

Schade Common Gate (SCG) Preamp

Rahul Athalye

12 December 2022

Major Circuit Blocks and Operation

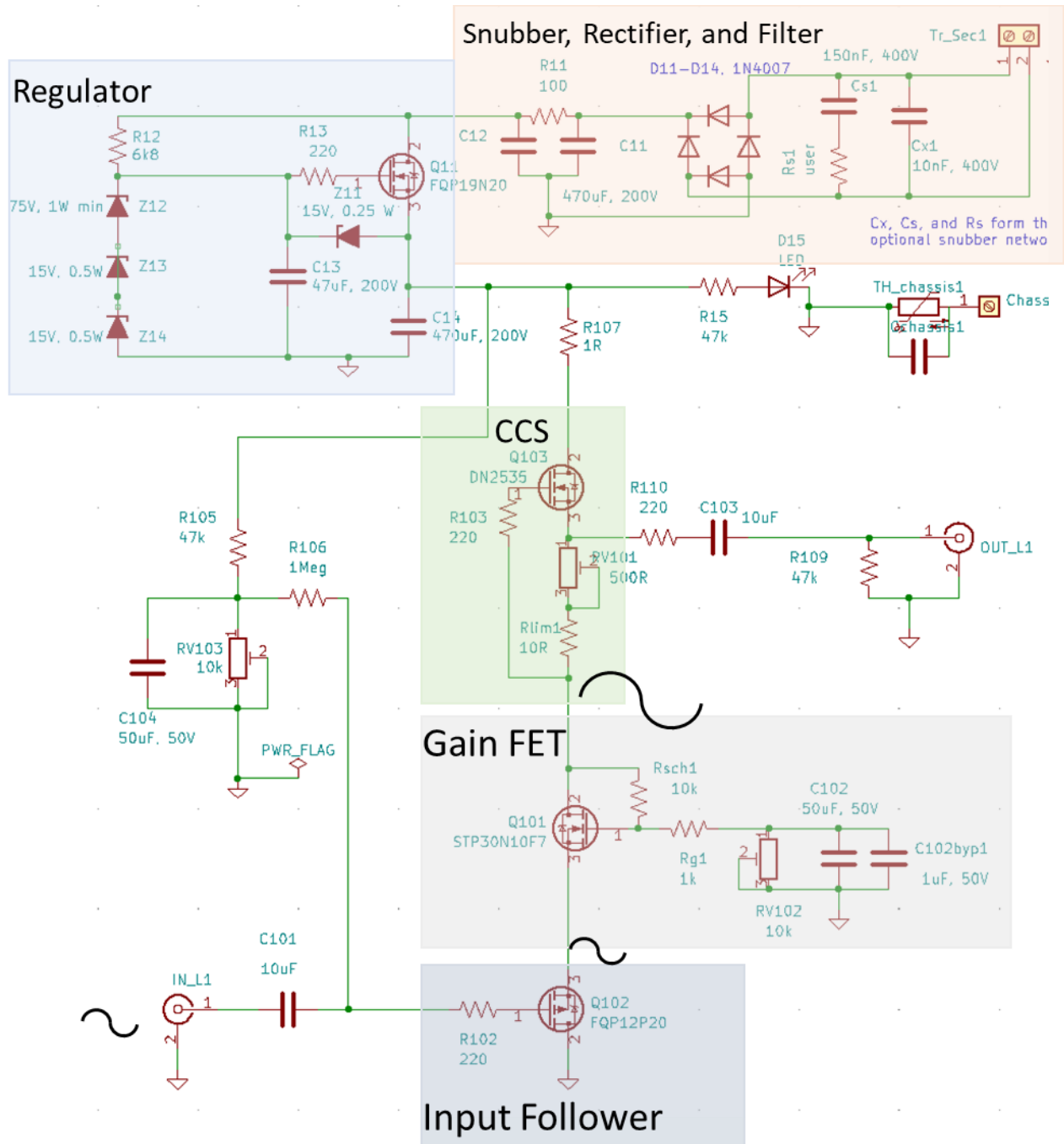


Figure 1: Schematic and major circuit groups (only one channel shown)

This circuit is based around turning an ordinary FET with typical pentode-like curves into a triode. This technique is described by O.H. Schade¹ for beam power tubes and pentodes and is often seen in tube pentode circuits. Nelson Pass's Zen series of amplifiers also employ a similar approach to linearize the gain FET. The novel portion of this circuit is that the 'triodised' FET is now driven from the source pin, thereby alleviating problems typically associated with the Schade topology, namely that the input impedance can be low. A P-channel FET operating in common drain mode (unity gain) is used to drive the gain FET.

Referring to Figure 1, Q102 is the P-channel FET operated in common drain mode. It provides unity gain and for the most part, does not contribute to the sound. The preamp input signal appears at the gate of Q102 providing high input impedance to the preceding stage. A copy of the signal (without any gain) appears at the source pin of Q102, which then serves as the input to the gain FET, Q101. The gain FET seeks to amplify the difference in signal between the source and gate pins. The input signal has appeared on the source pin of Q101; the gate pin is connected to the drain pin through the Schade network of R_{sch} and R_g . R_{sch} and R_g divide the output signal on the drain pin and feed it to the gate. Thus, Q101 is now amplifying the input signal (source pin) minus a copy of the output signal (gate pin) with all the attendant distortion introduced by itself. In this process, the curves of Q101 begin exhibiting properties of a highly linear triode, i.e., low drain impedance (vertical curves) and near equal spacing between V_{gs} curves.

The Schade network— R_{sch} and R_g —setup the amount of feedback applied and also form part of the network (including C102 and RV102) that sets the DC operating voltage for Q101. RV102 adjusts the V_{gs} for Q101 while C102 bypasses AC frequencies around RV102.

Q101 is loaded by a constant current source (CCS) formed by Q103 and RV101. Q103 is a depletion mode device that neatly and simply allows the current to be controlled with a minimum number of parts. The CCS maintains a constant current flow through Q101, the gain FET, based on the value of RV101. The output of the preamp could be taken from the drain of Q101 (gain FET) or from the source pin of Q103. The source pin of Q103 is within the CCS feedback loop and any variations in current in the AC domain would result in the CCS circuit adjusting the current accordingly. This topology is known as the mu-follower and this topology is used in the SCG.

The operating point of Q102 must be adjusted so that it has enough coverage for high swing input signals and also to stay outside the range where the gate capacitance of the device is variable. The network of R105, RV103, and C104 provide the bias voltage on the gate pin of Q102. Approximately 15-20V on the gate of Q102 is sufficient. R106 communicates this voltage to the gate of Q102.

The power supply for each channel consists of a RC snubber circuit² followed by an RC filter and lastly a Zener follower, which regulates the voltage and provides immunity from mains-related voltage fluctuations. The Zener string is fed by R12 to keep the Zeners in the operating range and the total Zener string voltage is communicated to the gate of Q11. Any noise appearing on the gate of Q11 is absorbed

¹ Original paper by O.H. Schade can be found here: <https://www.dos4ever.com/uTracer3/Schade.pdf>

² Mark Johnson's Quasimodo circuit and thorough app note: <https://www.diyaudio.com/community/threads/simple-no-math-transformer-snubber-using-quasimodo-test-jig.243100/>

Voltages and currents



Test Point (TP) #	Reference	Purpose
0	Ground	0V connection
1	Vd, Q101/201	Operating point for Q101
2	Vs, Q101/201 and Q102/202	Operating point for Q102
3	Vg,Q102/202	Correction operation of RV103
4	R107/207	Measure CCS current across R107 and R207.

Power-up procedure

Safety first: This is not your typical solid-state circuit with low voltages. **This circuit has potentially lethal voltages! There is between 120V to 200V on the board. Please use caution.** If you are not sure what that means, seek help. Read through the tube safety pages on the diyAudio forum. If you are still not comfortable, seek out someone who can test the circuit for you. This is a DIY circuit and you bear complete responsibility for any damage to yourself, others, property, or other equipment due to the use of the circuit and circuit board.

Get one channel working first by following all the steps below before powering up the second channel. Before applying power make sure R107 and R207 are disconnected and then follow the steps below.

A. Test the regulator.

Don't wire in R107 and R207 (all other parts can be wired at this time). R107/207 is the resistor just before the CCS. This will keep the rest of the circuit from seeing any voltage.

With the above configuration, connect voltmeter between TP4 and TP0 or ground. Power it up. If all goes well, you should read the sum of the zener stack minus 3 to 4V.

Switch it off, let the caps drain--**they will drain very slowly because there is no load yet. Be careful because the capacitors and the regulator circuit will have more than 130V and the voltage drains slowly.** Best way is to walk away for 5 minutes. After voltage has dropped to <5V, wire in R107 and R207.

B. Set the CCS current.

Use alligator clips and leads to shunt Rlim1/Rlim2 to ground, i.e., connect the leg connecting Rlim to the drain pin of Q101/201 to ground.

Connect voltmeter between the two TP4 points, i.e., across R107/207. Now, turn the RV101/201 pot. For TO-220 parts, set it to 30 mA. For 30 mA, and $R107 = 10\ \Omega$, it should read 0.30 V across TP4.

What you are shooting for is 3-4 mA more than what you expect through the gain FET (about 25 mA). This is because the Schade network of Rsch and Rg drains about 3-4 mA (for the 10k/1k combo) of current and this should be accounted for in the current through the CCS.

If all goes well and you successfully set the current, switch off power, wait for the capacitors to drain, and then take out the alligator clips.

C. Set Q102 operating point.

Connect voltmeter across TP2, Vs, and TP0, GND. Turn RV103/203 until you measure 20-30V for TO-220 FETs.

D. Set Q101 (gain FET) operating point.

Connect voltmeter across TP1, Vd, and TP0, GND. Turn RV102/202 until you measure 65V.

And you're done. Now repeat for the other channel.

Gain Calculations

The gain for this circuit is set by the ratio of R_{sch} and R_g . With $R_{sch} = 10k$ and $R_g = 1k$, the gain is 10X or 20 db. Here's some rough numbers for various values of R_g and assuming 10k for R_{sch} :

R_g , gainX, db gain

1k, 10X, 20 db

2k, 6X, 15 db

3k, 4.5X, 13 db

4k, 3.5X, 11 db

5k, 3X, 9.5 db

I have not tested these values, except 1k and 2k.

The R_{sch} , R_g , and RV102 (RV202) network must sink current flowing through it. If you decide to use values other than 10k and 1k, calculate the heat dissipation in each of the three resistors and allow a generous margin with respect to the power dissipated and wattage of the resistor—a 1:2 ratio is the minimum. At 60V at the drain pin of Q101, and $R_{sch} = 10k$, $R_g = 1k$, and RV102 = 5k, current through this chain is 3.75 mA. Power dissipated in $R_{sch} = (3.75mA)^2 \times 10k = 0.14W$. So, a 0.5W resistor is recommended, though 0.25W could suffice.

Heatsinking

Power dissipated in FETs = voltage across FET x current through FET.

Current through the circuit is about 30 mA. Assuming a supply of **130V after the RC filter**, table below shows the power dissipated in each transistor.

Part	Design Voltage Across Device	Power Dissipated
Q11	30	0.9W
Q103	40	1.2W
Q101	40	1.2W
Q102	20	0.6W

TO-220 devices can handle up to about 1W without a heatsink. For longer life and cooler FETs, heatsinks are recommended for Q11, Q103, and Q101. Refer to the parts list for recommended heatsinks. Small, clip-on heatsinks are sufficient.

Appendix: Specifications and Measurements

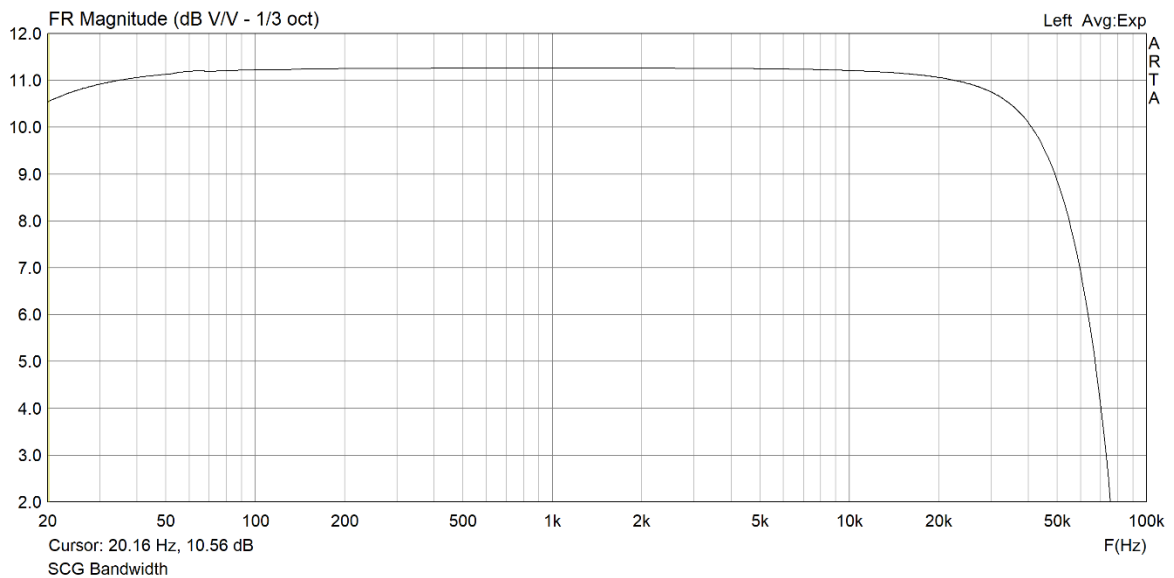
Gain: Adjustable using Rsch and Rg. Set to 10X or 20 db using Rsch = 10k and Rg = 1k.

Maximum voltage swing: With TP2/Vs at 20V and TP1/Vd at 60V, and regulator output at 100V, maximum peak-to-peak voltage swing is 80V or approximately 28 Vrms.

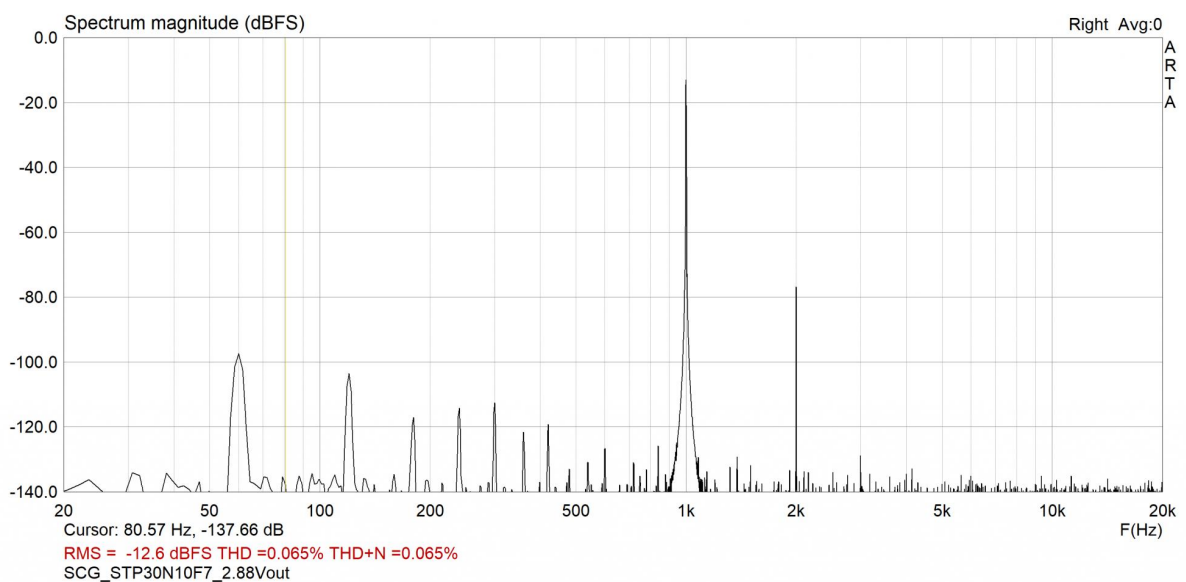
Bandwidth: - 3db at < 10 Hz and > 50 kHz

MEASUREMENTS (USING STP30N10F7)

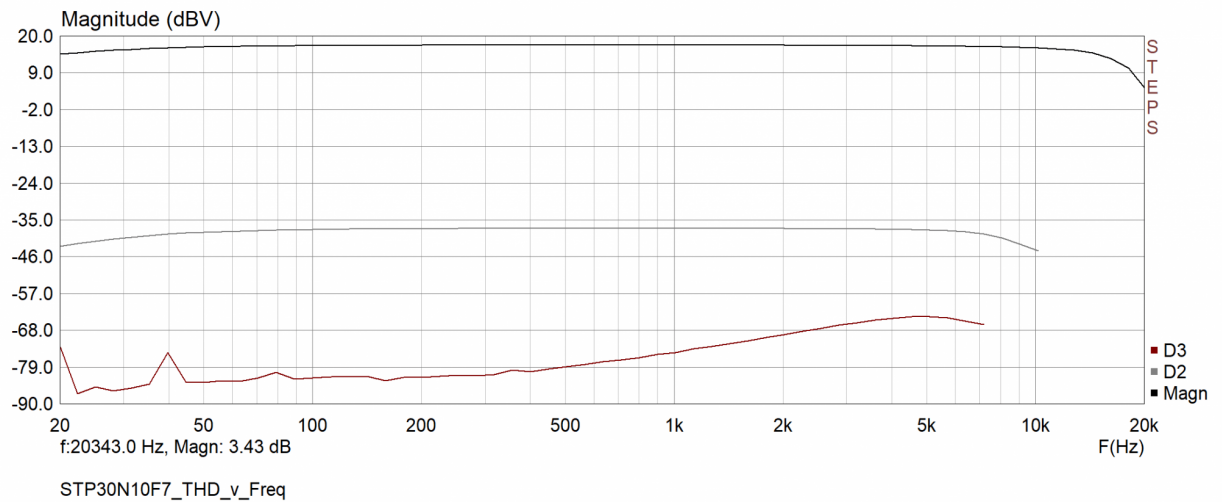
1. BANDWIDTH



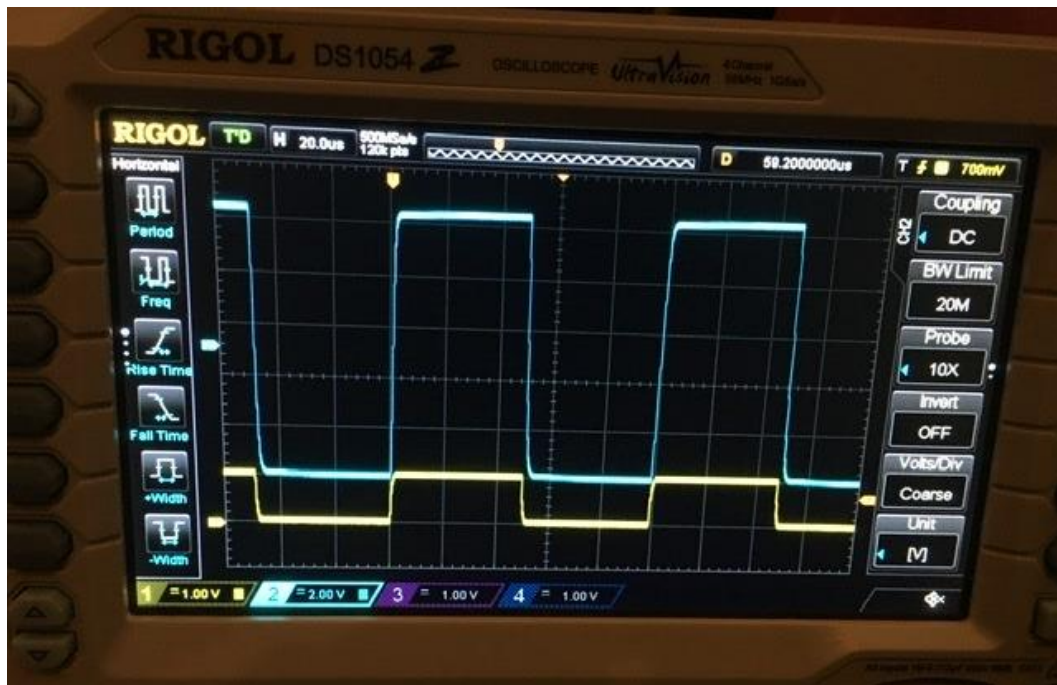
2. DISTORTION SPECTRUM



3. THD V FREQUENCY



4. SQUARE WAVE



10 kHz square wave. Yellow is input (1V/div) and blue is output (2V/div). 10V peak-to-peak 10 kHz square wave.