Designing Microphone Preamplifiers

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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
Overview

Section 1
Support Circuitry

Section 2
The Amplifier
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
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 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

![Microphone Preamp Diagram]
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
Microphones are commonly specified for 2 to 3 kohm loads
- Differential input impedance is \((R_1 \parallel 6.81k) + (R_2 \parallel 6.81k)\)
- Therefore, suitable values for \(R_1\) & \(R_2\) 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 $1 / (2 \times \pi \times R \times C)$
- 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
• $Z_{IN}$ 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 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

- Phantom Power
- 20 dB Pad
- Protection Bridge
- IN+ and IN- terminals
- +48V supply
- 6k8 resistors
- 33 uF capacitors
- 1k1, 10R, 267, 21k, 100pf components
- VCC and VEE power supplies
- IN+, IN-, and G (ground) connections
- 470 pf capacitor
- Rg, Rg1, and Rg2 resistors
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”

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

- Open Loop Gain
- Loop Gain
- Closed Loop Gain

20 kHz
Simple Mic Preamp

- Q1 and Q2 are simple current-feedback amplifiers
- Diff Gain = \( \frac{22k}{r_e + \frac{R_g}{2||14.3k}} \)
- where \( r_e = \frac{1}{g_m} = \frac{KT}{qI_C} \) = 26 ohms
- “\( r_e \)” varies with signal, resulting in THD
- Minimum gain = \( \frac{22k}{14.3k} = 3.7 \) 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 = \( \frac{5k}{r_e/74 + \frac{R_g}{2}||2.87k} \)
- Minimum Gain = \( \frac{5k}{2.87k} = 4.8 \text{ dB} \)
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.
- $R_f$ 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 $= 1 + \left(\frac{2R_7}{R_g}\right)$
- Min. gain $= 0 \text{ dB}$
Refinements to the CFIA

- Eliminating major sources of THD exposes more subtle distortion mechanisms

- Additional circuitry, such as cascaded 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

1.00E+08
1.00E+07
1.00E+06
1.00E+05

-3dB BW (Hz)

0 10 20 30 40 50 60 70
Gain (dB)

Rf = 2.21k
Rf = 4.02k
THD Performance Comparison

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

- Simple MP
- CFP MP

THD vs. Gain, +20 du Out

- 1570 1 kHz
- 1570 10 kHz
Noise Performance Comparison

EIN (dBu, 20 Hz - 20 kHz, Rs = 150, Rf = 2.21k) vs. Gain (dB)

-130.0 -120.0 -110.0 -100.0

0 10 20 30 40 50 60 70

Gain (dB)

EIN (dBu)

Simple Mic Pre
CFP MP
1570
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.
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Questions?