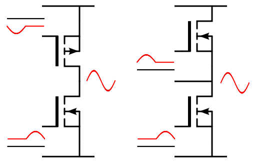
Class AB amplifiers with OpAmps and discrete transistors

Class AB output stage

Rail to rail output

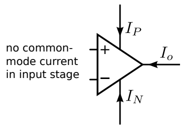
Complementary output
- Source P devices
- Sink N devices

Quasi complementary output
- All N devices with isolated source drive



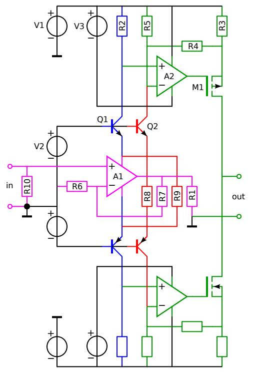
Stable bias

- Copy biasing from opamp
- Measure and control the bias (feedback biasing)



$$I_P + I_N + I_o = 0$$
$$I_P \approx \tfrac{1}{2}\left(\mathrm{sgn} I_o + 1\right) I_o + I_Q$$
$$I_N \approx \tfrac{1}{2}\left(\mathrm{sgn} I_o - 1\right) I_o - I_Q$$

Class AB power current driver



$$\frac{I_o}{V_i} = \frac{R_2}{R_1 R_3}\left(1+\frac{R_7}{R_6}\right)\left(1+\frac{R_4}{R_5}\right)$$

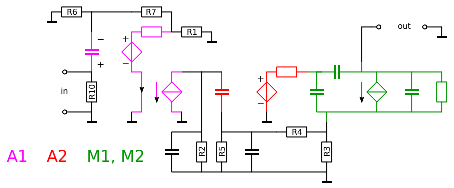
+ Low noise
+ No over-all feedback easies stability
- Gain mismatch between push and pull stage

Main amplifier
Current-to-voltage converter
Power transadmittance
Output quiescent current

R8, Q2 to decrease quiescent current
R9 to increase quiescent current

Power supply

Small-signal equivalent circuit



Modeling aspects

Bandwidth limitation of BJT can be modeled in the CCCS
Output capacitances Q1 and Q2 added to CM input capacitance of A2

Dynamic behavior can be investigated for different values of source, sink, or quiescent current:

Parameterize component values of small-signal MOS model
Use different parameter sets for source, sink or quiescent behavior
Model the current dependency of the MOS tansconductance

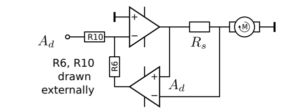
Reduction of offset and even-order distortion

Apply over-all feedback

Convert power current driver drive into integrator
Replace R7 with integration capacitor
Create feedback path with current sense resistor and difference amplifier

C_i Integration capacitance
R_s Resistance of current-sense resistor
A_d Voltage gain of difference amplifier

$$\frac{I_o}{I_i} = \frac{R_2}{R_1 R_3}\frac{1}{sC_i}\left(1+\frac{R_4}{R_5}\right)$$

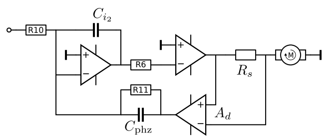


$$G = \frac{I_m}{V_i} = \frac{R_6}{R_{10} A_d R_s}$$
$$\mathrm{LP}_1 = \frac{R_2}{R_1 R_3}\frac{A_d R_s}{R_6 C_i}\left(1+\frac{R_4}{R_5}\right)$$
$$C_i = \frac{R_2}{R_1 R_3}\frac{1}{G R_{10}\pi B}\left(1+\frac{R_4}{R_5}\right)$$

The loop gain in the main amplifier of the power current driver is propotional with the integration capacitamce

A large bandwidth can be obtained using an extra integrator. Use a dual integrator with phantom zero for a low-distortion, wide-band class AB driver.

Design the circuit such that all other poles are non-dominant.
Frequency compensation in the power transadmittance stages can be accomplished with a phantom zero:
- Capacitor across R4
- Inductor in series with R3



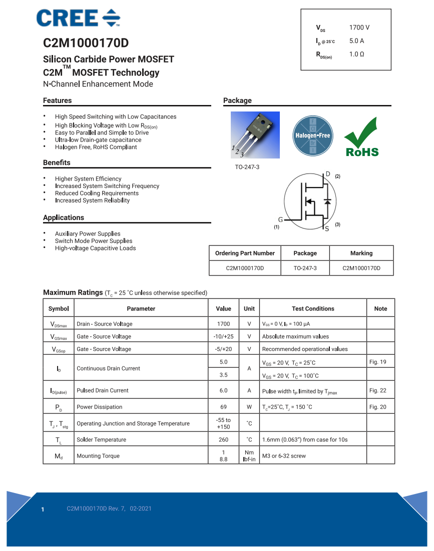
$$G = \frac{I_m}{V_i} = \frac{R_{11}}{R_{10} A_d R_s}$$
$$\mathrm{LP}_2 = \frac{R_2}{R_1 R_3}\frac{A_d R_s}{R_{11} R_6 C_i C_{i2}}\left(1+\frac{R_4}{R_5}\right) \qquad B = \frac{1}{2\pi}\sqrt{\mathrm{LP}_2}$$
$$C_{i_2} = \frac{R_2}{R_1 R_3}\frac{1}{4\pi^2 B^2 R_{10} G R_6 C_i}\left(1+\frac{R_4}{R_5}\right) \qquad C_{\mathrm{phz}} = \frac{1}{\sqrt{2}\pi B R_{11}}$$

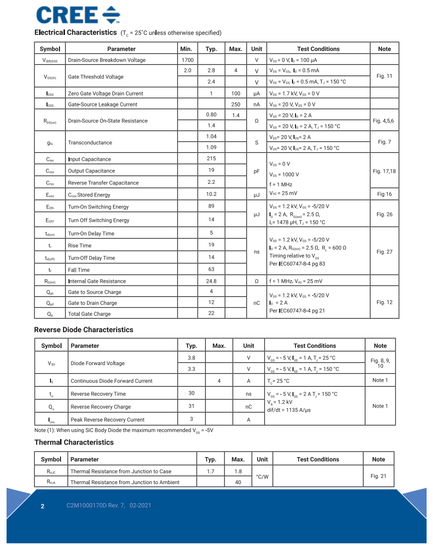
Design sequence

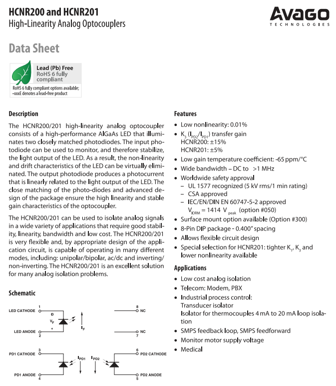
1. Select the power transistors; consider drive capability, dissipation and cooling.
2. Select current sense resistor and divverence amplifier; consider noise and offset (drift) for the amplifier and power dissipation and temperature coefficient for the sense resistor.
3. Assume reasonable budgets for quiescent current and current drive capability for the main opamp and design R2 and the power transadmittance with a bandwidth at least five times larger than the required bandwith of the total circuit.
4. Design the main amplifier consider the drive requirements for R1 (no voltage or current clipping or slew-rate limitation)
5. Design R6 and the integration capacitance such that the integrator bandwidth (servo function) is at least five times the required bandwidth for the complete circuit.
6. Select the BJTs (power dissipation)
7. Design the first integrator.

High-voltage class AB output stages

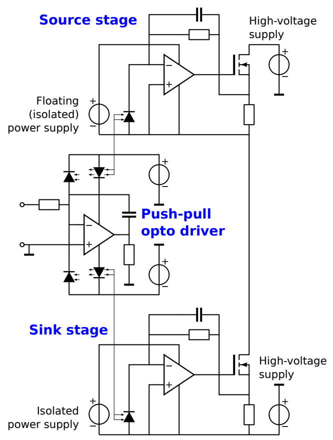
- High-voltage Si or SiC transistors
- Stacked transistors
- Isolated drivers







High-voltage class AB current driver with optically isolated output stage



Can be used as core amplifier in:

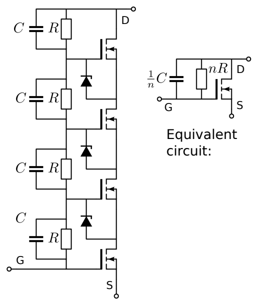
High-voltage class AB current drivers
High-voltage class AB charge drivers
High-voltage class Voltage drivers

Add loop integrator and design all other poles non dominant.

Over-all feedback reduces effect of gain mismatch between source and sink drivers.

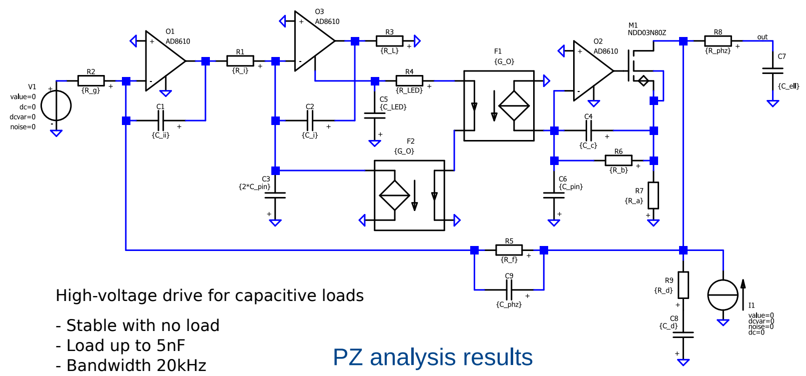
Stacked transistors

Alternative for high-voltage devices



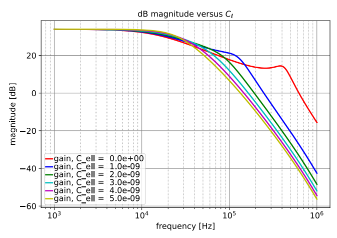
Resistor values s as large as possible (gate leakage current)

Capacitor values as small as possible (tolerances on gate-drain capacitance)

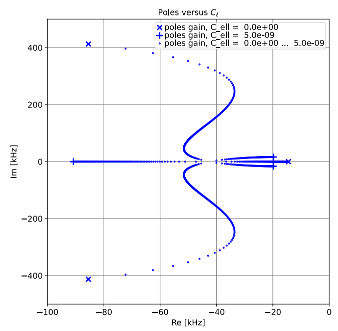


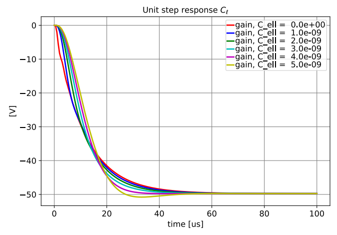
High-voltage drive for capacitive loads

- Stable with no load
- Load up to 5nF
- Bandwidth 20kHz
- Quiescent current 1mA
- Load voltage 600Vpp

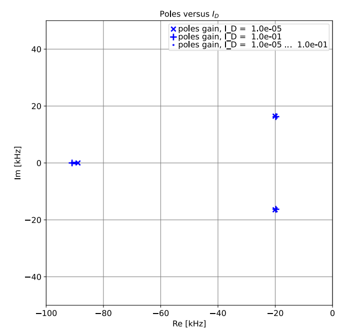


Small-signal frequency response of the voltage driver





Unit step response of the voltage driver



PZ analysis results

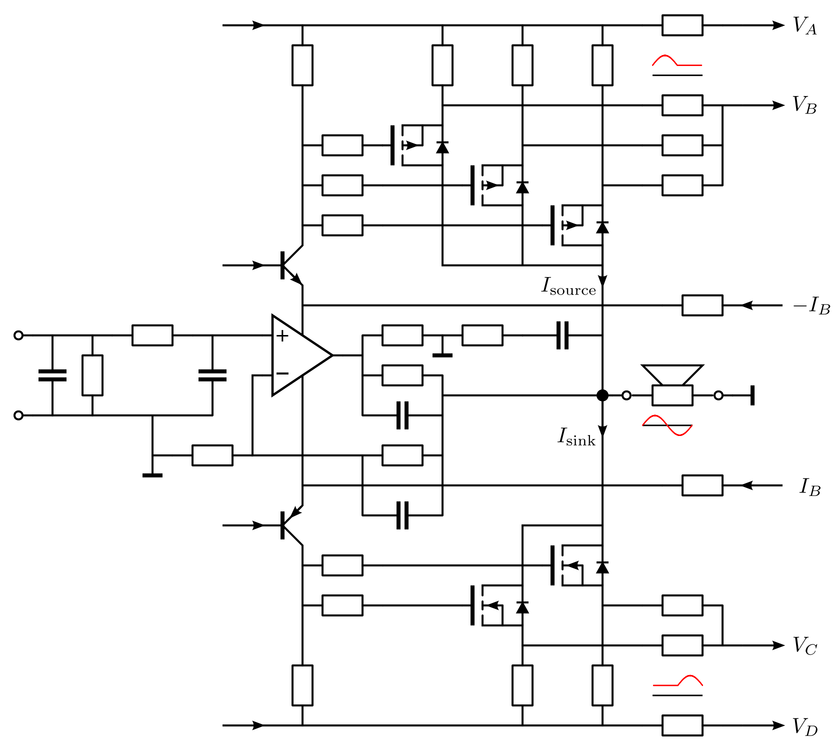
Gain type: gain

DC gain = -49.75

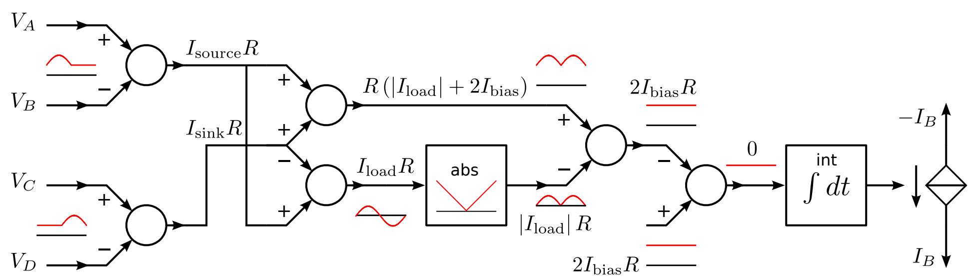
pole	Re [Hz]	Im [Hz]	Mag [Hz]	Q
p_1	-1.978e+4	-1.629e+4	2.562e+4	0.6477
p_2	-1.978e+4	1.629e+4	2.562e+4	0.6477
p_3	-9.077e+4		9.077e+4	
p_4	-2.435e+5		2.435e+5	
p_5	-7.893e+5		7.893e+5	
p_6	-1.703e+6		1.703e+6	
p_7	-4.793e+6		4.793e+6	
p_8	-6.583e+6		6.583e+6	
p_9	-1.731e+7	-1.775e+7	2.479e+7	0.7160
p_{10}	-1.731e+7	1.775e+7	2.479e+7	0.7160
p_{11}	-1.064e+8		1.064e+8	
p_{12}	-1.116e+8		1.116e+8	
p_{13}	-1.155e+8		1.155e+8	
p_{14}	-9.232e+8		9.232e+8	
p_{15}	-1.356e+9		1.356e+9	

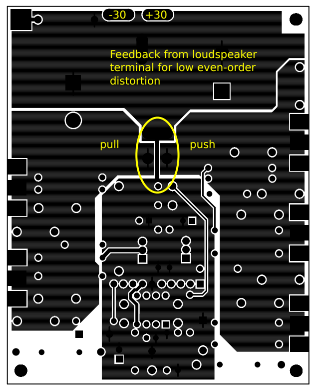
zero	Re [Hz]	Im [Hz]	Mag [Hz]	Q
z_1	-2.411e+5		2.411e+5	
z_2	-2.102e+6		2.102e+6	
z_3	6.693e+5	-2.395e+6	2.487e+6	1.858
z_4	6.693e+5	2.395e+6	2.487e+6	1.858
z_5	-2.762e+6	-2.364e+6	3.636e+6	0.6580
z_6	-2.762e+6	2.364e+6	3.636e+6	0.6580
z_7	-5.345e+6		5.345e+6	
z_8	-2.476e+7		2.476e+7	
z_9	-1.034e+8		1.034e+8	
z_{10}	-1.116e+8		1.116e+8	
z_{11}	-1.200e+8		1.200e+8	
z_{12}	-1.639e+8		1.639e+8	
z_{13}	-7.961e+8		7.961e+8	

Solo: High-end Audio Power Amplifier with PentaFET output stage

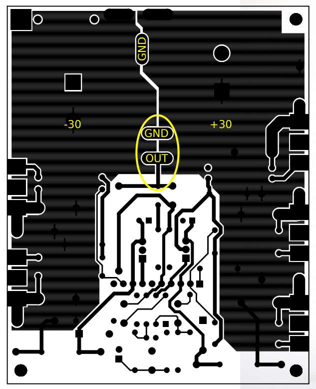


Analog Bias Computation and Control

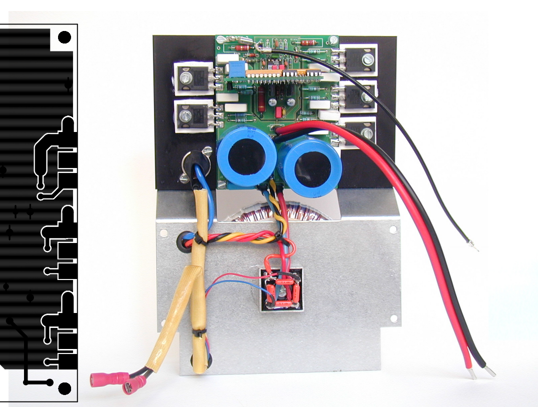


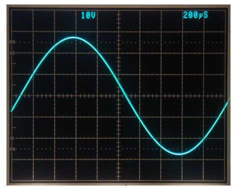


PCB top

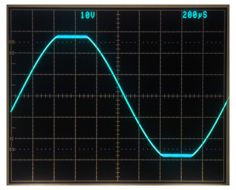


PCB bottom

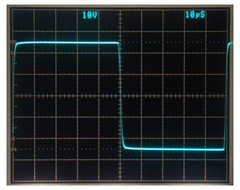




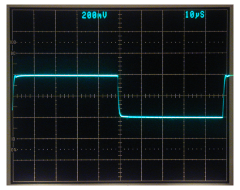
55Vpp, 500Hz, 3.6Ohm



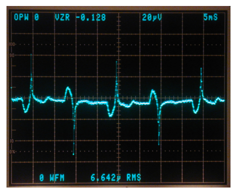
Overdrive, 500Hz, 3.6Ohm



50Vpp, 10kHz, 3.6Ohm

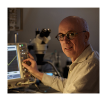


400mVpp, 10kHz, 3.6Ohm



Hum: -130dB

Technical specifications



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