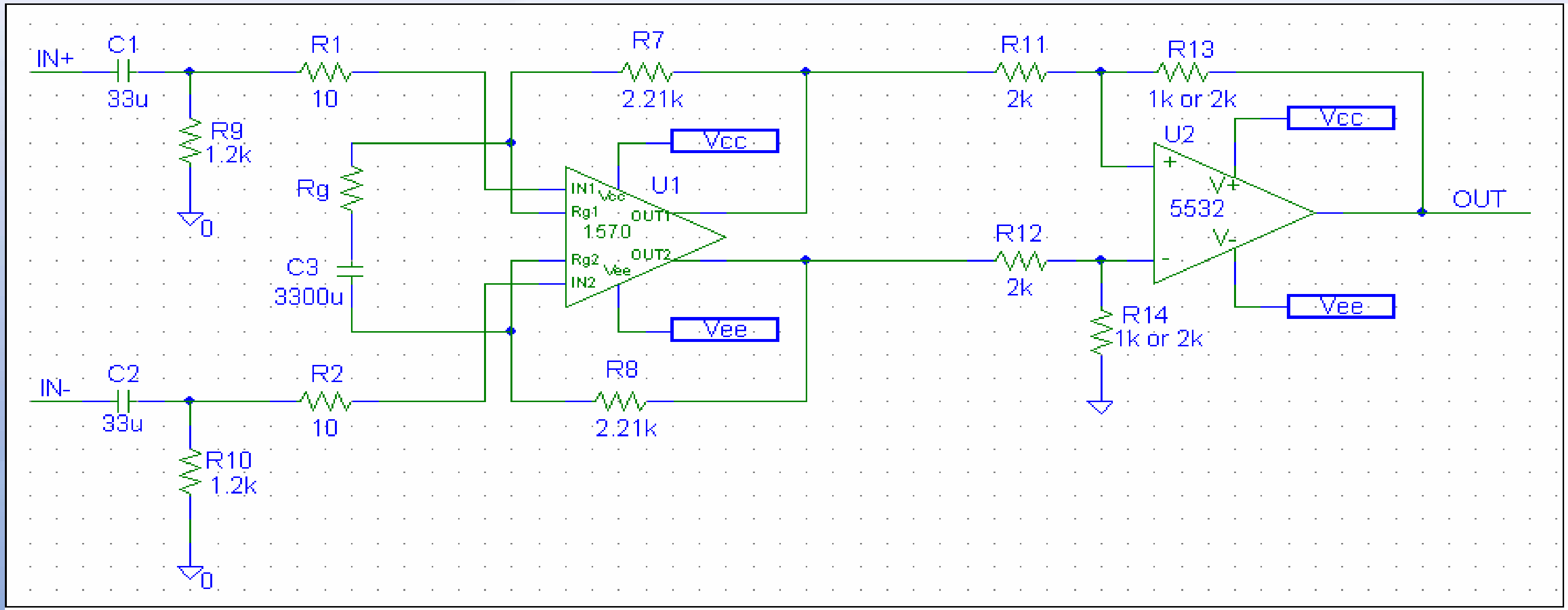

- David Birt, 1990
- Provides CMRR
- Gain = $R_3/R_1$
- Provides a convenient input for a CM DC reference voltage
- U2 input offset and noise appear as CM at OUT+ - OUT-

# Birt Circuit Applied to 1570 and A/D Drive



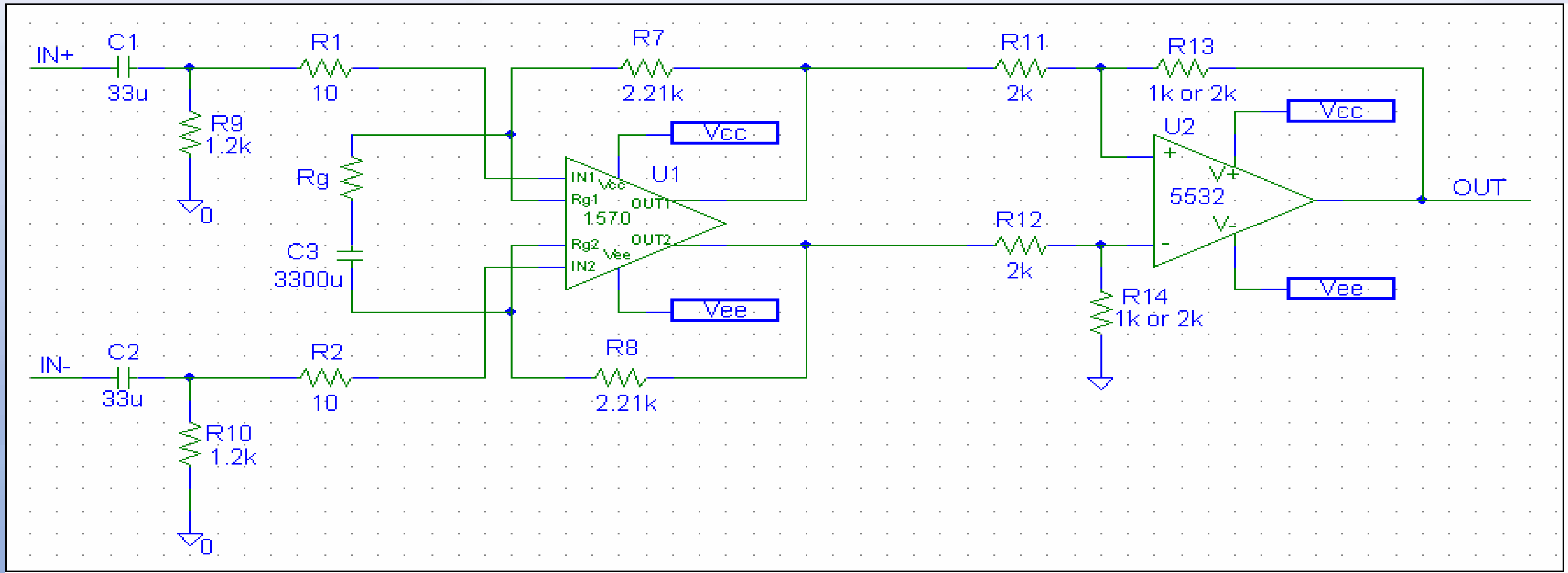

- The resistor ratios provide 18 dB of attenuation before the A/D
- The feedback networks enable capacitive load driving with low audio-band output impedance

# Converting Differential Output to Single-Ended



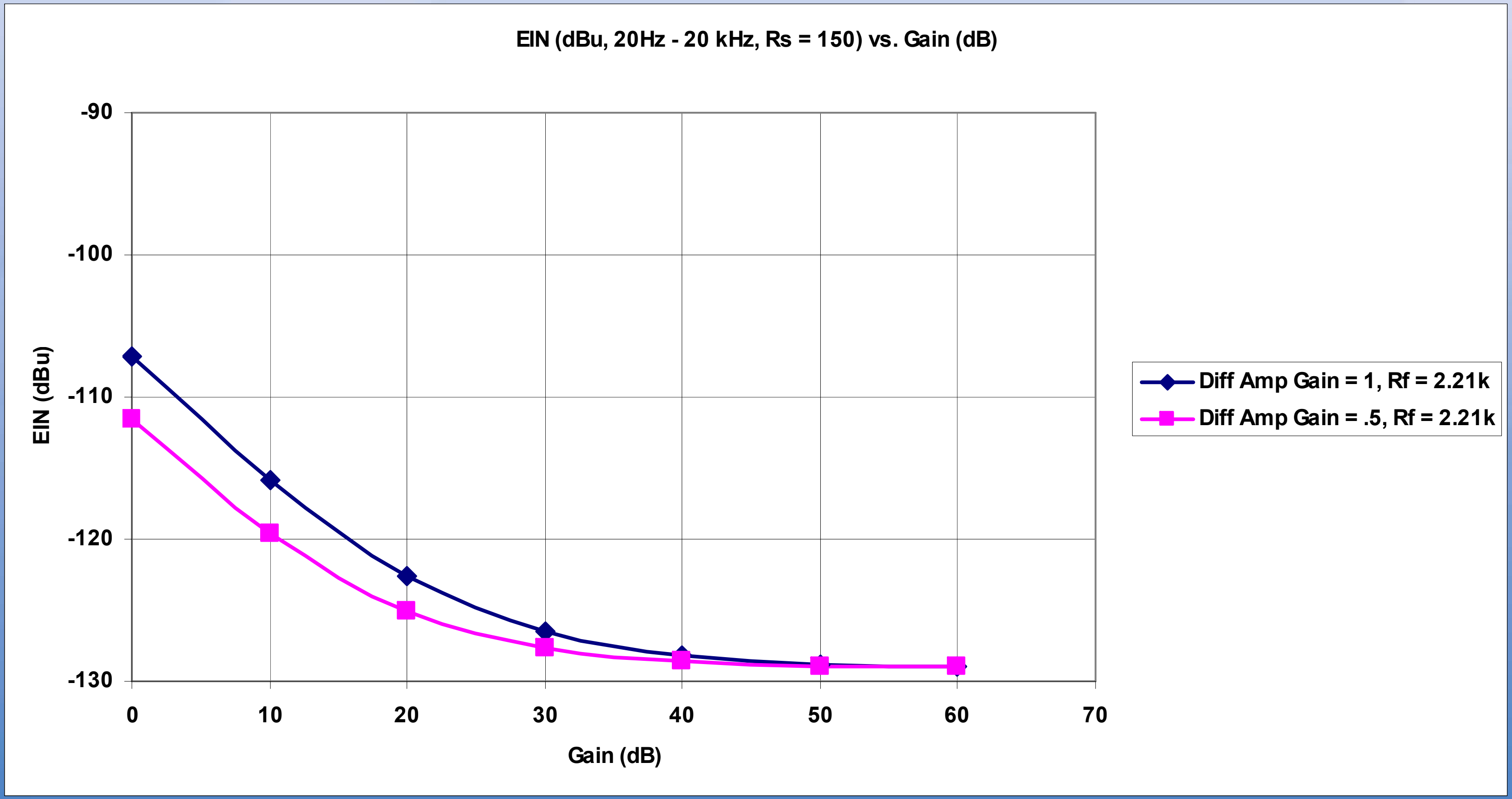

- The traditional 4-resistor differential amplifier works fine
- At low gains, the noise of this stage can become important
- Resistor matching controls the CMRR

# Differential to Single-Ended Conversion




- What should the gain of the diff amp be?
- If G=1, we leave headroom on the table
- If G=.5, we take advantage of all of the swing capability of the differential output
- For the case of G=.5, the front end gain is always 6 db higher

# 1570 + Differential Amplifier Noise vs. Gain Performance

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# Conclusions

- Microphone preamplifiers with a wide gain range controlled by a single resistance involve tradeoffs between low-gain noise and high-gain distortion performance
- The current-feedback instrumentation amplifier is capable of good performance at both extremes
- An integrated approach can provide excellent performance in very small PCB area at moderate cost

# Amplifier References


David Birt, "Electronically Balanced Analogue-Line Interfaces," Proceedings of the Institute of Acoustics, Vol. 12, Part 8 (1990)

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Graeme John Cohen, "Microphone Amplifier History and Design", presented at the Audio Engineering Society Adelaide Section, August, 2006

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# Acknowledgements

Thanks to Steve Green for preparing the "Support Circuitry" section.

Thanks to Greg Benulis, Rosalfonso Bortoni, Fred Floru, Bob Moses, and Les Tyler for their assistance in the preparation of this tutorial

***Questions ?***

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