Discrete OpAmps

Designing and building discrete operational amplifiers is a fascinating business for me. Although IC technology is pretty mature today there are still situations where discrete design beats ICs—typical advantages of discrete amplifiers are potentially high supply voltages, high maximum dissipation (e.g. class A output stages), much extended options with respect to choice of passive components and the possibility to tweak even the last bit of the amplifier for the task at hand. Here you'll find several schematics and links about this topic.

918 Discrete OpAmp

918_documentation.pdf

With the great help of Steven Hogan (www.soundsteward.com) and Larry Hathaway (www.jensen-transformers.com) I'm able to provide this unique documentation. The 918 was designed by Deane Jensen and is the predecessor of the famous 990.

SGA-SOA-1 Simple Discrete Operation Amplifier

SGA-SOA-1_documentation.pdf

A simple yet well performing and widely proofen circuit designed by me. Provided with a 2520 style footprint and comprehensive documentation. Some pictures to check out. The typical specifications for R_L = 600 Ω and V_{supply} = ±18 V:

- Input offset voltage: < 20 mV
- Input bias current: −1.1 µA
- Input voltage noise: 1.5 nV/√Hz at 1 kHz
- Current noise density: 0.6 pA/√Hz at 1 kHz
- Open loop voltage gain: 80 dB
- Gain-bandwidth product: 30 MHz at 10 kHz
- Unity-gain bandwidth: 15 MHz
- Slew rate: ±10 V/µs
- Output swing: ±17 V
- Class A output drive: 600 Ω for full voltage swing
- Maximum output current: ±300 mA
- Supply current: 21 mA (no load)

Gerber files for this design can be downloaded in the Gerber files section.

SGA-SOA-2 Simple Discrete Operation Amplifier

SGA-SOA-2_r1.pdf

The successor of the SGA-SOA-1 which is now fully tested. Improvements have been made mainly regarding slew-rate, gain-bandwidth product and CMRR; all this at the same parts count and quiescent current. The typical specifications for R_L = 600 Ω and V_{supply} = ±18 V:

- Input offset voltage: < 20 mV
- Input bias current: −1.1 µA
- Input voltage noise: 1.5 nV/√Hz at 1 kHz
- Current noise density: 0.6 pA/√Hz at 1 kHz
- Open loop voltage gain: 80 dB
- Gain-bandwidth product: 40 MHz at 10 kHz
- Unity-gain bandwidth: 15 MHz
- Slew rate: ±14 V/µs
- Output swing: ±17 V
- Class A output drive: 600 Ω for full voltage swing
- Maximum output current: ±230 mA
- Supply current: 21 mA (no load)

R6 should be altered for lower supply voltages to maintain the 1.6 mA bias current through D3/D4. Suggested values are 18 kΩ (±15 V), 15 kΩ (±12 V) and 12 kΩ (±10 V).

SGA-HVA-1 High Voltage Discrete Operational Amplifier

SGA-HVA-1_r1.pdf

A discrete opamp for high supply voltages, fully tested. This is a real general-purpose opamp which will perform very well in various implementations. The typical specifications for R_L = 600 Ω and V_{supply} = ±40 V:

- Input offset voltage: < 5 mV
- Input bias current: −1.1 μA
- Input voltage noise: 1.5 nV/√Hz at 1 kHz
- Current noise density: 0.6 pA/√Hz at 1 kHz
- Open loop voltage gain: 130 dB
- Gain-bandwidth product: 65 MHz at 10 kHz
- Unity-gain bandwidth: 10 MHz
- Slew rate: ±21.7 V/μs
- Output swing: +37.3/−37.5 V
- Class A output drive: 1.9 kΩ for full voltage swing
- Maximum output current: +85/−95 mA
- Supply current: 18 mA (no load)

R6 should be altered for lower supply voltages to maintain the 1.6 mA bias current through D3/D4. Suggested values are 33 kΩ (±30 V), 27 kΩ (±24 V), 20 kΩ (±18 V), 16 kΩ (±15 V), 12 kΩ (±12 V) and 10 kΩ (±10 V).

SGA-LNA-1 Low Noise Discrete Operation Amplifier

SGA-LNA-1_r1.pdf

An opamp with very low voltage noise; typical applications include moving coil preamplifiers and noise measurement amplifiers. Stable at noise gains of about three and above. Fully tested. The typical specifications for R_L = 600 Ω and V_{supply} = ±24 V:

- Input offset voltage: < 10 mV
- Input bias current: ±100 nA
- Input voltage noise: 0.5 nV/√Hz at 1 kHz
- Current noise density: 1.7 pA/√Hz at 1 kHz
- Open loop voltage gain: 80 dB
- Gain-bandwidth product: 145 MHz at 100 kHz
- Slew rate: ±48 V/μs
- Output swing: ±22 V
- Class A output drive: 1.4 kΩ for full voltage swing
- Maximum output current: ±50 mA
- Supply current: 25 mA (no load)

SGA-JFA-1 JFET Discrete Operational Amplifier

SGA-JFA-1_r1.pdf

A discrete opamp with JFET input stage I'm currently working on. The JFET input pair is bootstrapped for good common-mode performance; for low distortion and high slew-rate a compensation scheme which includes the output stage is used. Can be used at lower supply voltages (down to about 20 V) without any circuit change. Higher supply voltages up to ±40 V are basically possible as well but care should given to the heat dissipation of the circuit. The preliminary specifications for R_L = 600 Ω and V_{supply} = ±30 V:

- Input offset voltage: < 1 mV
- Input bias current: very low
- Input voltage noise: 1.5 nV/√Hz at 1 kHz
- Current noise density: very low
- Open loop voltage gain: 130 dB
- Gain-bandwidth product: 12 MHz at 10 kHz
- Unity-gain bandwidth: 12 MHz
- Slew rate: ±38 V/μs
- Output swing: +27.9/−28.2 V
- Class A output drive: 900 Ω for full voltage swing
- Maximum output current: ±190 mA
- Supply current: 38 mA (no load)

SGA-HSA-1 High Speed Discrete Operational Amplifier

SGA-HSA-1_r1.pdf

A very high speed discrete opamp, under development. It achieves its exceptional speed by means of a heavily degenerated input stage, and a second stage with capacitive high-frequency level shifter (C4) to remove secondary slew-rate and settling time limitations. Noise and DC precision performance is necessarily reduced compared to my other designs, but still rather good compared to some high-speed monolithic opamps. The preliminary specifications for R_L = 600 Ω and V_{supply} = ±15 V:

- Input offset voltage: < 30 mV
- Input bias current: −3.3 µA
- Input voltage noise: 4.7 nV/√Hz at 1 kHz
- Current noise density: 1 pA/√Hz at 1 kHz
- Open loop voltage gain: 130 dB
- Gain-bandwidth product: 45 MHz at 10 kHz
- Unity-gain bandwidth: 49 MHz
- Slew rate: approximately ±450 V/µs
- Output swing: +13.8/−13.1 V
- Class A output drive: 1.4 kΩ for full voltage swing
- Maximum output current: approximately ±50 mA
- Supply current: 18 mA (no load)

NDFL-DOA-1 NDFL Discrete Operational Amplifier

NDFL-DOA-1_r1.pdf

An untested conceptual study implementing nested differentiating feedback loops as presented by Edward M. Cherry. As the shown design essetially uses two operational amplifiers in series the resulting open-loop gain is drastic. Some preliminary specifications for R_L = 600 Ω and V_{supply} = ±18 V:

- Input offset voltage: < 5 mV
- Input bias current: −1.1 µA
- Input voltage noise: 1.5 nV/√Hz at 1 kHz
- Current noise density: 0.6 pA/√Hz at 1 kHz
- Open loop voltage gain: 240 dB
- Gain-bandwidth product: 10 GHz at 10 kHz
- Unity-gain bandwidth: 13 MHz
- Slew rate: probably around ±180 V/µs
- Class A output drive: 600 Ω for full voltage swing
- Maximum output current: approximately ±250 mA
- Supply current: 40 mA (no load)

Resources

The Philbrick Archive
Cool site with many pictures, datasheets and application notes from the grandfather of opamp manufacture.

990-2007.pdf
Sales brochure with a lot of information about the 990 discrete operational amplifier.

JFET Opamp.PDF
Paper by Fred Forssell about a JFET discrete opamp design.

www.eisenaudio.com/diy500/tables/opamps/
Good overview of discrete opamps for audio.

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