# Design Notes for WA1GFZ Mosfet Audio Driver

Circuit design by Francis Carcia, WA1GFZ. Original design Copyright March 22, 2010.

Prototype by Thomas Cathey, K1JJ.

PCB layout by John Williams, W9JSW.

## Original overview by Tom, K1JJ – March 31, 2010

From this article - http://amfone.net/Amforum/index.php?topic=23632.0

After a couple of months of design work by WA1GFZ and building/testing by me, we have a working MOSFET Audio Driver. I have it running now on my 4-1000A plate modulated by a pair of 4-1000A's.

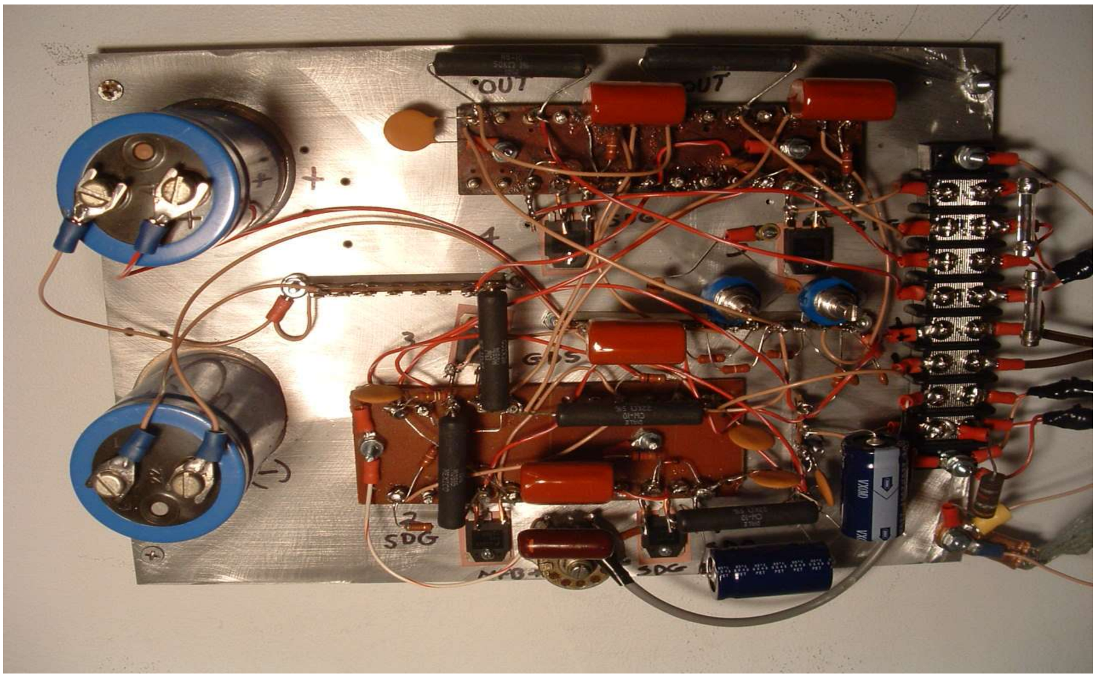
One volt of audio in, hundreds of clean watts out, with negative feedback if desired.

The results appear to be quite good with this first prototype. It will pass a 50hz triangle waveform well with sharp points and near perfect slope. This is not easy to do unless direct coupled. My version uses 2.2 ufd coupling caps which allows response down to about 10hz. The high end is easily 12 khz and very clean. It uses a single + - 300V supply for everything. It will drive any set of modulator tubes. My 4-1000A tetrode-connnected modulators work well. The 10hz lows limitation is good to prevent mod transformer burn out. Even 30hz is a better limit. This is set by the coupling caps... bigger = lower response.

Because there is only one transformer in the system now (mod xfmr) I am able to tap the negative feedback (NFB) off the modulation transformer secondary winding. (Ed. See Feedback Section below to see the current way Tom provides feedback). Normally this is impossible to do with two transformers in line. (Like with a driver transformer, etc)

The driver uses five 11N90 900V MOSFETS at about $3.00 each. I have them mounted on a heatsink and the Fets show no signs of getting warm. Compared to my older 100w 8 ohm amplifier driving a Linear Standard transformer audio driver, this unit is an improvement. The low end is cleaner and more intense. I now have difficulty choosing which phase to run and can almost justify the "shark fins" phase. This is tough to do with transformer rigs. Before, the opposite phase was very obviously the correct choice. This requires a great low end response to pull off.

The two pots shown in the pictures set the bias for each modulator tube.



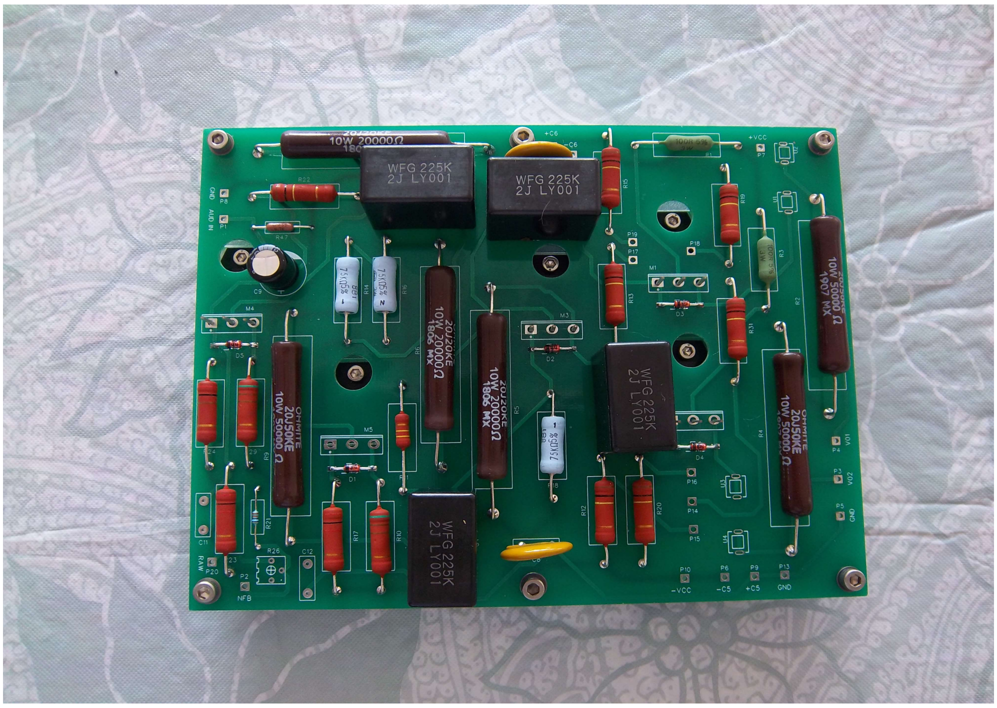
# Design Notes for WA1GFZ Mosfet Audio Driver

**2019, Tom opines** - I used a Variac on my + - 300V supply. I found I could reduce it somewhat to just what was required to drive the tube modulators. Same results in class A, less heat. Still, the 11N90s barely get warm. In my case using tetrode configured 4-1000A modulators, I was able to back it down to +- 260 volts. Big low-mu triode modulators like 833As will require the most voltage.

Important: The driver board's MOSFET gate bias resistors are optimized for +- 300V. When the power supply voltage is changed too low, some of the FET gate bias resistors need to shift in value to get back to maximum output capability. So watch the scope carefully when reducing voltage.

How it works, simplified: The + - 300V supplies basically center tap and produce 0 volts to the tube grids thru the FETS. You set this DC offset that sets the negative bias and adjusts the idle current for the tubes. Then the audio signal comes thru push-pull and swings the grids up and down around this DC bias point. So if you need less than +- 300V of audio swing to fully drive the tubes, you can back down the overall supply somewhat. Put an audio tone thru at full RF and audio power and you can easily see this + - 300V voltage Variac adjustment threshold on the scope.

## The Board



## Frank's Build Comments

The board has been built and integrated into the hot rod Valiant with 4- 36LW6 sweep tube modulators making about 200 watts of peak audio power. No circuit changes are required running +/- 270 VDC. The only circuit modification was to add 5 ground lugs to the mounting screws to terminate the power ground traces to the heat sink. The driver is sitting on the table next to the Valiant that is unshielded and out of the case running 250 watts carrier output.

The circuit values are fine as long as the operating voltage isn't reduced down to around 220 volts. R23, R17 and R18 would need to be increased so the stages don't clip on voice peaks.The driver without feedback has a gain of about 60dB. It is a good idea to include local feedback until it is wrapped around the modulator. I used a 50K 10 watt resistor in series with 100uF off VO2 just to be safe and I set the feedback pot to full feedback. This will keep the gain at a good starting point. When you wrap the feedback around the modulator plate use the tube connected to VO1 because the tube is an inverter.

The stiffer you make the power supply the cleaner the signal you will make. I used a Anteck 100 VA transformer with a dual 200 volt winding. Like Tom I used a pair of 680uF filter caps. I would go with the 230 volt transformer is you plan to run 300 volts and get maximum output. I need about 50 ma peak to drive my modulator screens with the control grid grounded. I'm running about 35 ma resting current with 900 volts on the plates. My positive supply moves around a bit so I would go with a better power supply filter and maybe a larger transformer for full power applications.

I made the mistake of putting .001 bypass caps on each of the 4 screens. This is a problem because R2 and R4 50K resistors set up a discharge time constant that causes the caps to act like a charge pump and mess up the bias by driving it higher.I tried reducing the value of R2 and R4 to 25Kohms and the problem went away but my power dissipation went up. It would have been better if we had used 20 watt resistors at the higher current. The peak dissipation was close to 10 watts on voice peaks at 25K. This about double when the resistors were 50K 10 waters. The FETs can easily handle this extra current if the heat sink is large enough. I'm considering parasitic suppressors on each screen. My concern is the parallel tubes wanting to take off.

Simulation shows I need to go lower than 25K even though the board seems to function fine driving 2000pf per phase.

I plan to reduce the cap values to 330 pf and stay with 50K in R2 and R4.So if you plan to drive a tube with a bypass cap make sure the driver can discharge the cap on the negative cycle. The effect was quite strange. "S es" would peg the mod current meter.The board works fine and John did a good job leaving plenty of room for larger components. I would consider 20 watt power resistors even though most of them are running at around 3 watts average power to avoid making too much heat. The three watt resistors dissipate about 1 watt worse case. Again I think 5 watt resistors would fit to really make it bullet proof. My heat sink has 1/2 inch fins to fit in the Valiant. It is a bit under sized for full power applications. gfz

## Components

**Power Supply Caps** - The power supply bypass caps C5/C6 are not critical as long as there is no hum. Best practice is to keep the PS feed leads as short as is practical.

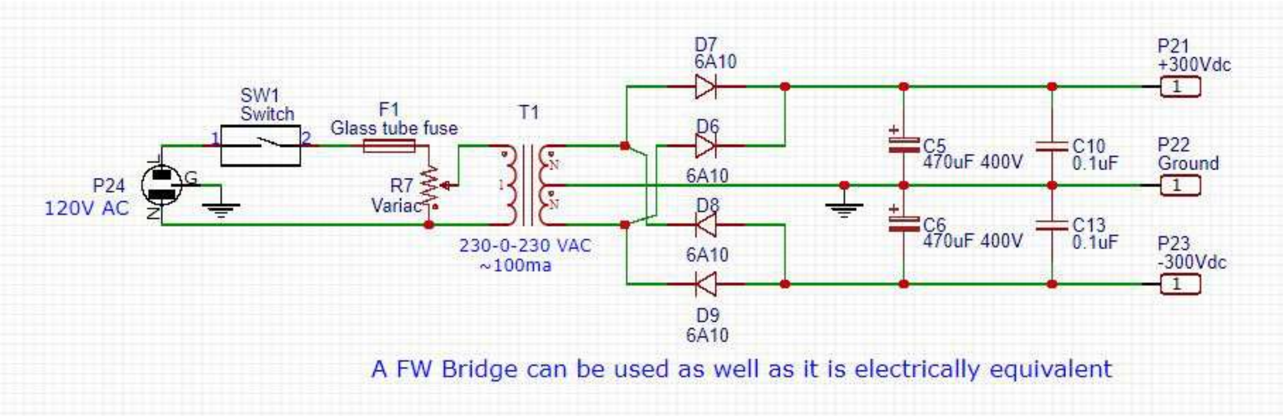
**Bias pots** – They should be linear. A 100K pot will give a +/- 100 volt bias range. 2.5 watts would be good, The user can use a smaller pot with fixed resistors on each side to limit the range and give better resolution as long as the total resistance is 100K. My case I will need between 0 and 5 volts of bias for the Valiant bias. I will not need much voltage range so I can use a smaller value and wattage pot. It is also possible to increase the values of R13, R15, R12 and R31 to allow for a smaller pot value. You just need to make sure the resistors don't dissipate over a watt each or they could drift in value making the tube bias wander around. Ask Tom what he used for his rig. The bias pot wipers go to R19 and R20.

**Transformers** - The driver is class A so load is fairly constant around 100ma per polarity. Again this will depend on the power source. The best set up would be a dedicated power supply like Tom has.

## Power Supply

The best way to make power is a center tapped transformer with two sets of full wave rectifiers making positive and negative voltages. This way the voltages will track with the load. Here is an example schematic.

# Design Notes for WA1GFZ Mosfet Audio Driver




Antek has the AS-1T230 - 100VA 230V Transformer for $34 new which would be a good choice.

A dedicated power supply scaled to the required current with properly fused input would make it very hard to damage the 11 amp FETs or damage any resistors. The user only needs to worry about the output impedance of the driver since it is DC coupled. There is no active current limiting in the output stage to keep the circuit simple. Simple current limiting circuits oscillate when they activate driving device dissipation very high. It is better to limit the power source so you never get into trouble. K1JJ has used this circuit for almost a decade without any part failures to date.

## Heat Sink

The board dissipates 60 watts just sitting doing nothing. A lot of the power is consumed by resistors but I think it should be on a heat sink size depending on the load. My rig needs 75 volts 30 to 50 ma peak each phase to drive the screens so it is going to make some heat. Everything is running in class A. I'm planning a heat sink a bit larger than the board with 1 inch fins mounted with the fins vertical. Fins facing up should also be fine.

Tom has the history here with his proven layout. - "From my real experience with the prototype: I use a small 6" X 8" heatsink with 1/2" fins. (underneath - not shown here). The FETs and sink barely get warm and I leave them keyed on all the time. (The 4-1000A modulator tubes get T/R keyed in the fil CT). My guess is you could get away with just a 1/8" aluminum plate. It will also depend on how hard you idle and bias it - 833As vs: smaller 811As, etc.Big tubes, then use a heatsink - small tubes then just a plate will probably do."

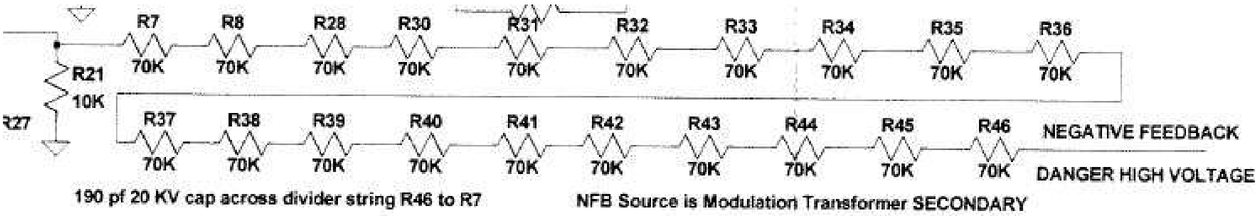
## Feedback/Divider String

The feedback network around the modulator was developed by K1JJ. Feedback current must be limited to protect R26 and M4. Tom's network works between 2000 and 3000 volts on the modulator plates.

Tom is pulling feedback off one of the modulator plates so lethal voltages are present. He was unable to make feedback work off the secondary side of his modulation transformer due to phase shifts in the iron. The driver phase shift can be improved at the expense of higher operating current but the limiting factor will always be the modulation transformer.

This is a snip of the original schematic divider string. Please use 21 100K 3W resistors instead. HV end is attached to one of the modulator plates. The NFB HV resistor ladder source is the plate cap of one modulator tube. This tube is the one whose grid is connected to VO1 P4. DANGER, high voltage is on this resistance ladder so mount it on fiberglass/insulators and respect the HV. The output of the ladder across R21 10K pick-off resistor to ground is less than 10 volts, which then connects to the audio driver board input at the “NFB” point. This low voltage connection can be run with regular shielded audio cable or preferably small coax. Bear in mind if the 10K pick-off resistor blows or is disconnected from ground, HV will appear on this point, though limited in current by the 100K’s in series. (2 meg total)

# Design Notes for WA1GFZ Mosfet Audio Driver




## Troubleshooting and pre test data

I recorded the operating voltages at each FET in simulation. This is assuming the output bias is set at -5 volts and the power supply is +/- 300 VDC.

M1: Gate = -.47 (set by bias pot ), Drain= +295.7, Source = -4.92
M2: Gate = -.47 (set by bias pot) , Drain +295.7, Source = -4.92
M3: Gate == -157.3, Drain = +160.7, Source = -161.7
M4: Gate = +5.86, Drain = +135, Source = +1.5
M5: Gate = -292, Drain = -53, Source -296

## Bringup Guidance

1. Do not connect to the modulator tubes until the bias is set or you may need new tubes.
2. Do not connect to modulator tubes until it is verified that the board works and all operating voltages look normal or there will be a race between blown fuses and melted grids.
3. The output current is limited by R1 and R3 and the fuses. These values can be adjusted by the user if necessary.

## Power Supply and Bias Determination

Tom gives this advice - I would use a Variac on the PS if not simply for testing and being able to ramp it up safely. Also, you can find the sweet spot of operation. It is a small Variac.

As far as what parameters to set for triode-connected 813s, I usually just make sure the tubes are running right and the MOSFET driver is OK and then set the bias pots to max cutoff. Then turn everything on, key it up and slowly move the pots until the 813s are idling where you want.

Frank could probably customize the driver resistor biasing to idle with the exact FET biases, but that is probably not needed. When you run the tones thru for testing you will get a good idea where you are. My guess is the 813s will run fine with the way Frank has it biased. Perhaps the only guys who will need FET adjustment biasing are running 833As or power hog triode tubes. We will have to see.

As long as there is not excessive driver heat and the tones look good, all is well.

Maybe eventually, if needed, Frank will make a listing of a few critical FET resistor values that can be optimized for a few popular tubes… maybe not needed, I dunno.

**** My driver worked FB right out of the box – with minimal heat. **I would run it as close to +- 260 to 300V to please the MOSFET fixed biasing needs and then use the bias pots to satisfy the modulator tube bias idling.**

## Fuses

**"Are the modulator tubes safe when a fuse is blown?"**

A. When a fuse blows the grid is pulled down to the negative rail by R2 or R4

If so, then a rough estimate will be the starting fuse and then you just have to experiment to see how low you can go before they blow during normal operation.

**Medium or fast acting?**

A. I would do a fast fuse because it could become a race between the fuse melting or the grid melting if something stupid happens. Tom has never had this failure in almost a decade. R1 and R3 values could be increased to limit current if necessary but that will also limit the output voltage swing

I like fast acting, but hard to say without testing. Even a spark gap event could take out a grid fuse.

## Future R&D

For the guys running, as Tom calls them, big dumb triodes:

Here is a thought: Say your application will never need a positive bias on the tubes. Then you can eliminate R15 and R31 and just terminate the plus side of the bias pot to ground. (I had both rails on the pots to balance the voltage as load changes.)

Say you want tight regulation of your negative bias. Hang a Zener between the negative side of the bias pot to ground. Make the Zener voltage a bit higher than you will ever need. This will put a regulated bias voltage on the output stage gates.

Still need tighter regulation Reduce the value of R2 and R4 but make sure your FETs have enough heat sink and you have enough power supply. I have a simulation going that has R2 and R4 as low as at 10Kohms

BTW. Simulation I have reduced the value of R18 from 82K to 75K it will increase the maximum output swing a couple volts.

This is untested so ….

## Driving the screens of Tetrodes:

The case of a Valiant with sweep tubes driving screens:

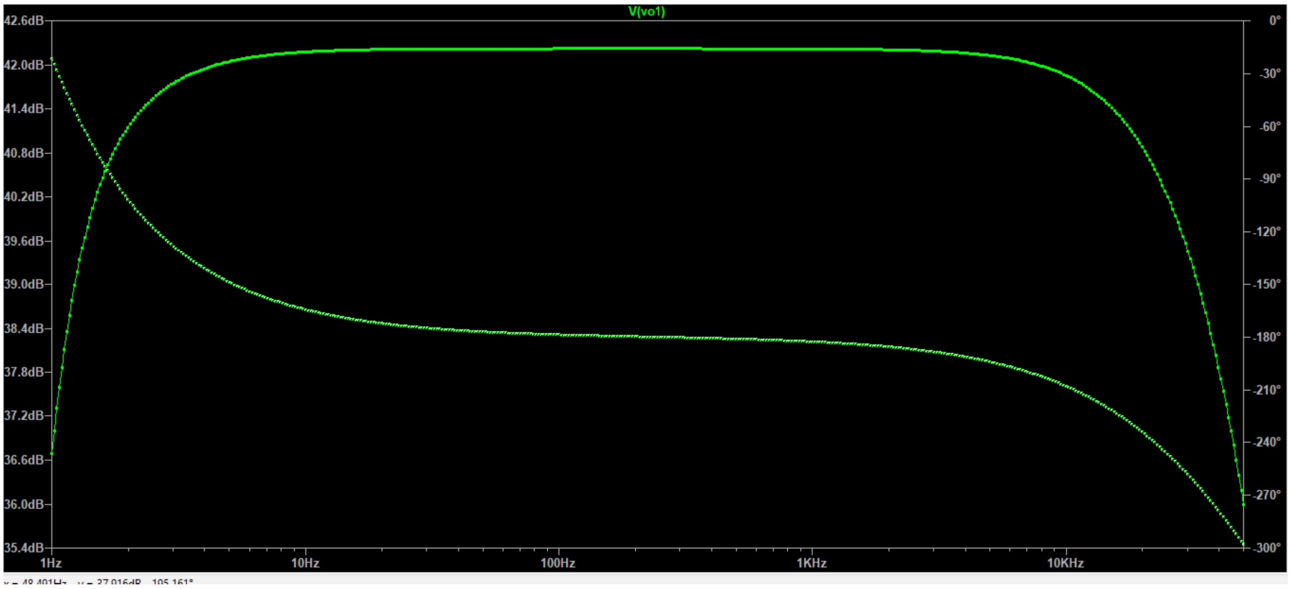
I will need between -10 and plus 10 volts of bias on the screens of my 36LW6s. I will probable reduce the value of the bias pots to reduce the bias range that will result in finer resolution of the bias pots. I will probably put two zeners on each pot to regulate the pot voltages if I find them unstable. K1JJ has the only history on bias stability with the basic circuit as it was posted. This may also apply to triode connected 813s. I would be good to hang a cap across each Zener.

## Graphs

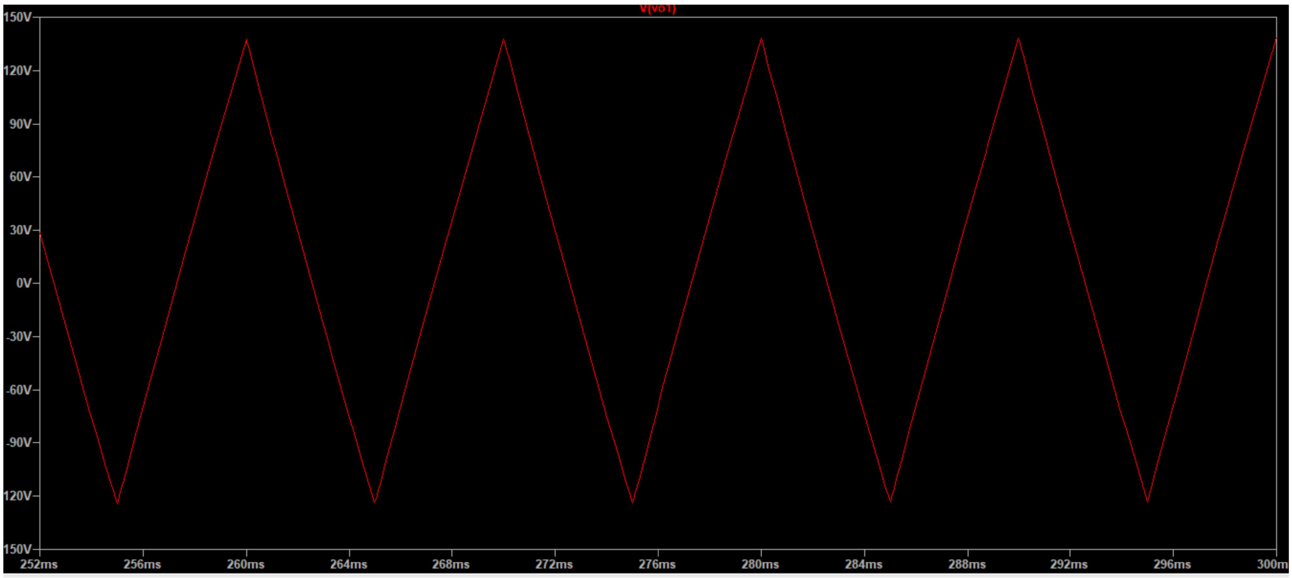
Following graphs are from the simulation using Ltspice.

**Response curve of current design input to output.** Bottom trace is phase (Ltspice)

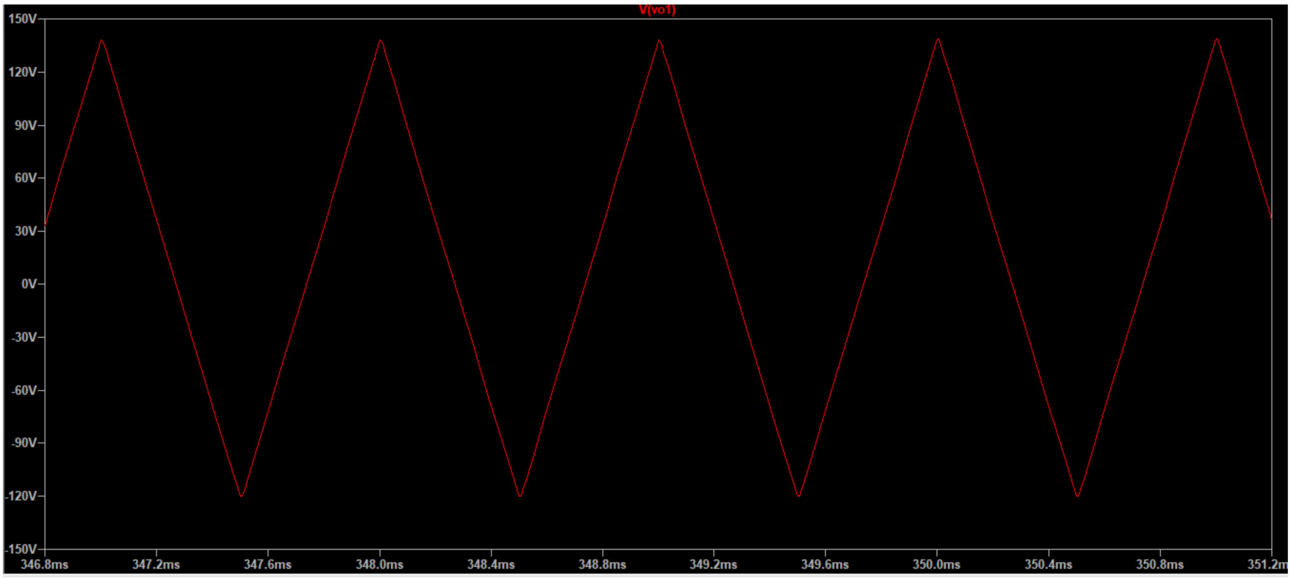
I measure the 1dB roll off 2hz to 18.6kHz. Phase change 44 degrees 10Hz to 10kHz and 30 degrees 100Hz to 10kHz. The phase shift is a bit better inside the feedback loop because the M4 input coupling is outside the loop and accounts for some of the total phase shift. gfz




**100 Hz Triangle**




**1kHz Triangle**




## 10kHz Triangle