Designing Microphone Preamplifiers

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THAT Corporation

This presentation is an abbreviated version of a tutorial given at the 2010 AES Conference in San Francisco.

The complete tutorial is available at

http://www.thatcorp.com/Seminars.shtml

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Overview

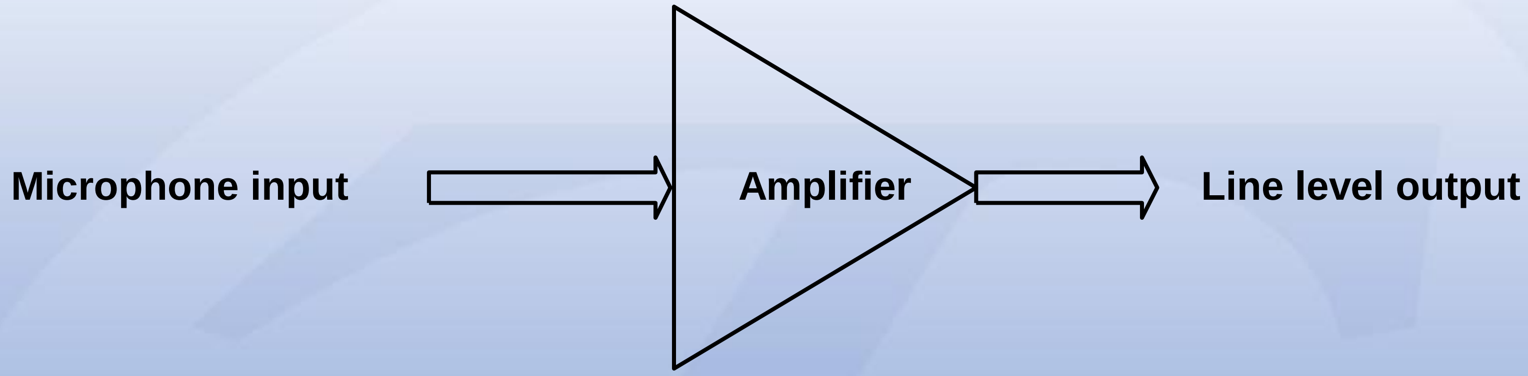
Section 1

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

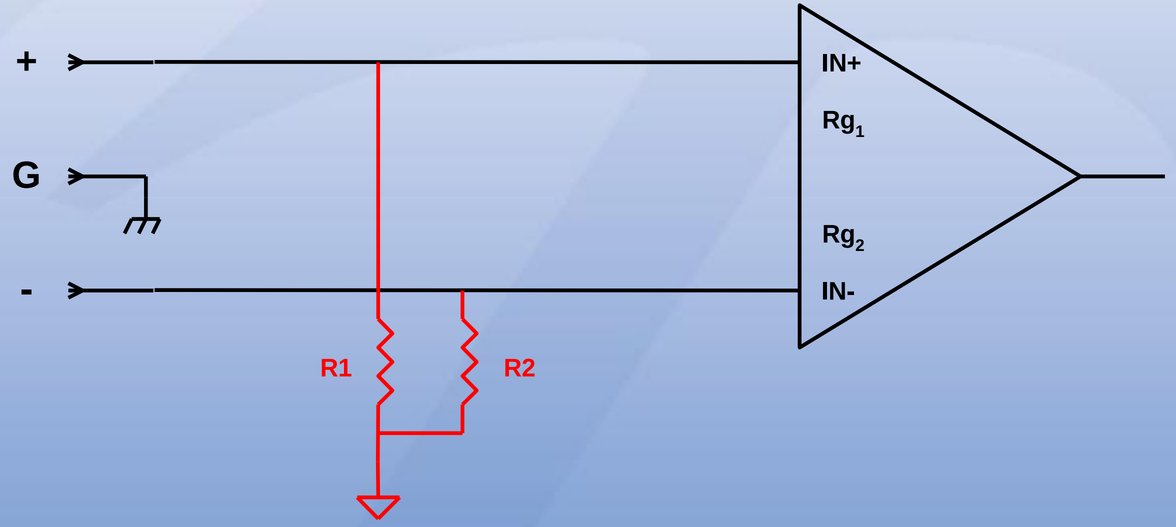
- **Also robust**
- **Performance can be excellent**
- **Cost can be high**

Transformerless Solid State

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

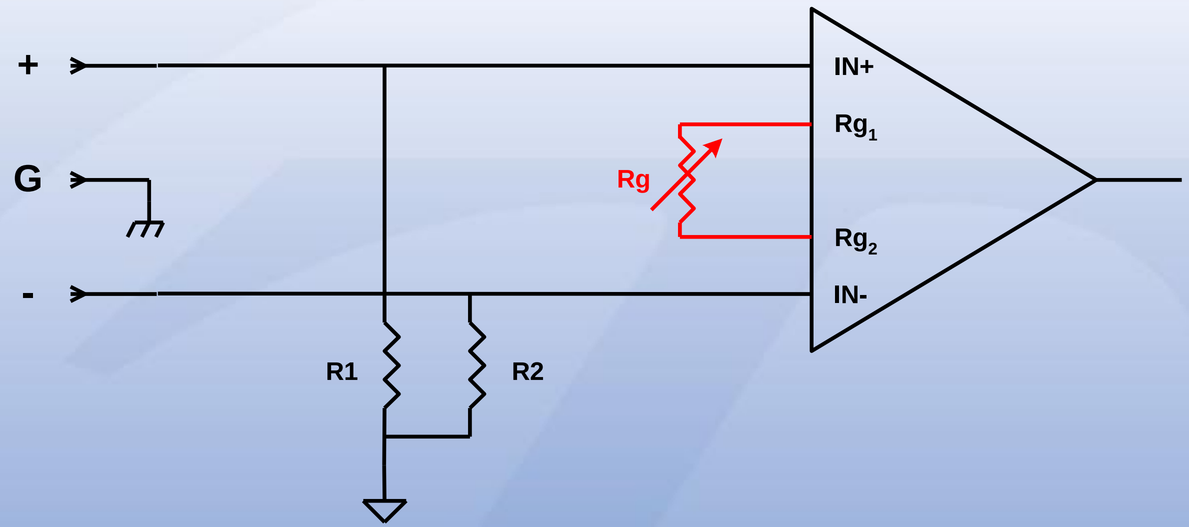
Transformerless solid state designs are the focus today

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)

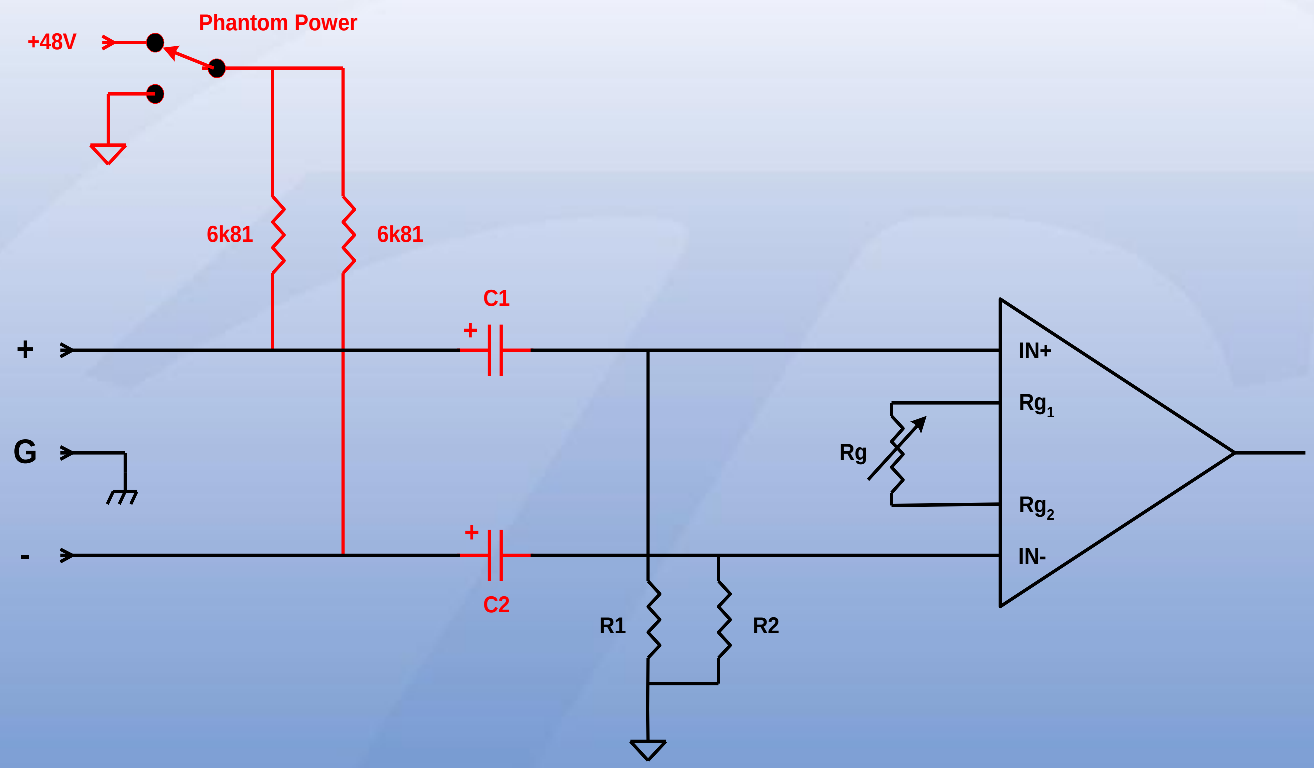
Manually controlled options

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

Digitally controlled options

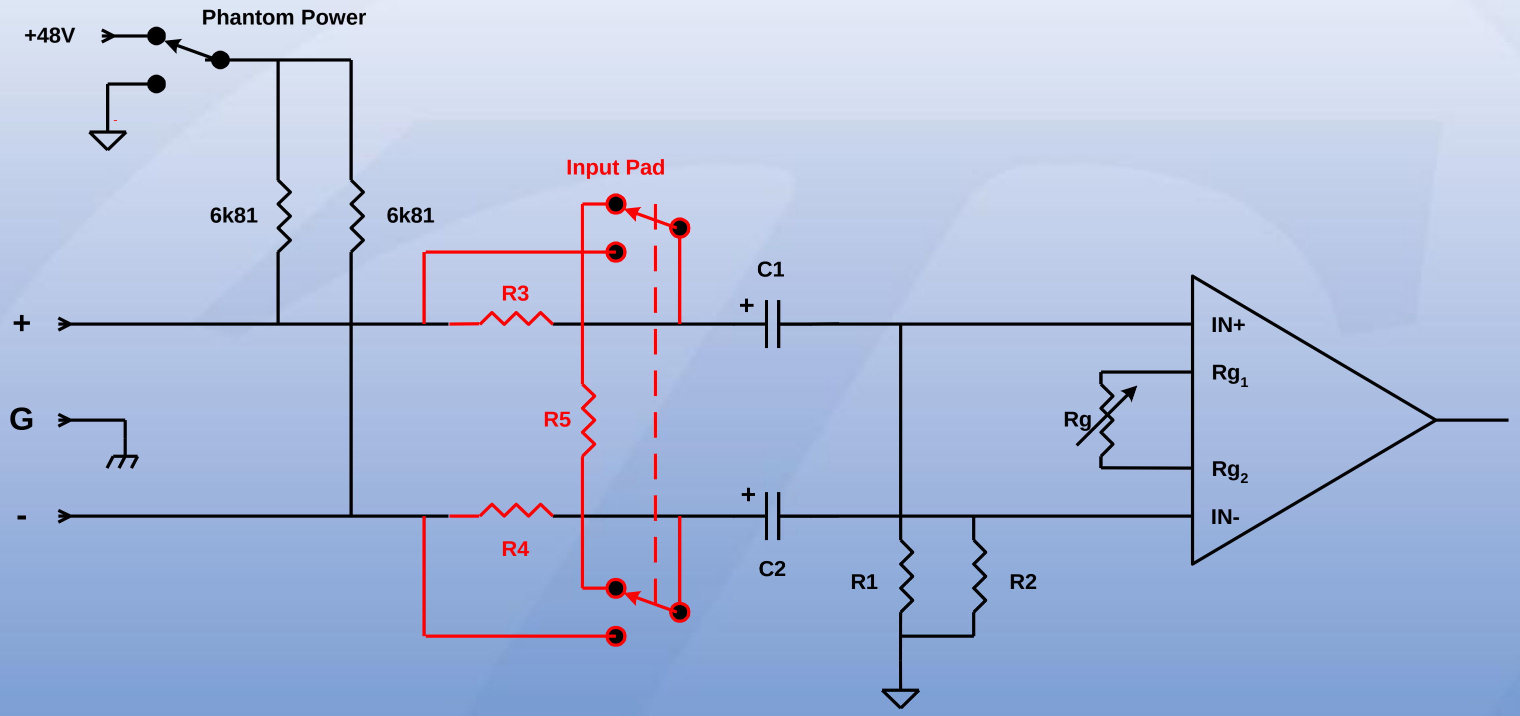
- Digitally switched resistor network with a predetermined number of steps
- Switches are either relays or silicon devices
- Both discrete and integrated circuit solutions are available

Phantom Power



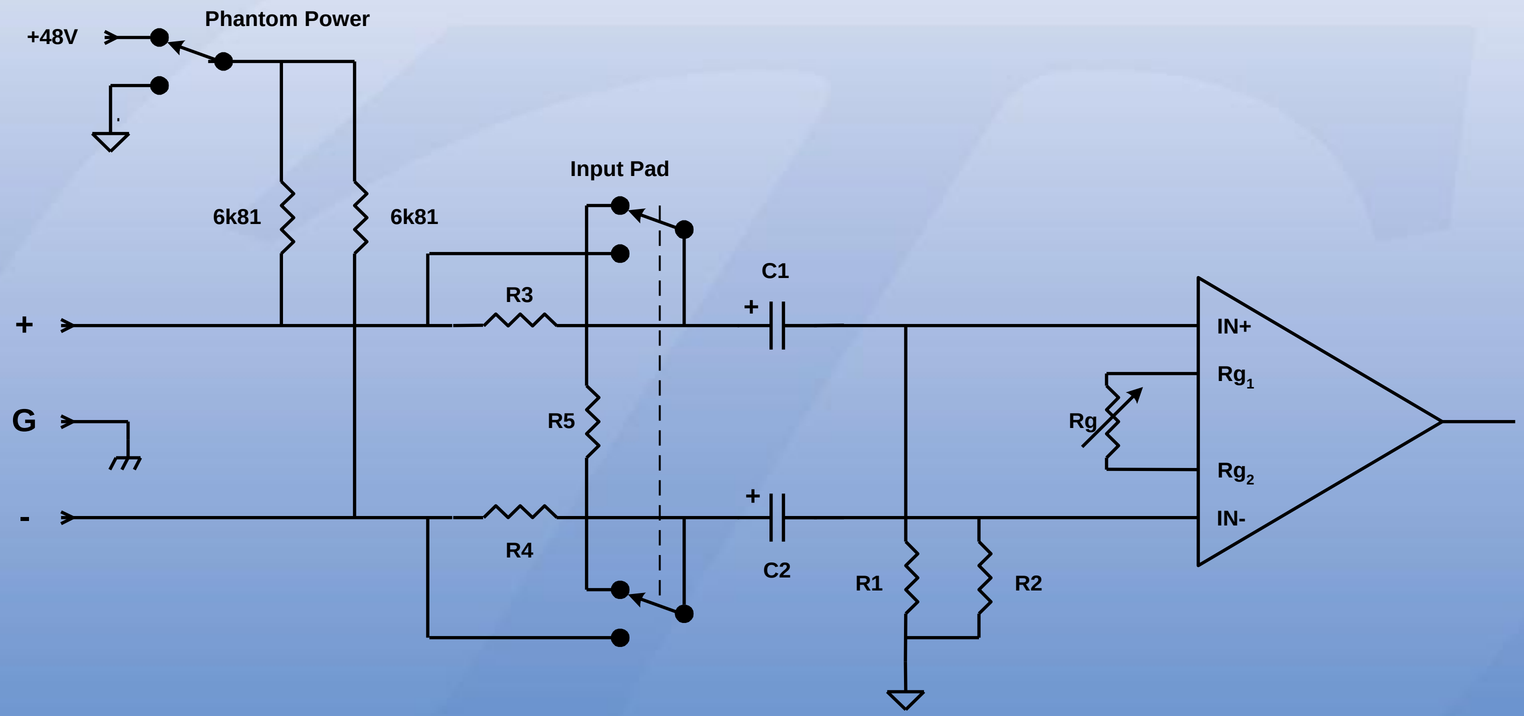
- C1 and C2 required to block the 48 V from the amplifier inputs
- 6.81k series resistors are specified in the standards for 48V phantom power
- On/Off is available via a
  - Simple mechanical switch in manual applications
  - Relay or silicon switch in digitally controlled systems

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

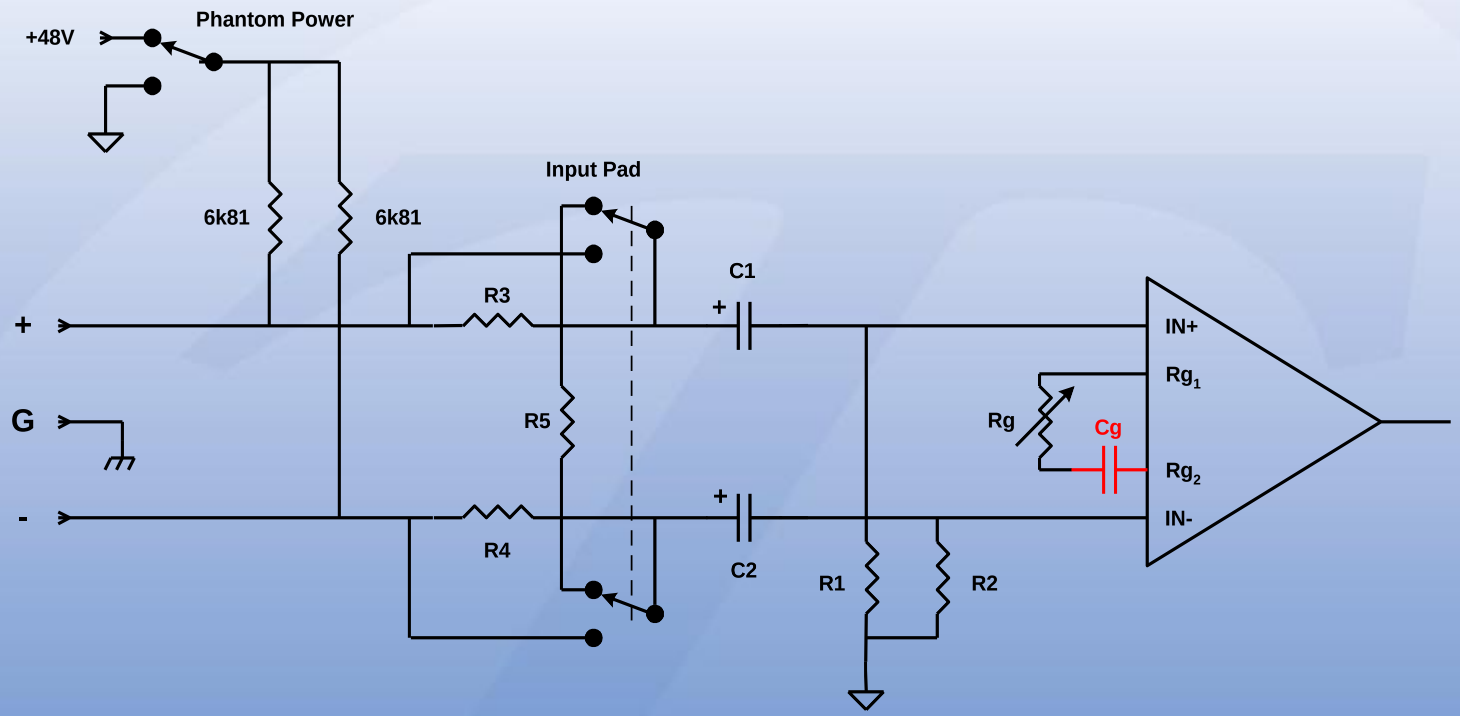
“Complete” Microphone Preamp



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

there are gremlins in the details!!

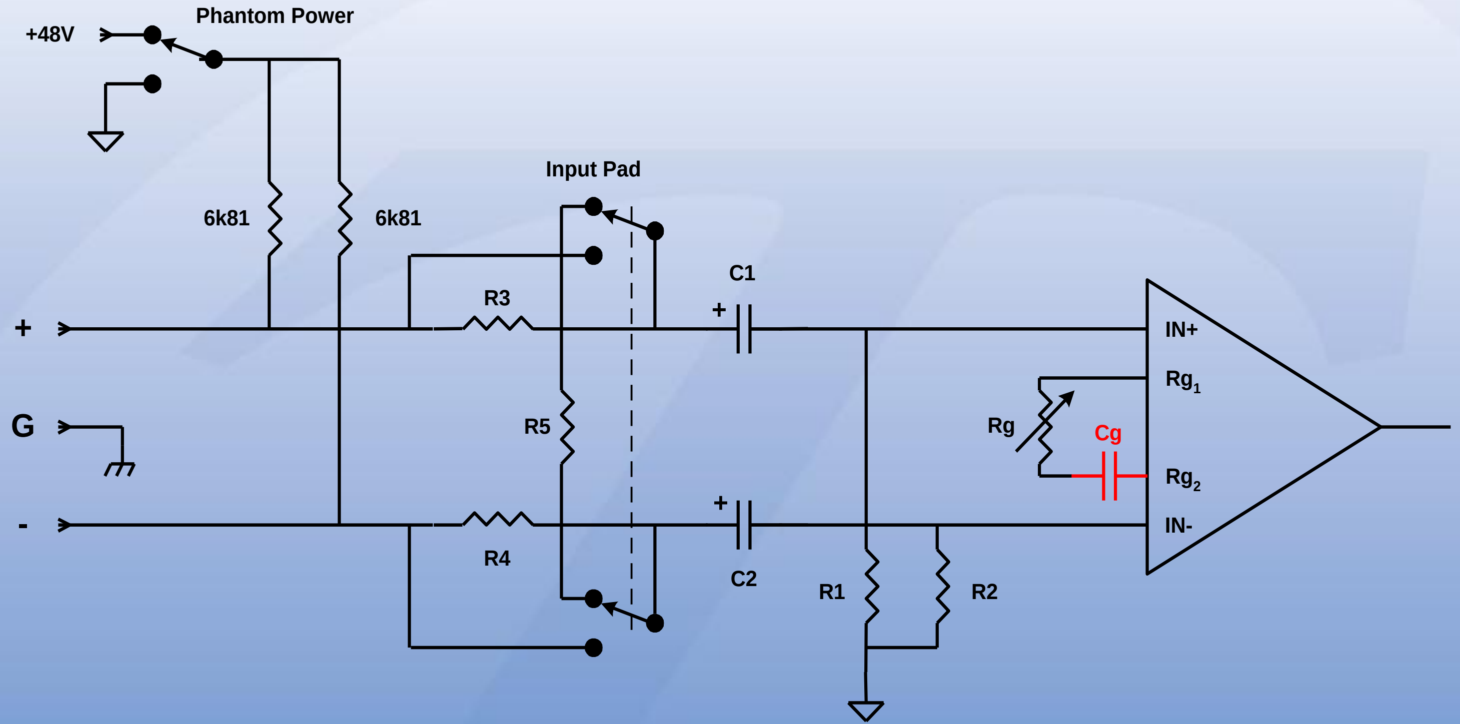
DC Offset Changes



- **Changes in gain can result in the DC offset changes at the output of the amplifier**

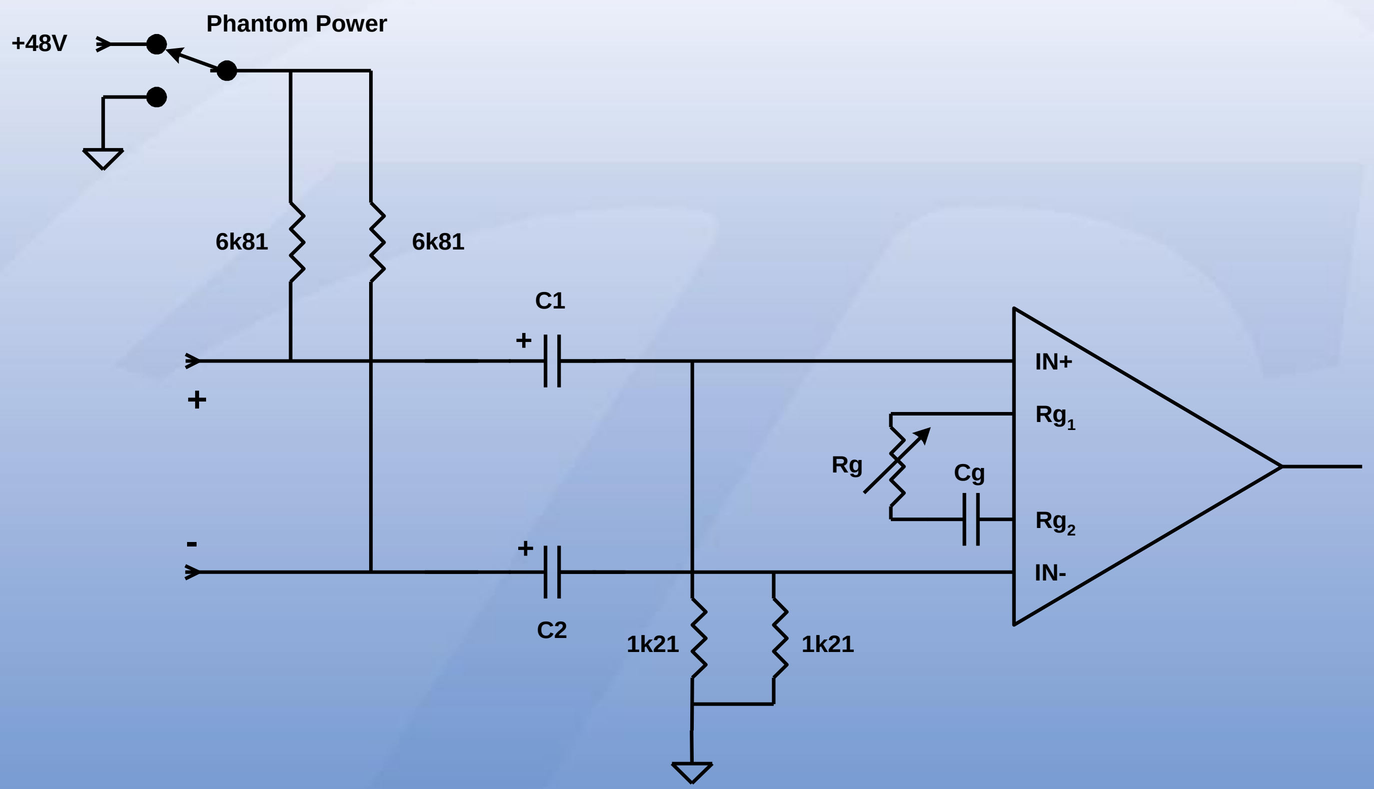
- **2 solutions are available**
  - **Adding a capacitor (Cg) sets the DC gain to a fixed value and avoids these offset changes**
  - **A servo-amplifier can also be effective, but we don't have time to discuss them today**

Trade-offs with Cg



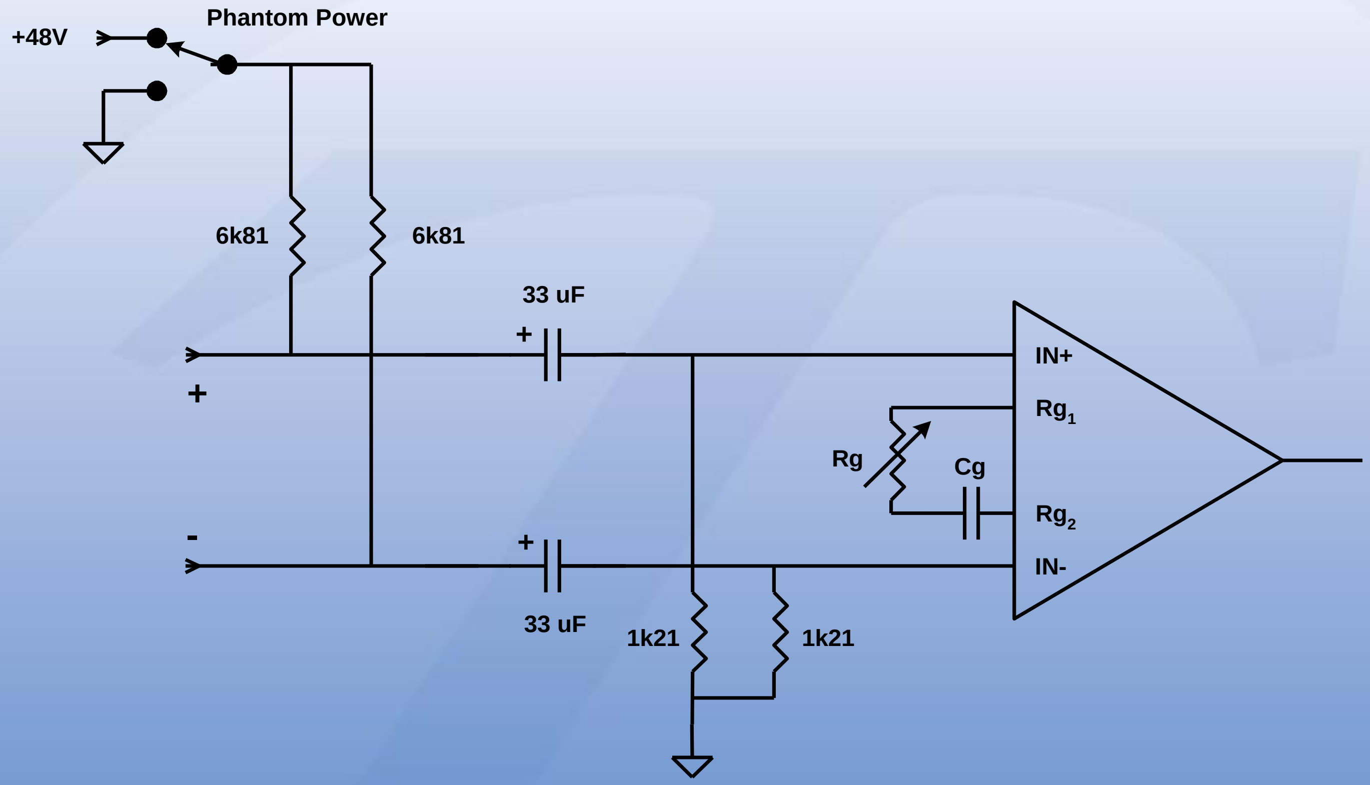
- Rg and Cg create a high-pass filter in the signal path
- Rg can vary from <5 to >10k ohms
- Cg must have a very large capacitance to avoid low frequency audio attenuation
  - Worst at highest gain

Resistor Value Selection



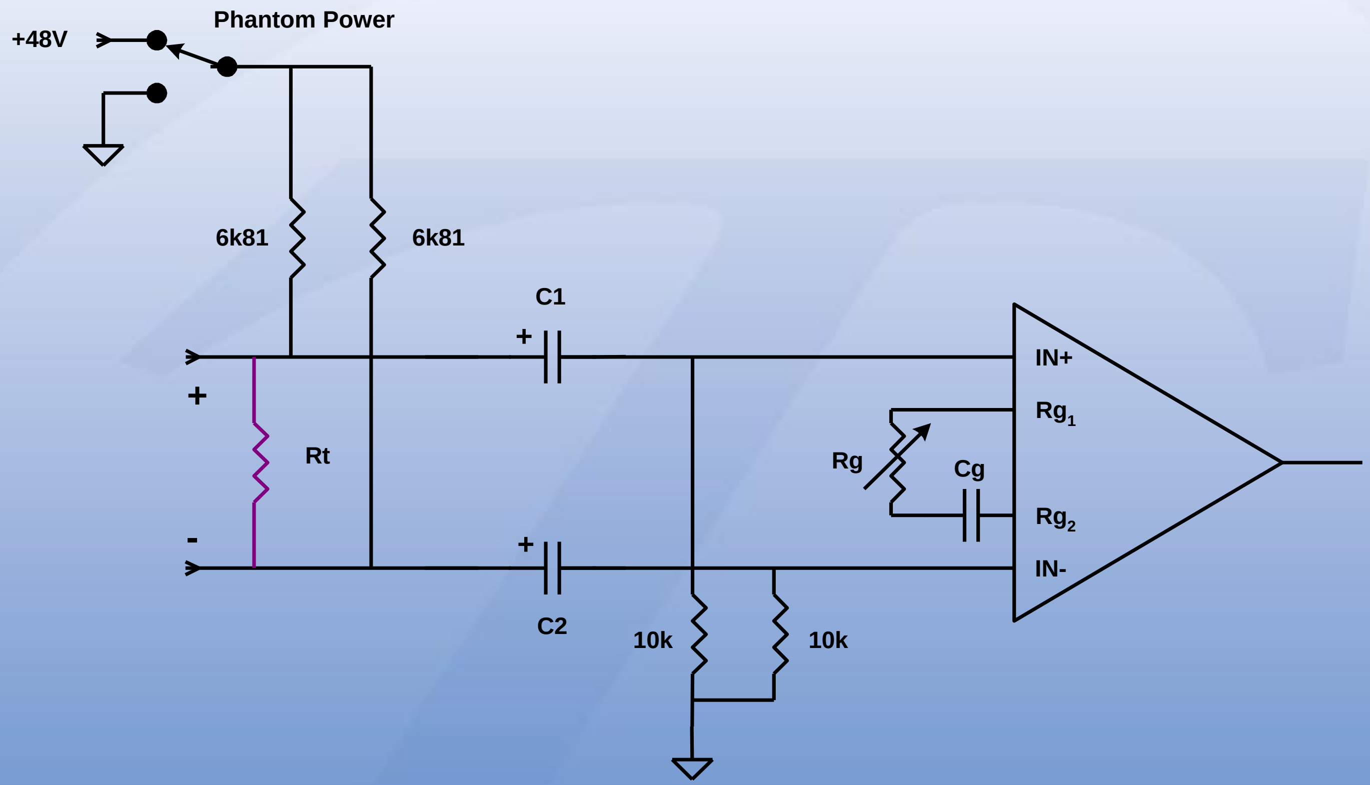
- Microphones are commonly specified for 2 to 3 kohm loads
- Differential input impedance is (R1 ll 6.81k) + (R2 ll 6.81k)
- Therefore, suitable values for R1 & R2 are between 1172 and 1924 ohms

Capacitor Value Selection



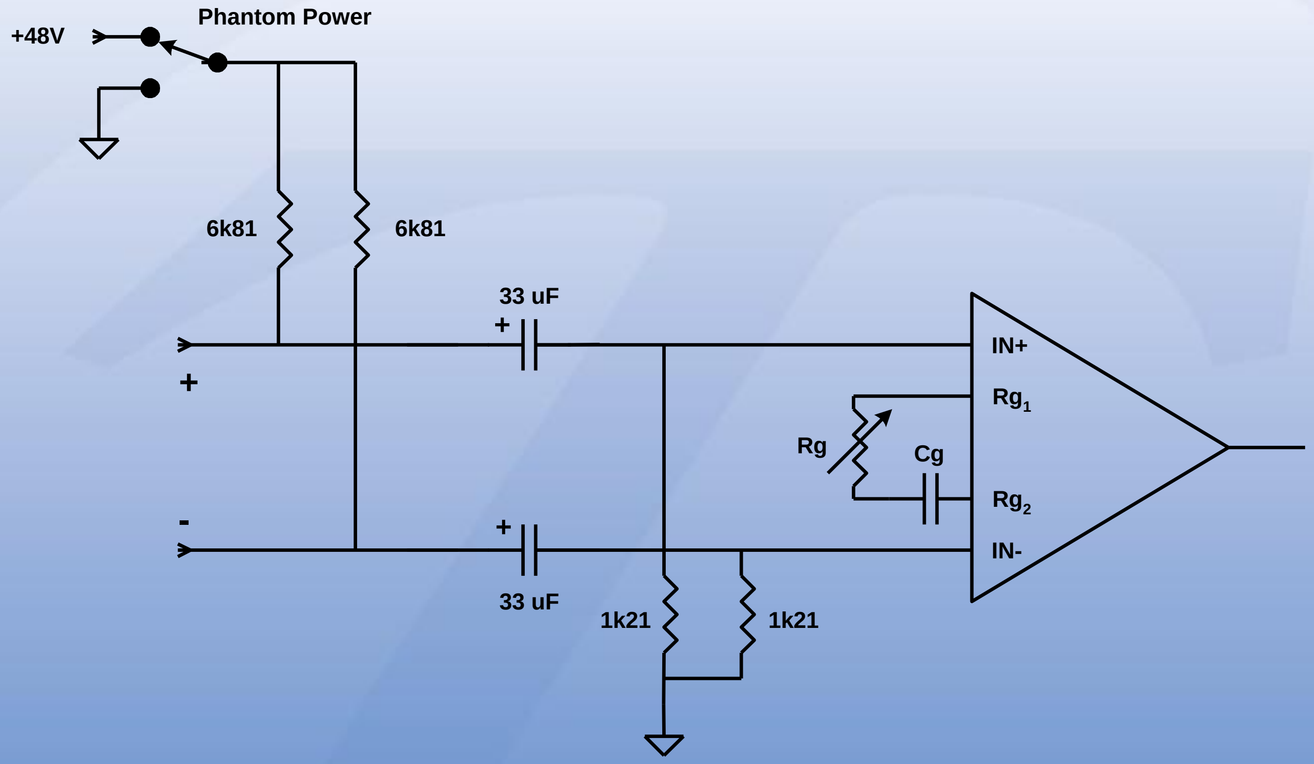
- High-pass filter corner frequency is set by the blocking capacitor and bias resistor and is equal to 1 / (2 x pi x R x C)
- For a 5 Hz corner frequency, the minimum values for C1 & C2 are 26 uF
- The next largest standard value is 33 uF
- Results in a nominal corner frequency of about 4 Hz

Alternative Resistor-Capacitor Value Selection



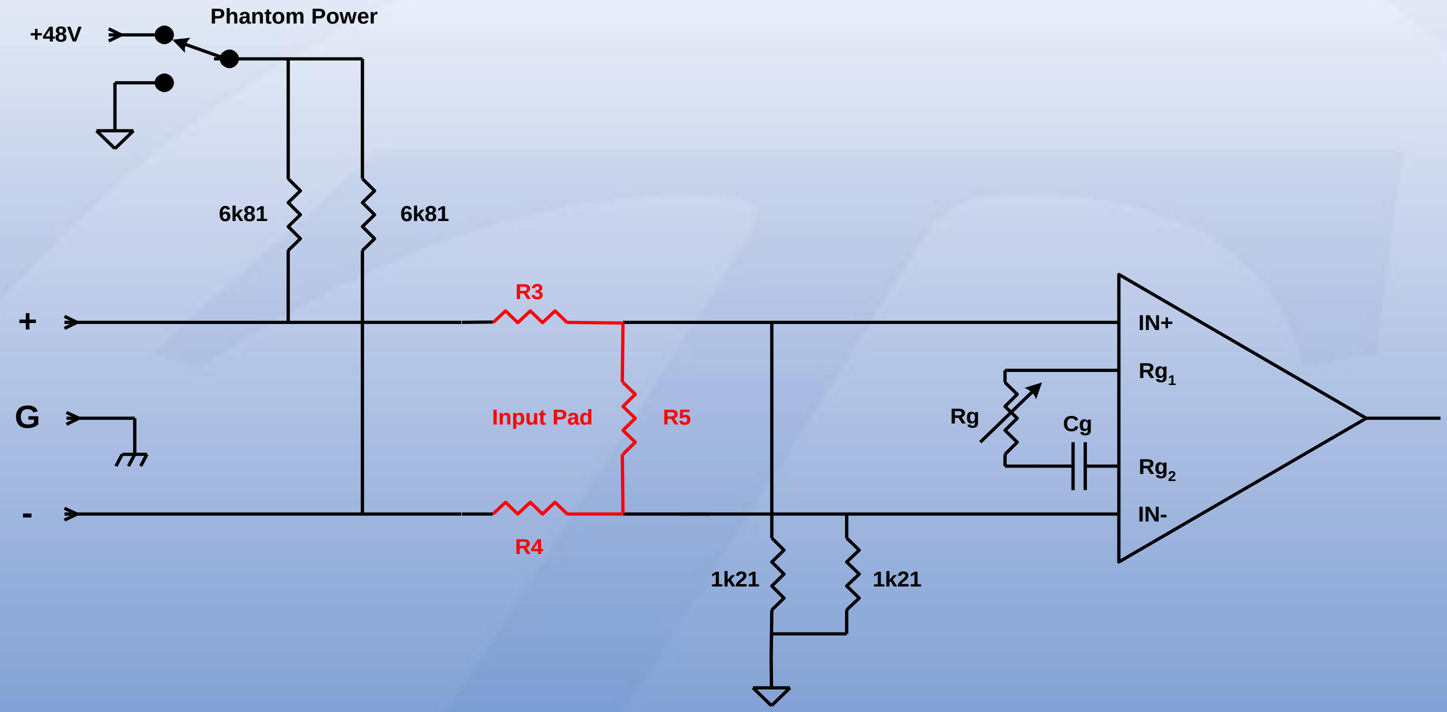
- C1 and C2 can be made smaller if bias resistors are made larger
- Rin is defined by Rt
- However, C1 and C2 convert 1/f noise to 1/f^2 noise
- 10k resistors contribute thermal noise and current noise*R

Common Mode Rejection (CMRR)



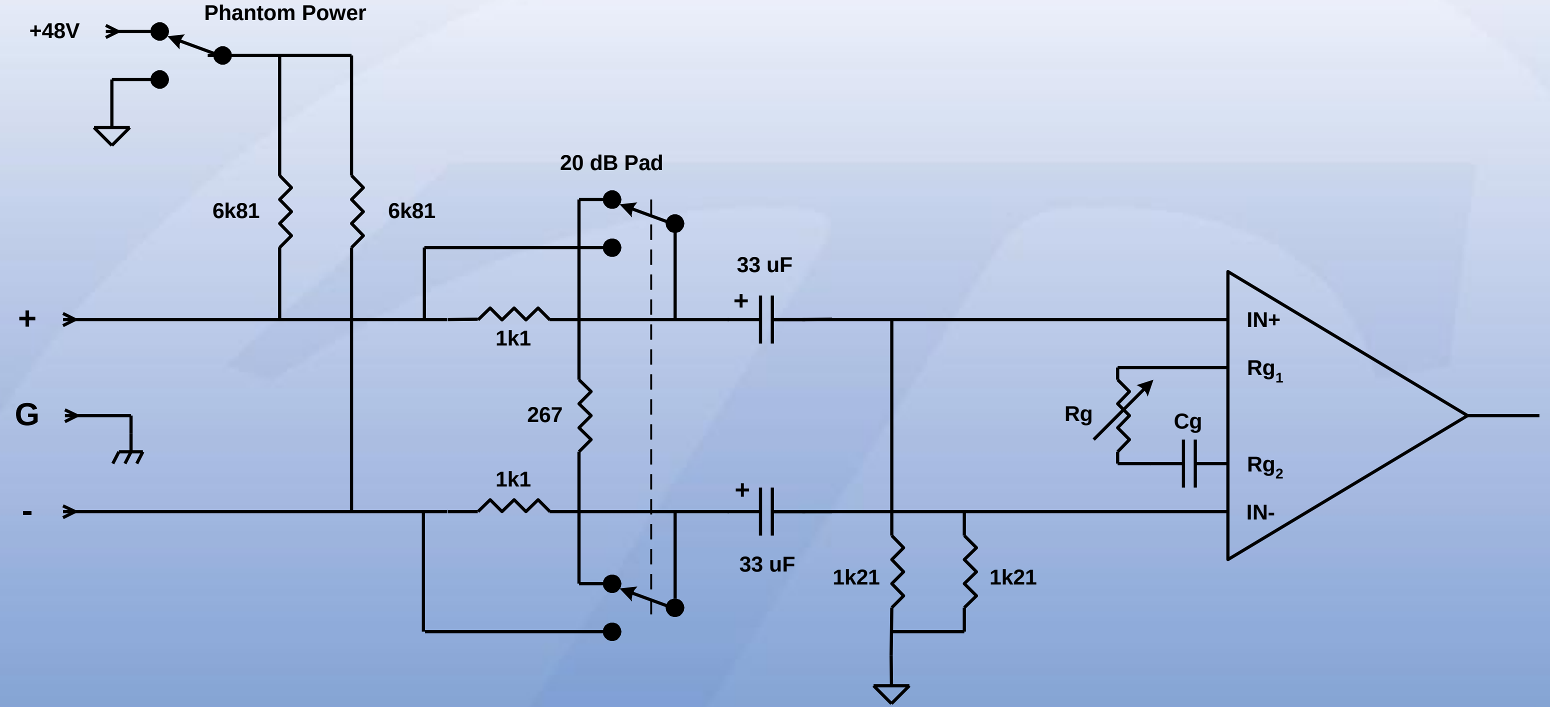
- **Common-mode to differential conversion results from mismatches in:**
  - **6.81 k resistors**
  - **1.21 k resistors**
- **Low frequency CMRR affected by capacitor mismatch**

U-Pad Attenuator



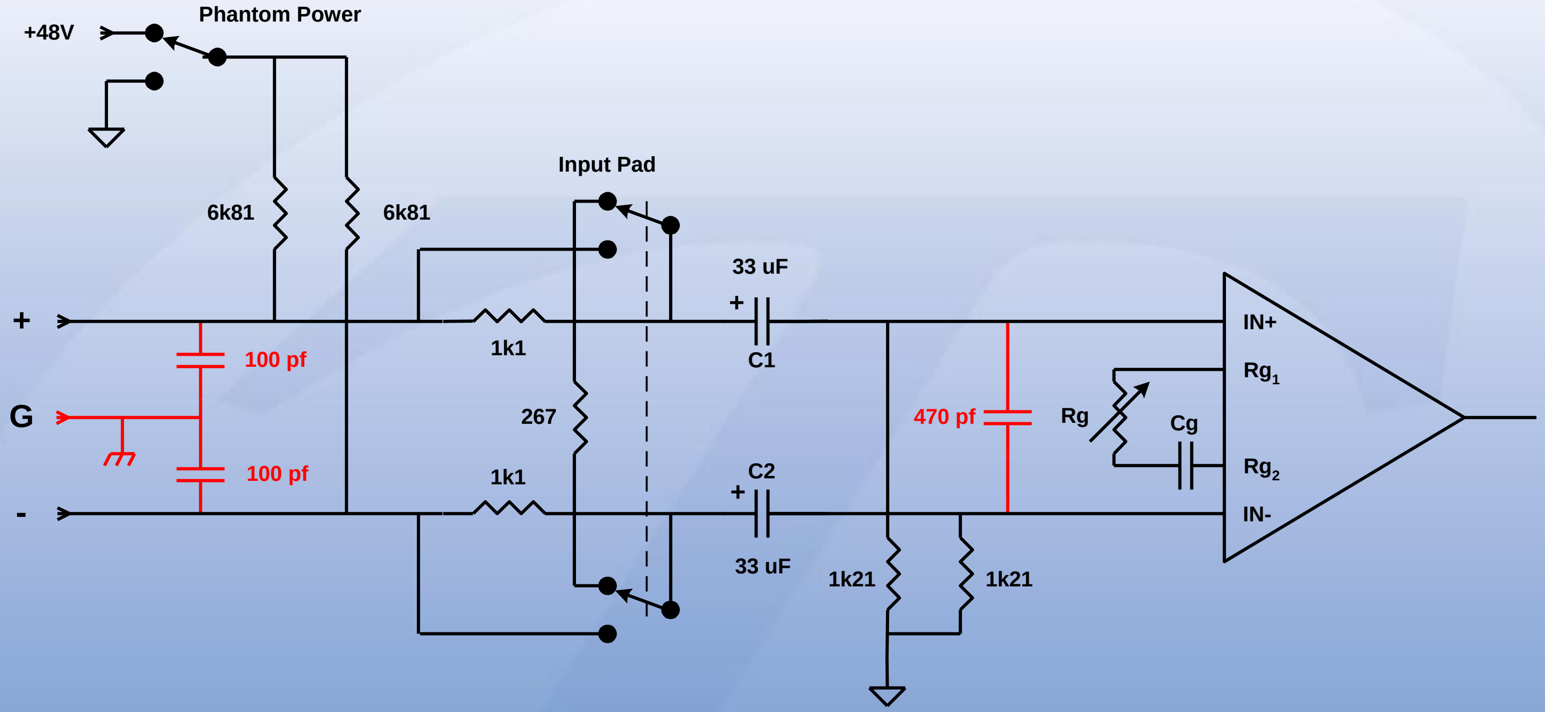
- Z_{IN} with and without pad can be closely matched
- Can be designed for any attenuation
  - 20dB is typical
- Noise performance is degraded
- Better noise, less headroom with less attenuation

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

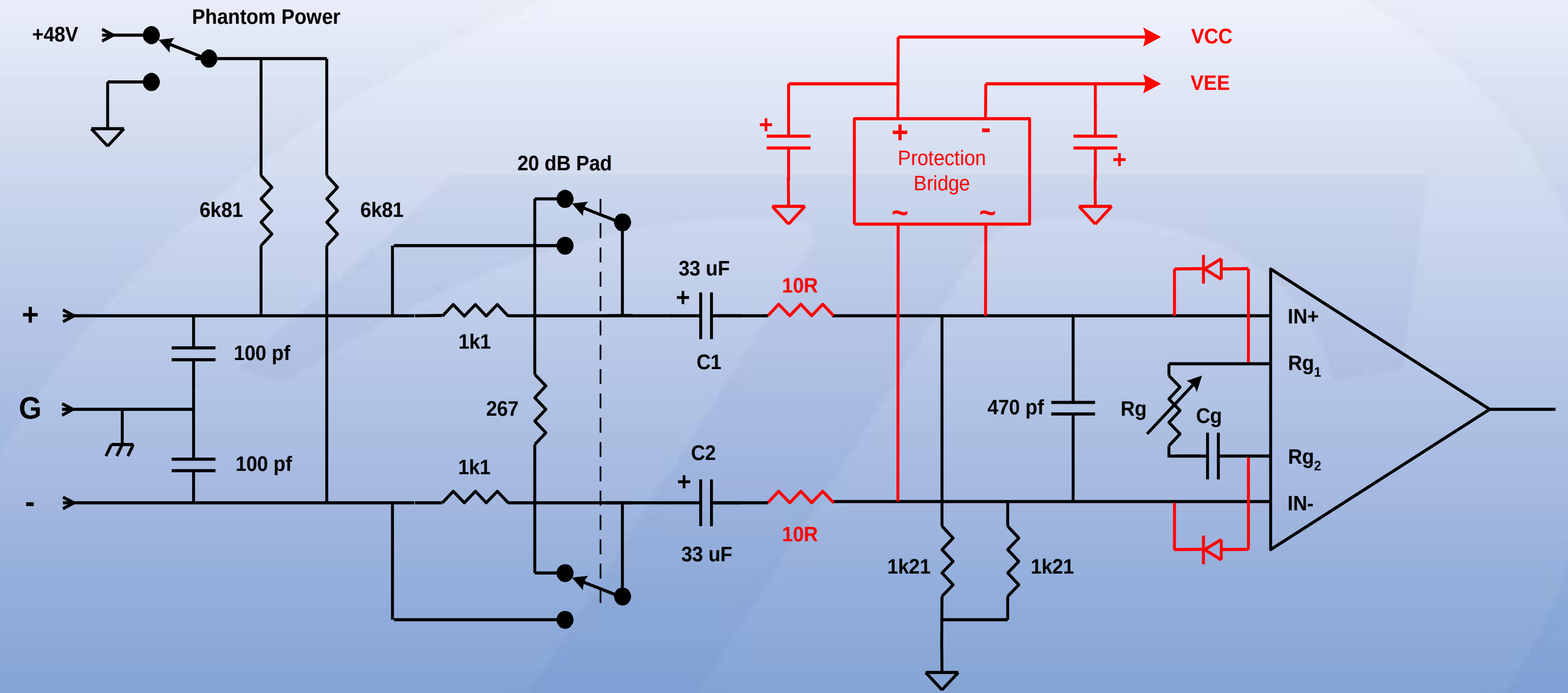
Phantom Power Faults

- **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**

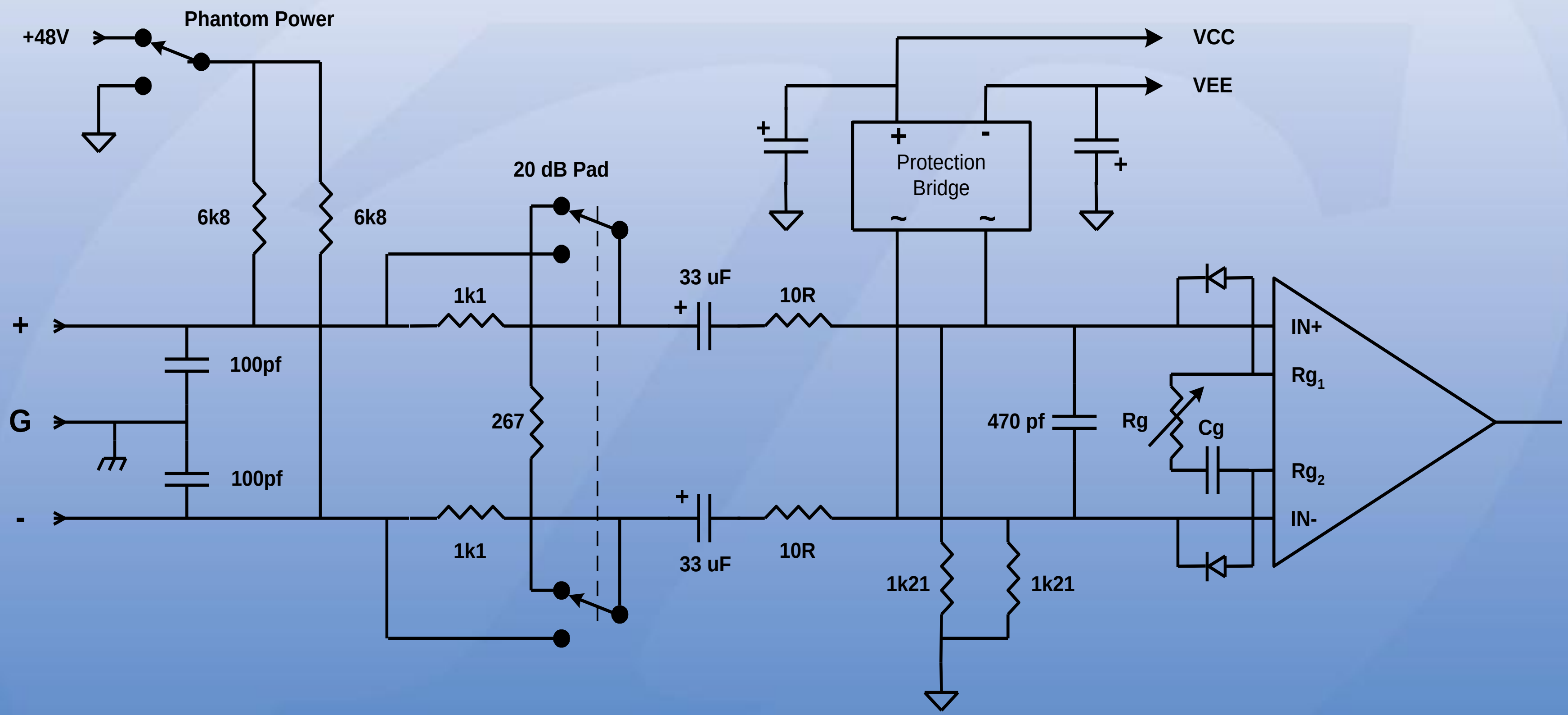
- **Big currents flow as C1, C2 discharge**
  - **Currents over 3 *amperes* flow in the capacitors**

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 127th AES Convention, Oct 2009**
- ***"The 48 Volt Phantom Menace"*** **Audio Engineering Society Preprint from the 110th AES Convention, May 2001**

All THAT Corp references are available at thatcorp.com

Amplifier Topologies

What's inside the triangle?

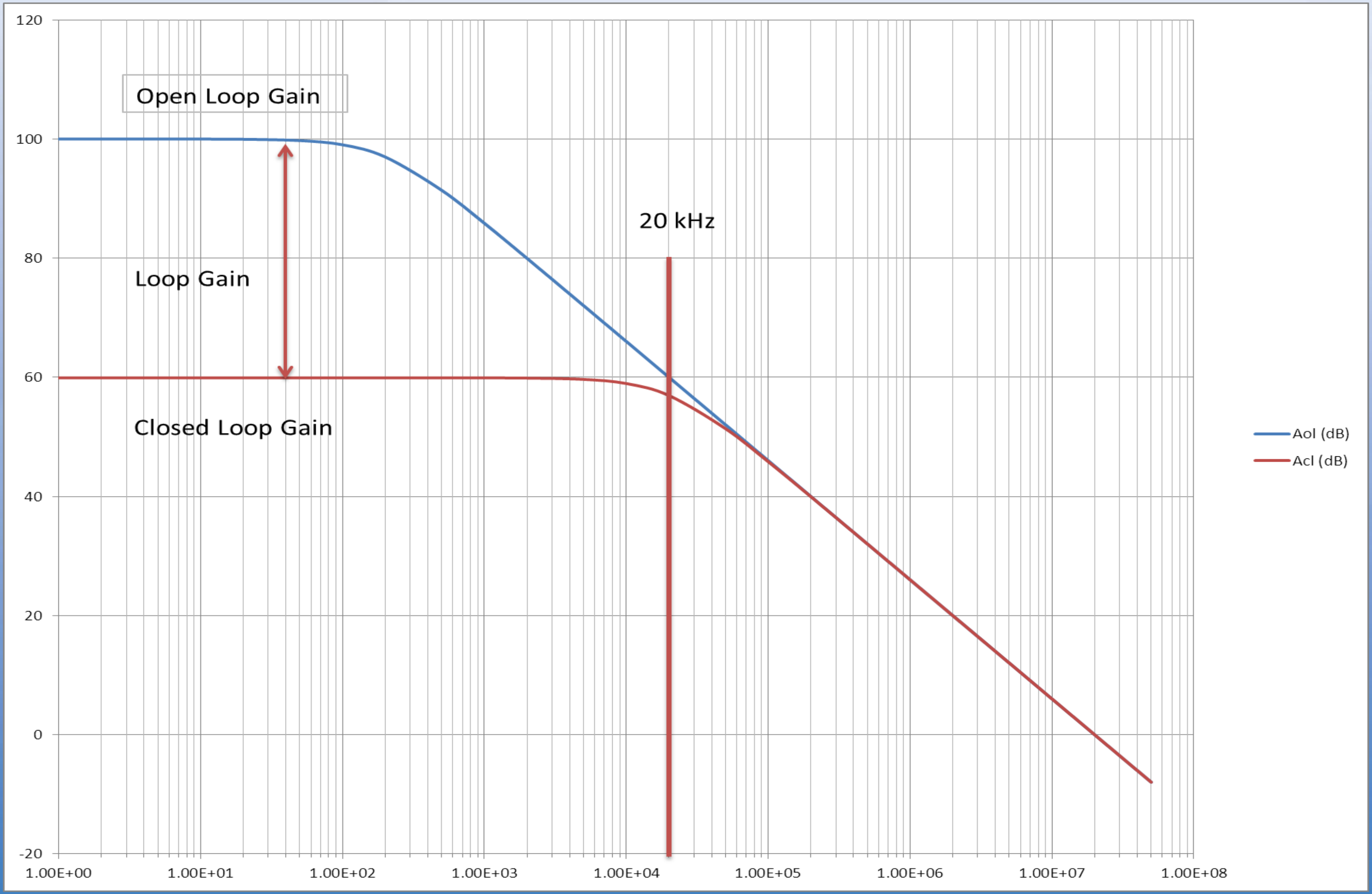
Scope

- 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.

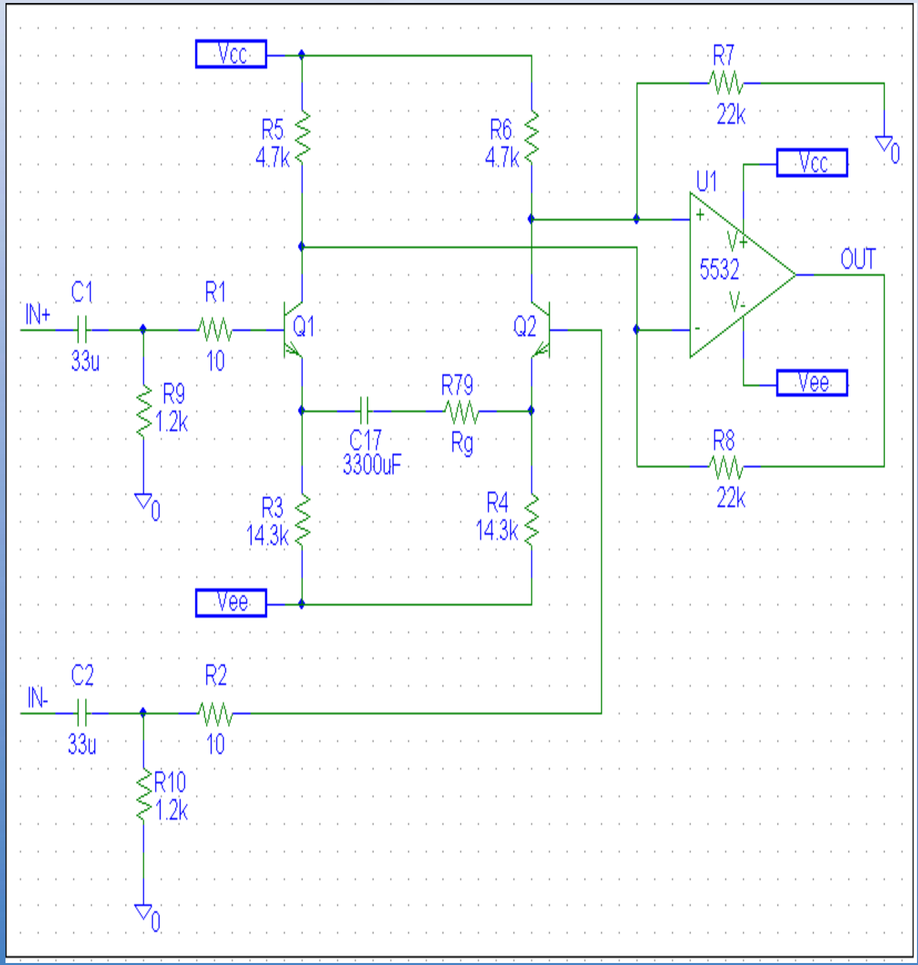
What About Op-amps?

- Voltage feedback op-amps have fixed Gain Bandwidth (GBW) product
- A 20 MHz GBW op-amp may have no loop gain at 20 kHz when set for 60 dB closed loop gain
- Direct correlation between distortion and loop gain
- Most are too noisy (and we need 2 for a differential input)
- We can add a pair of transistors to help

Op-Amp Gain Bandwidth

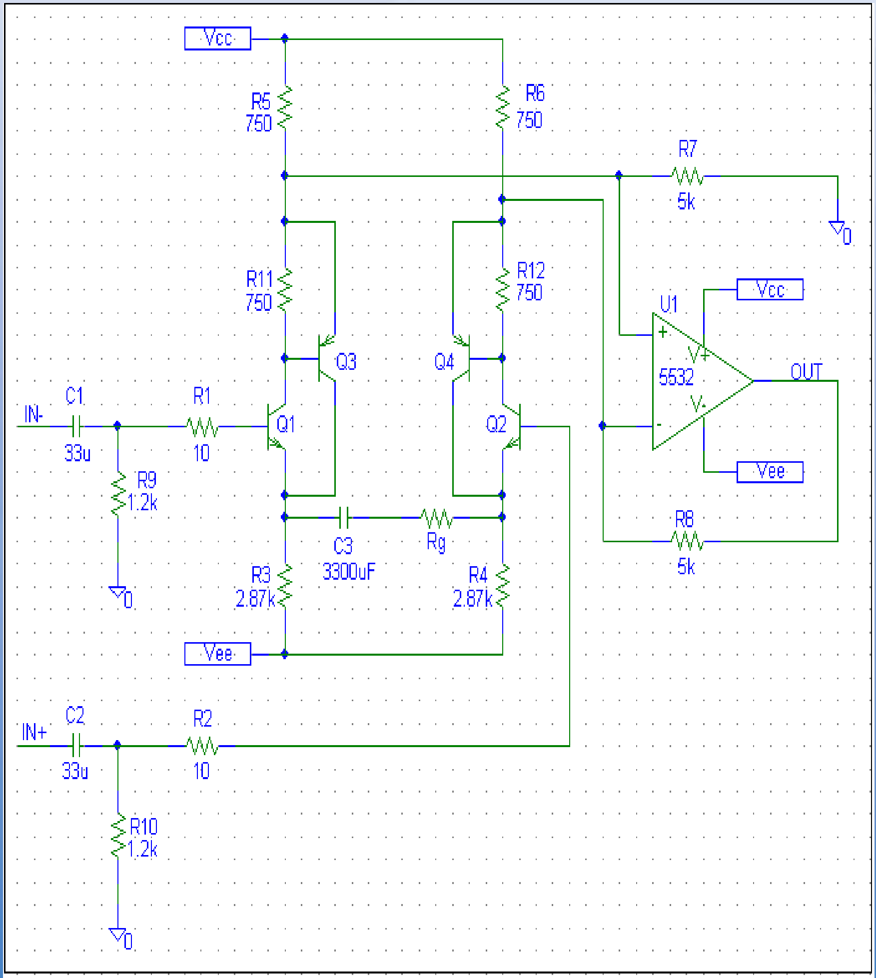


Simple Mic Preamp



- Q1 and Q2 are simple current-feedback amplifiers
- Diff Gain = $22k/(r_e + R_g/2||14.3k)$
- where $r_e = 1/g_m = KT/qI_C = 26$ ohms
- "r_e" varies with signal, resulting in THD
- Minimum gain = 22k/14.3k = 3.7 dB

Complementary Feedback Pair

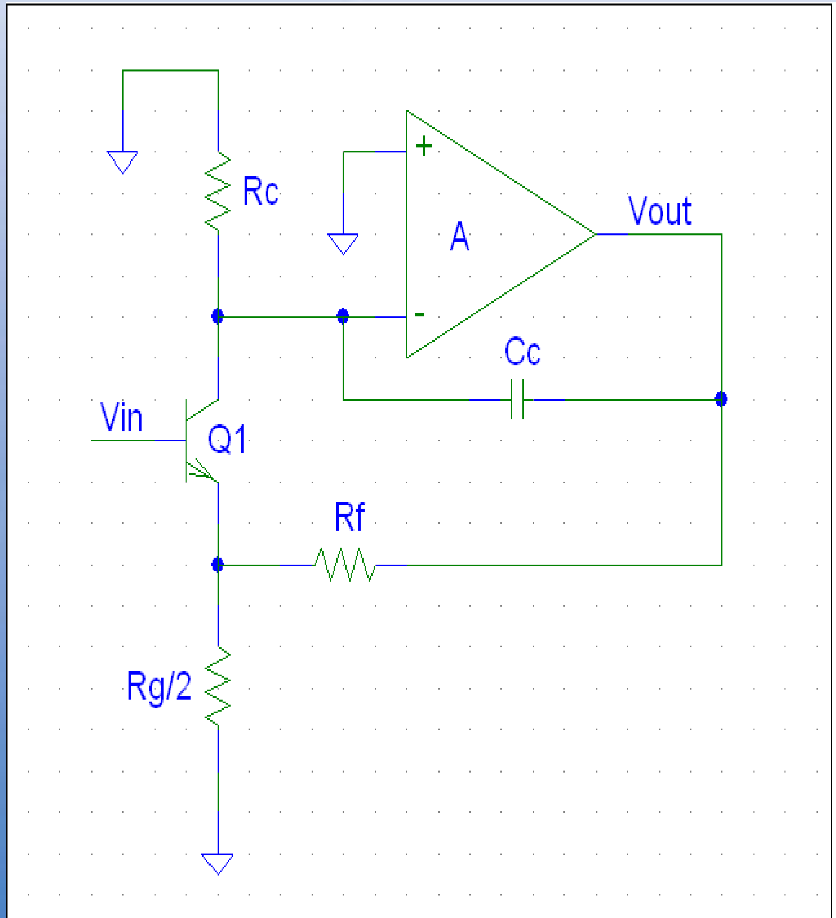


- Input devices are each a compound transistor (Complementary Feedback Pair)
- Output impedance at NPN emitters is reduced
- Still signal-dependent, but much less
- Gain = 5k/(r_e/74 + Rg/2||2.87k)
- Minimum Gain = 5k/2.87k = 4.8 dB

Current Feedback Instrumentation Amp

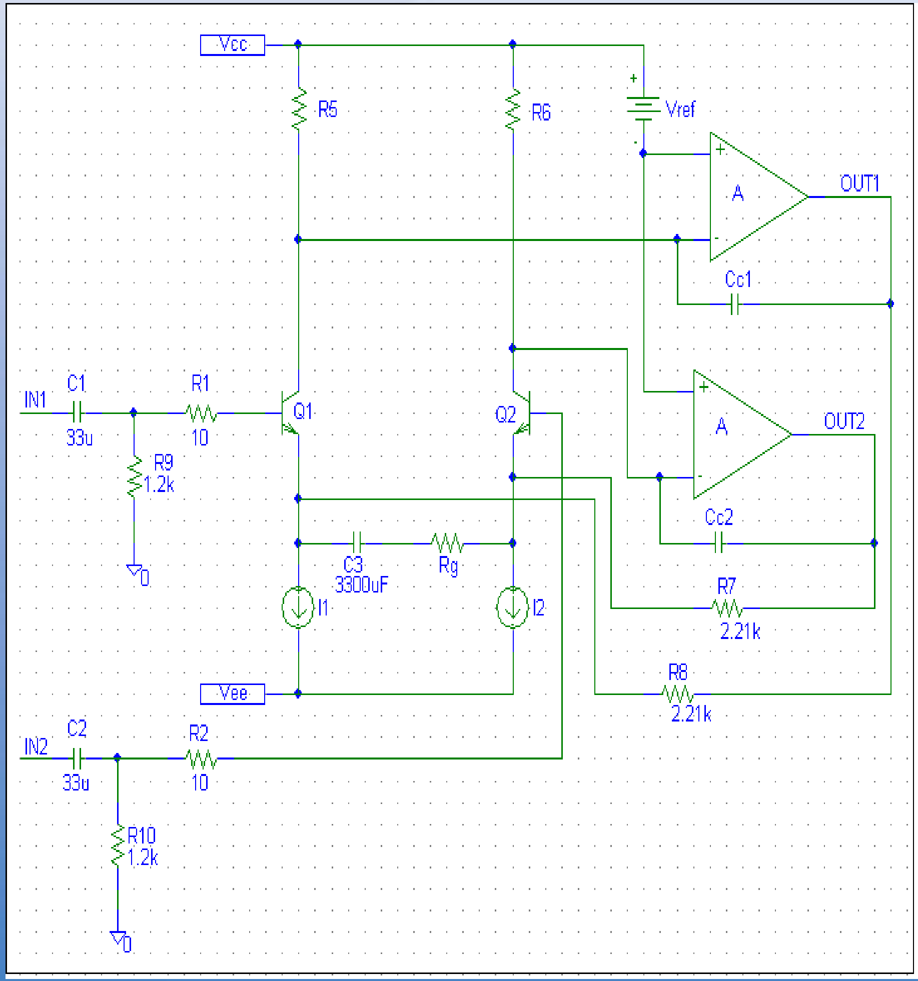
- Topology used in most integrated microphone preamplifiers
- Scott Wurcer – AD524 IEEE Paper 12/82
- Graeme Cohen AES Paper – “Double Balanced Microphone Amplifier” 9/84

What's "Current Feedback"?



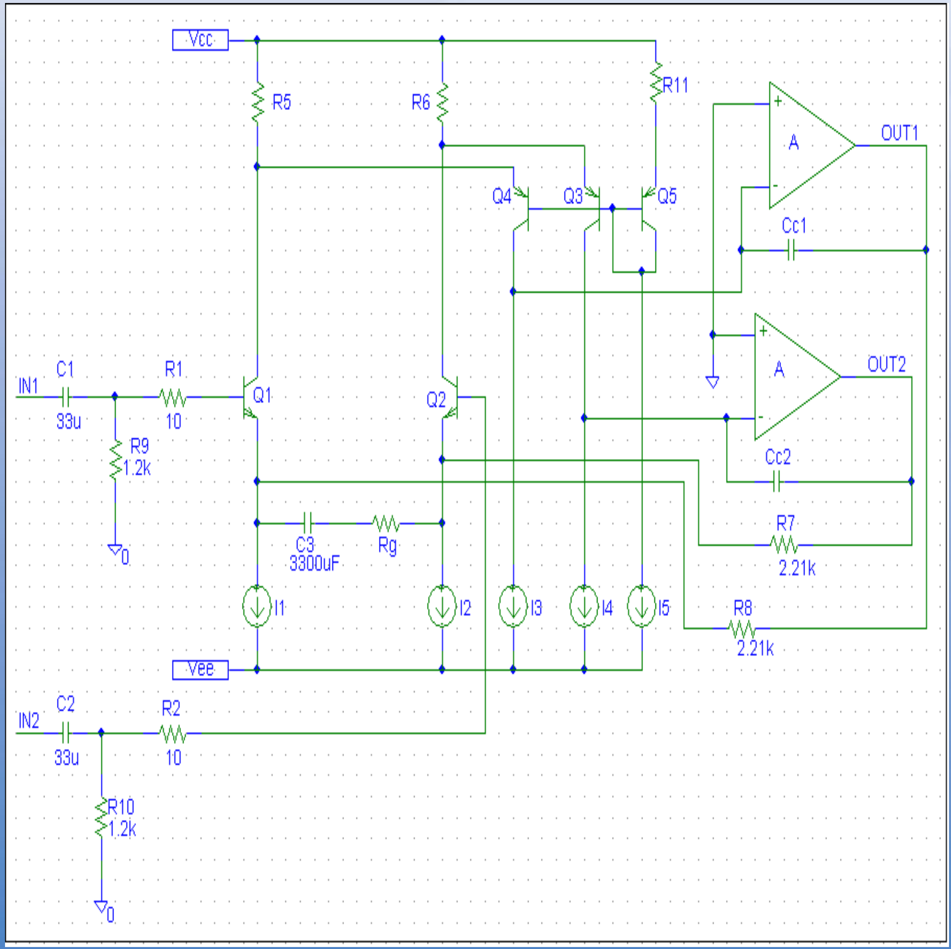
- Closed loop bandwidth stays substantially constant with closed loop gain until r_e becomes a significant factor
- Open loop gain and closed loop gain vary together
- Rf controls BW

Basic CFIA Mic Preamp



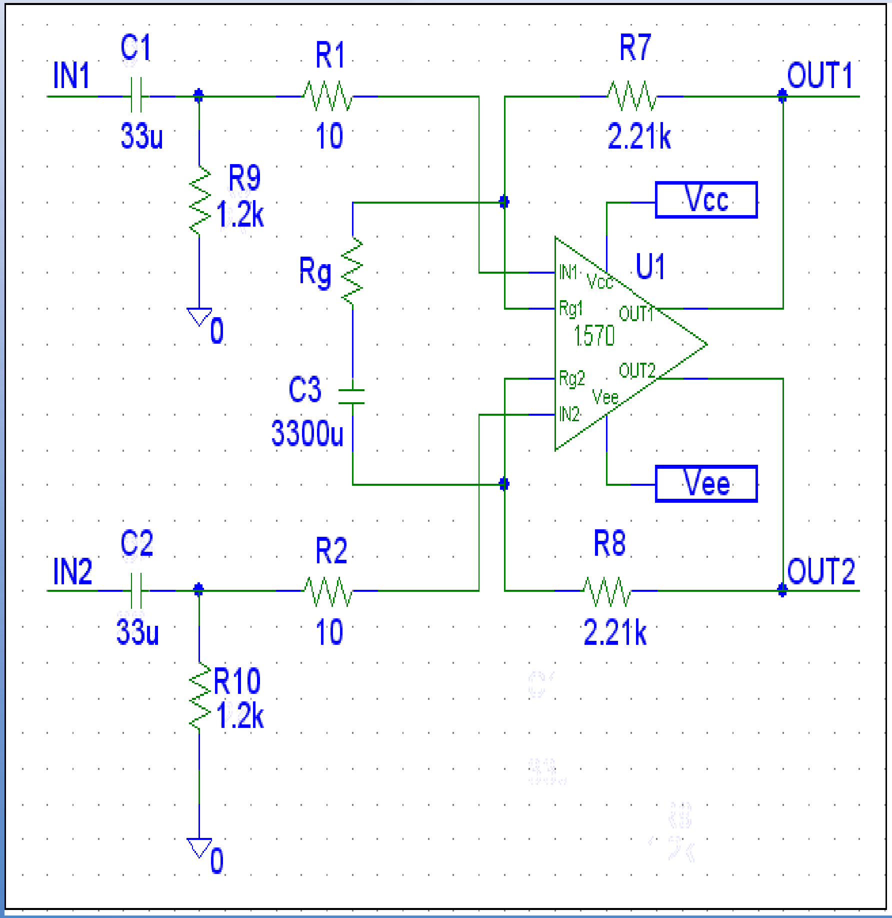
- Large loop gain (A) keeps Q1 & Q2 current constant
- Current sources I_1 and I_2 allow for unity gain
- Gain = $1 + (2R_7/R_g)$
- Min. gain = 0 dB

Refinements to the CFIA



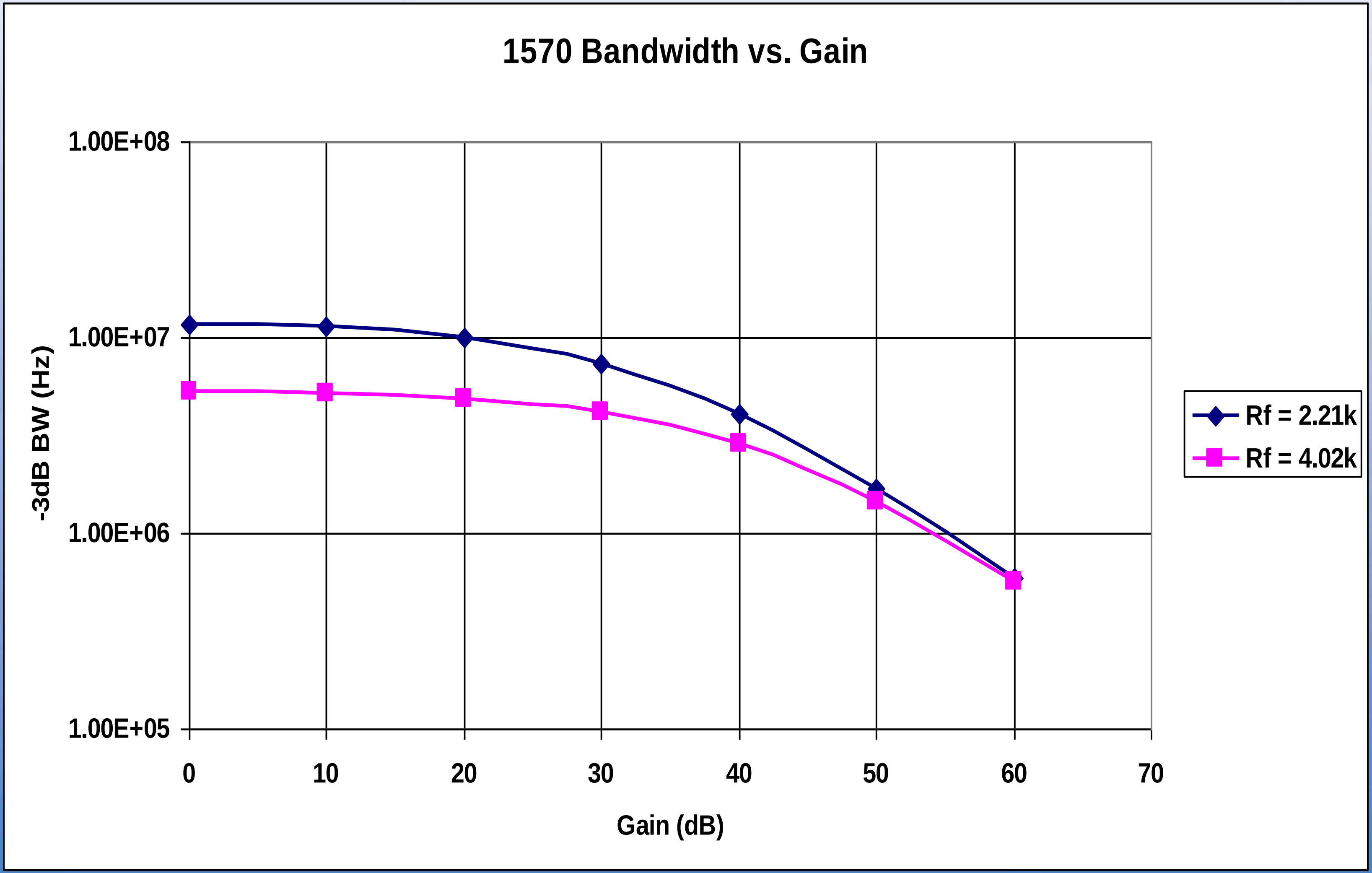
- Eliminating major sources of THD exposes more subtle distortion mechanisms
- Additional circuitry, such as cascoded current sources and folded cascode loads, can minimize these effects
- At this level of complexity an IC makes sense
- Good device matching inherent in integrated circuits improves performance

A Real Example CFIA



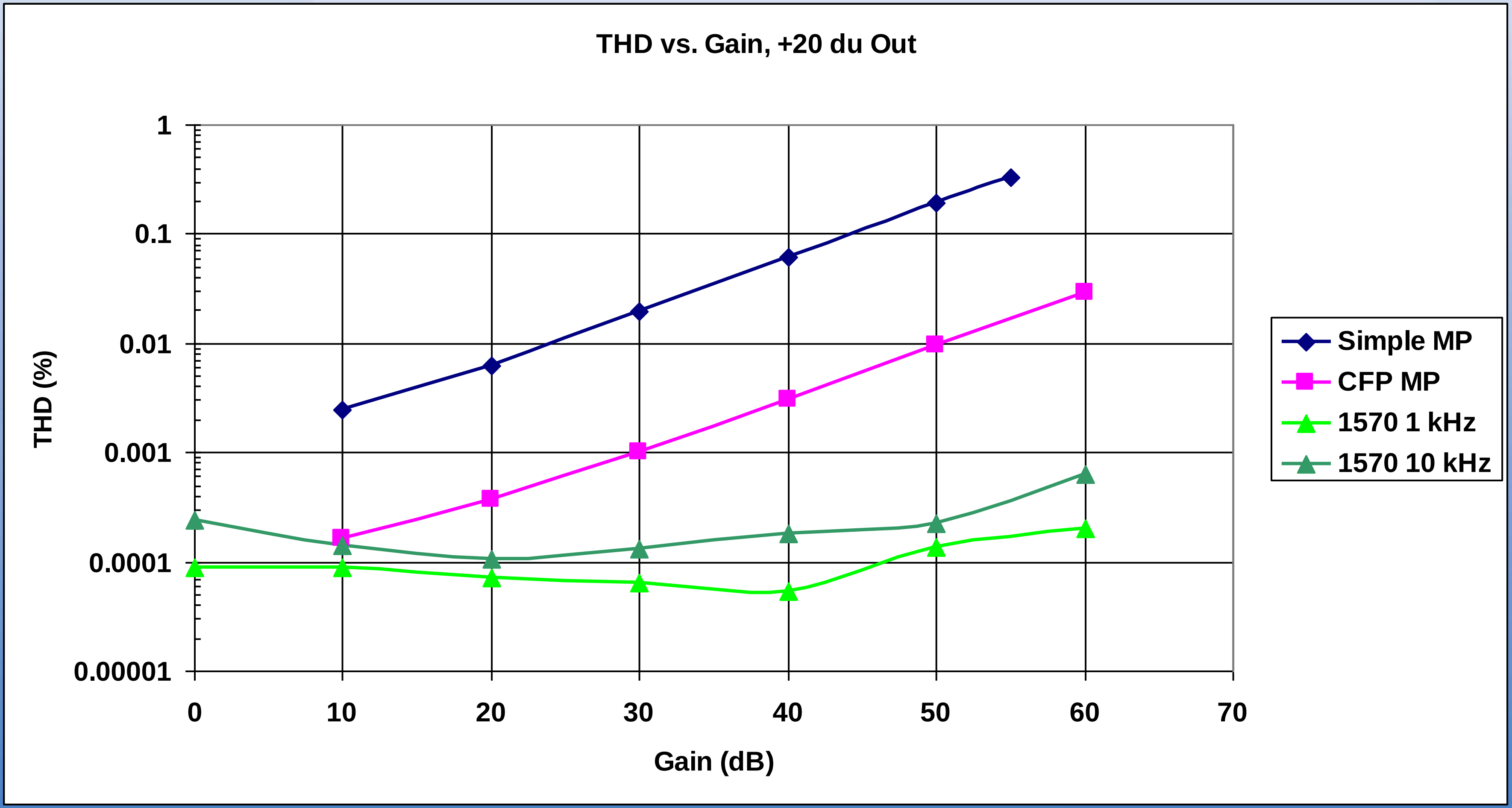
- An integrated circuit current-feedback instrumentation amplifier front end
- Utilizes the techniques described on the previous slide
- Compensated for R_F values down to 2 kohm

Example CFIA Bandwidth vs. Gain

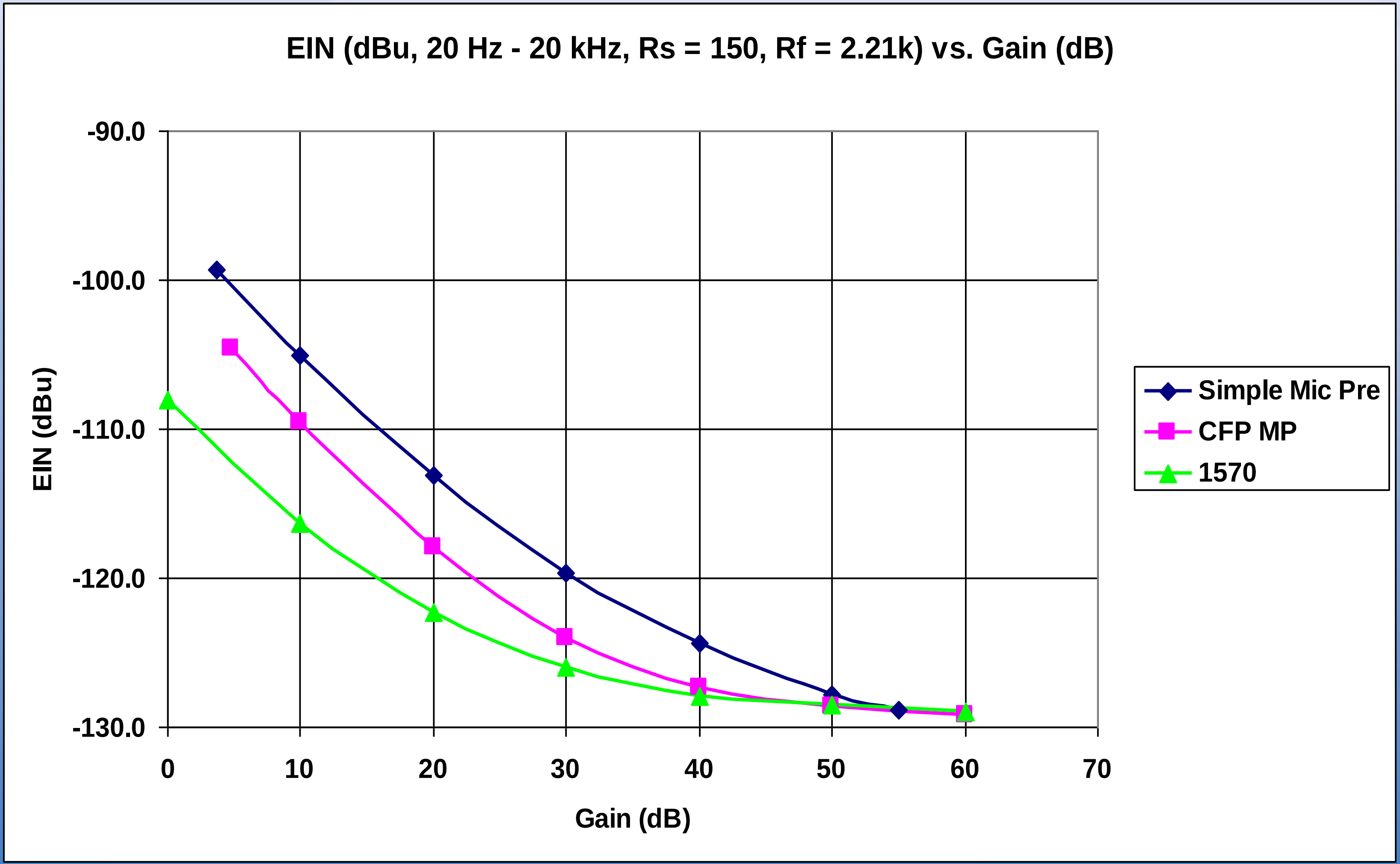


THD Performance Comparison

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



Noise Performance Comparison



Conclusions

- Microphone preamplifiers with a wide gain range controlled by a single resistance involve trade-offs 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

Acknowledgements

Many thanks to Gary Hebert for his assistance (and patience) in preparation for this tutorial.

Questions ?

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