Amplifiers for high efficiency loudspeakers

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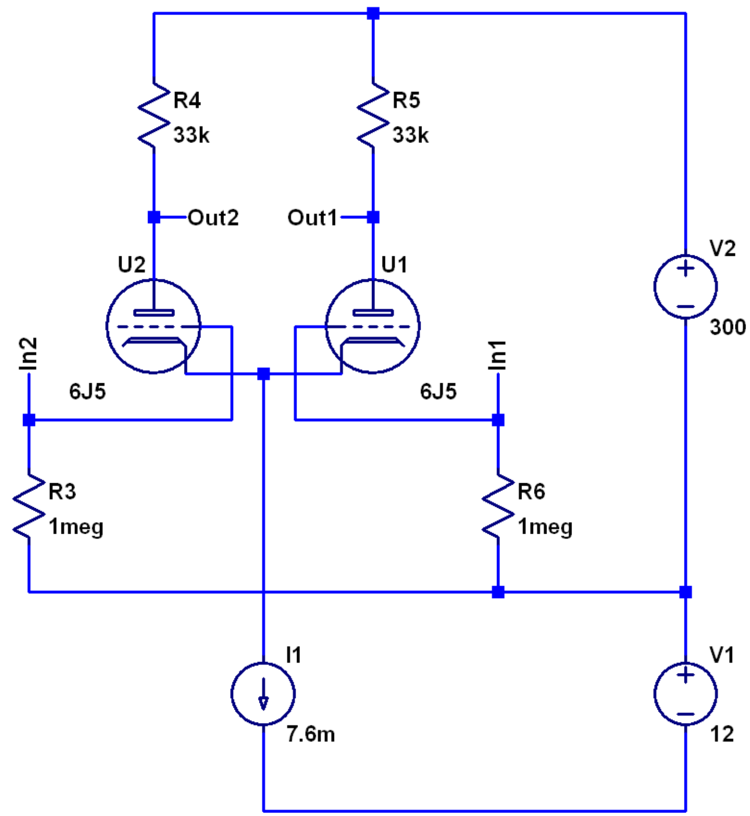
General topics

- Weakness of the long-tailed pair
- HT filtering
- Mains voltage variation
- Capacitor coupling to the output stage
- Output transformer
- Regulators
- Conclusions

Long-tailed pair

- Invented by Alan Blumlein in 1936 (UK Patent 482,740)
- Basis of most phase splitters
- Input of all op-amps

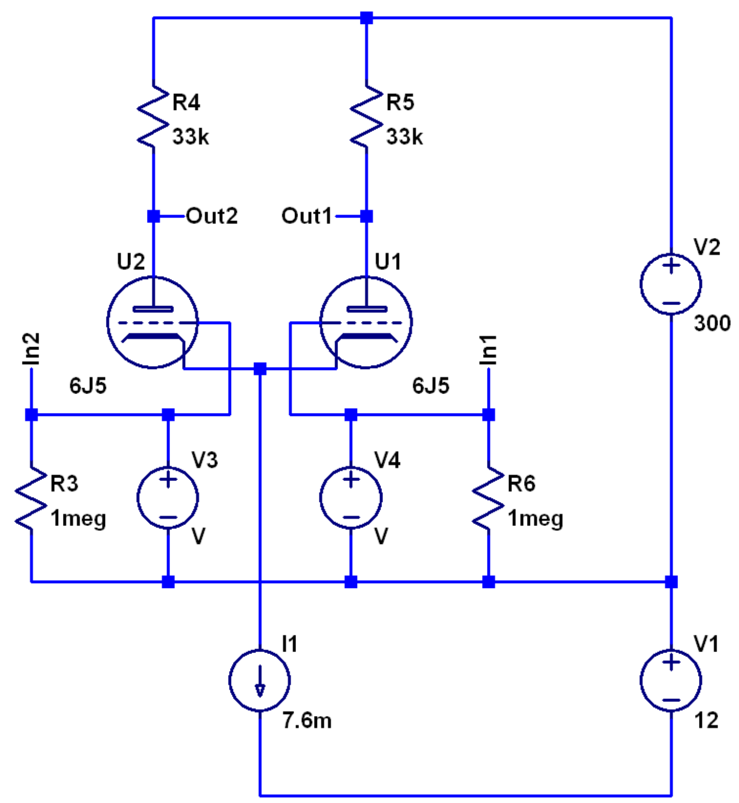


Long-tailed pair assumptions

- Perfect constant current sink in the tail
- Perfectly matched amplifying devices
- Perfectly matched loads
- No stray capacitances or leakage resistances

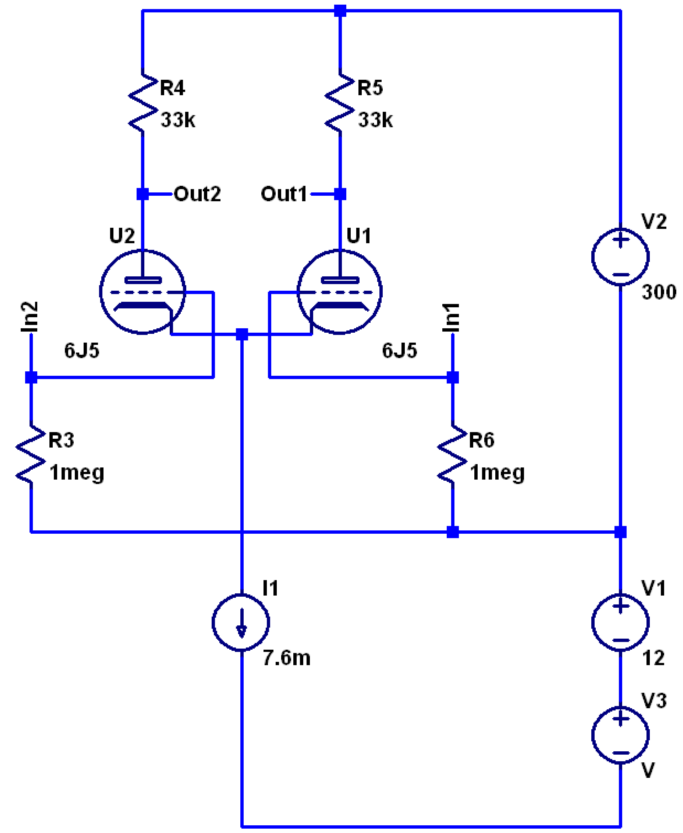
CMRR
(Common Mode Rejection Ratio)

- Apply identical hostile signals to both inputs (V3, V4)
- CCS voltage tracks hostile signal, leaving both V_{gk} unchanged
- Perfect rejection



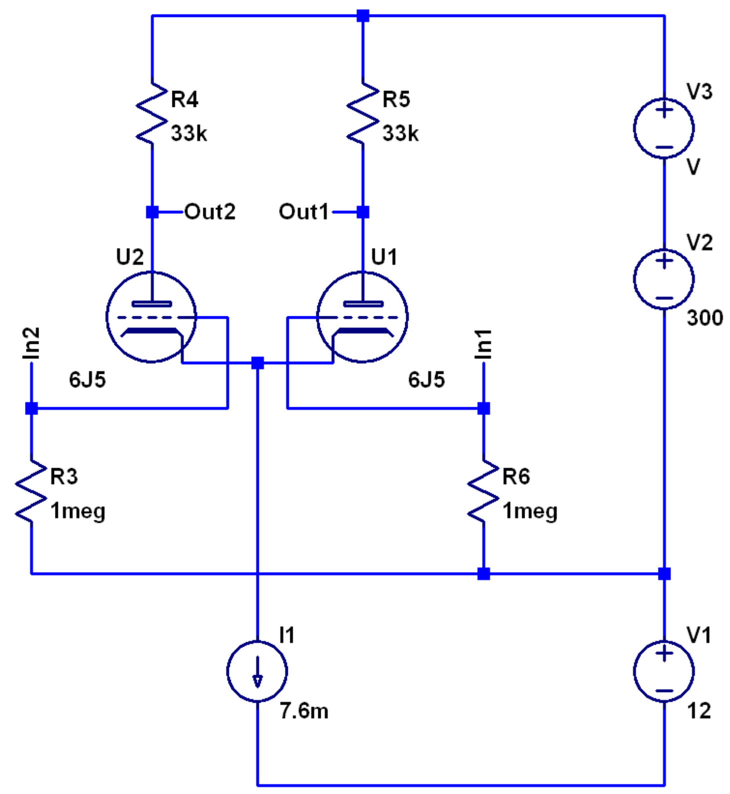
-PSRR
(negative Power Supply Rejection Ratio)

- Apply hostile signal (V3) in series with negative rail
- Hostile signal is in series with constant current source, but I_k is unchanged
- Perfect rejection



+PSRR (1)
(positive Power Supply Rejection Ratio)

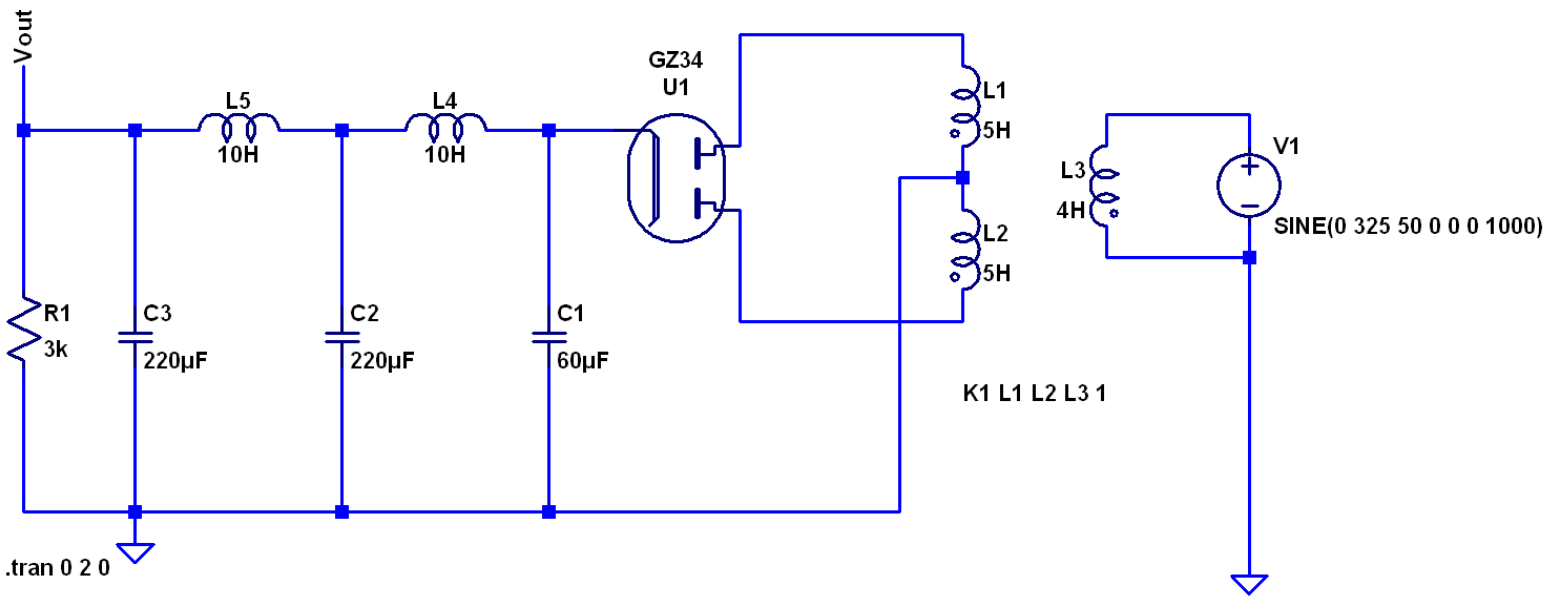
- Apply hostile signal (V3) in series with positive rail
- CCS enforces constant I_k (and therefore anode current)
- $V_{Out1} - V_{Out2} = 0$
- Perfect rejection?



+PSRR (2)
(positive Power Supply Rejection Ratio)

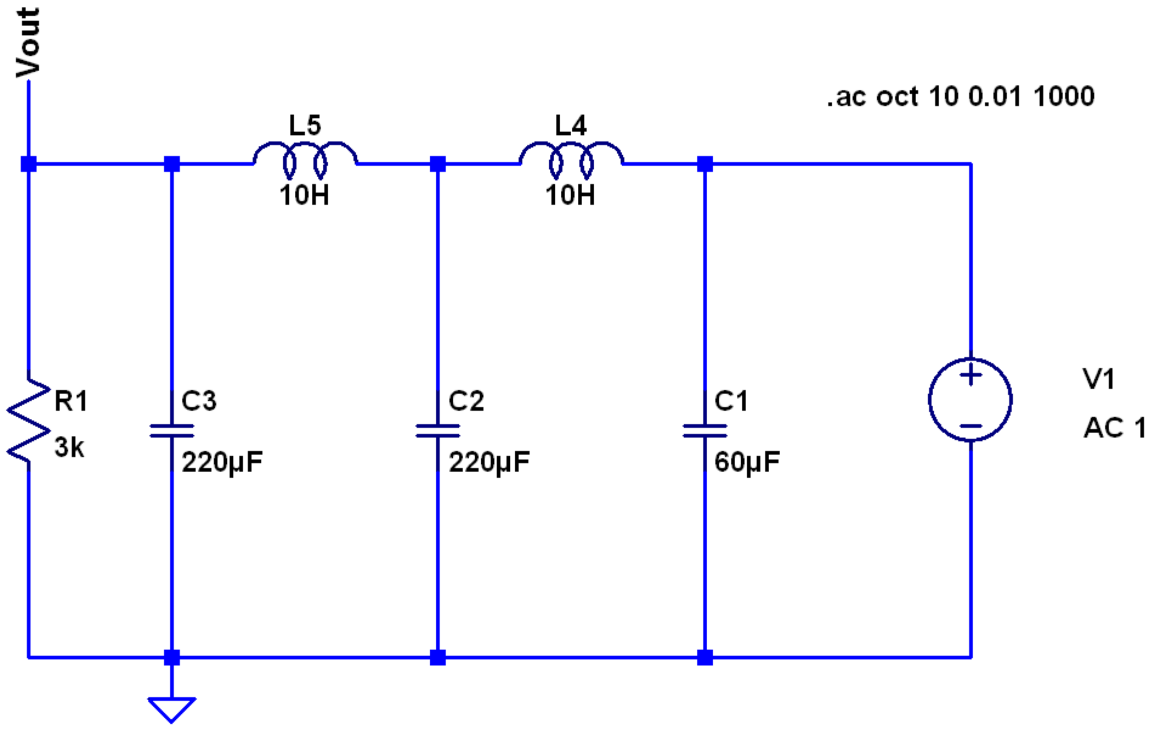
- The CCS forces constant current through each anode resistor
- If current is constant, the voltage dropped across each resistor must be constant
- If the voltage dropped across each resistor is constant, the full hostile voltage must be at each anode (despite $V_{Out1} – V_{Out2} = 0$)
- **Zero** rejection

Classical 300V HT supply



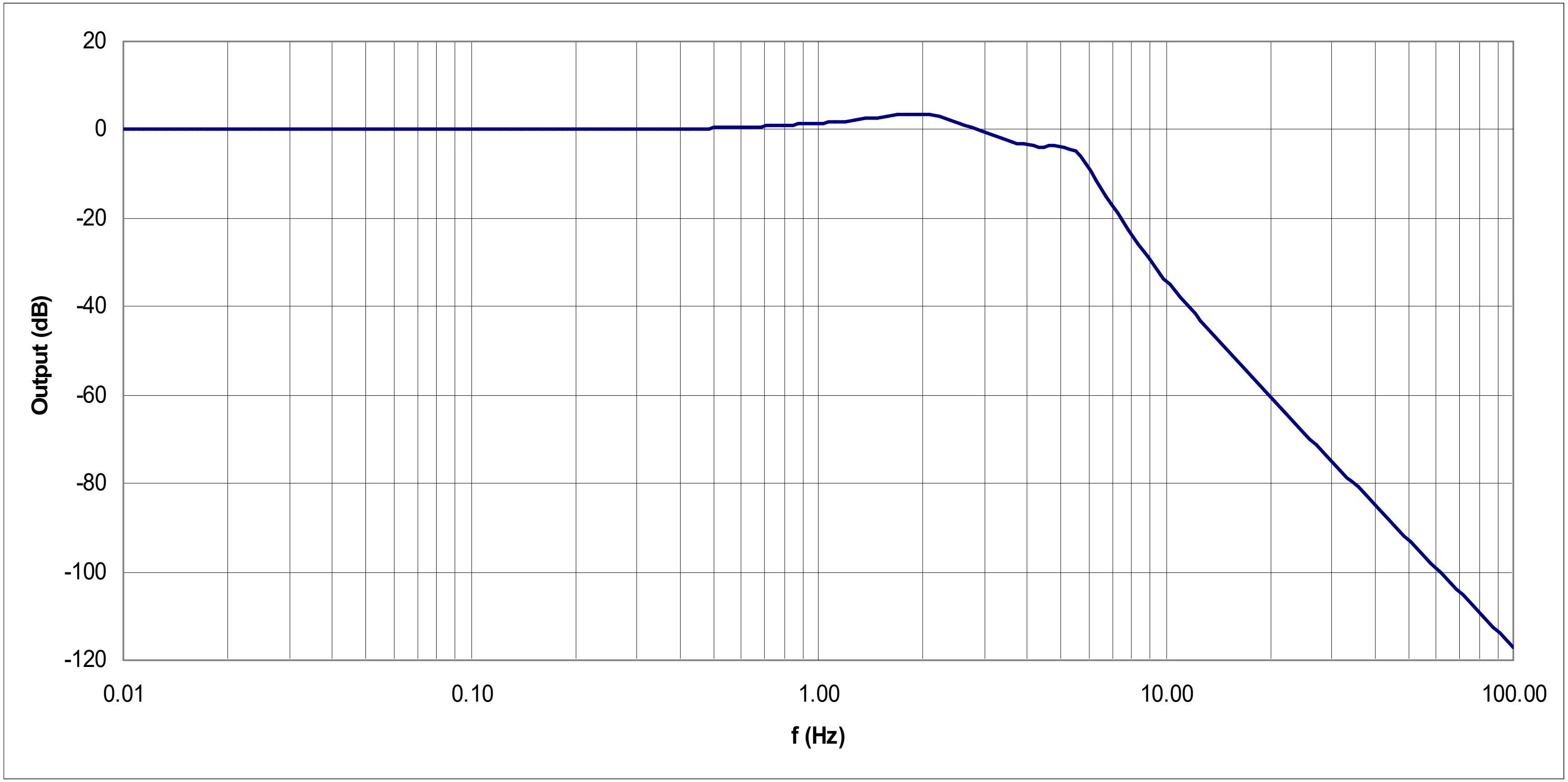
Filter rejection

- We can use SPICE to investigate rejection as a function of frequency



Filter output against frequency

(+3.5dB at 1.9Hz, -117dB at 100Hz)

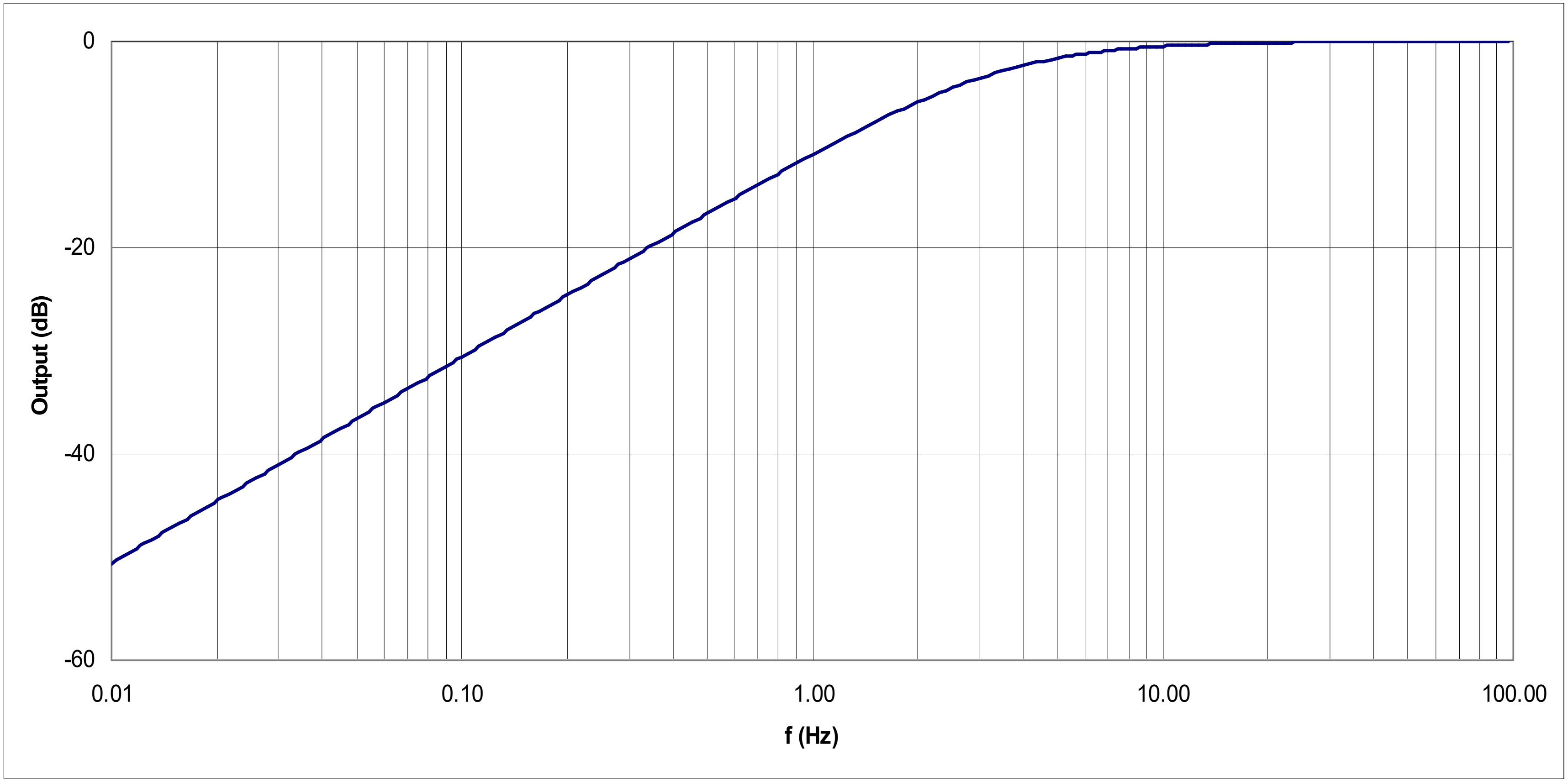


Mains voltage

- European mains voltage is $220V_{RMS}$ ± 10%
- Short-term variation is much smaller, perhaps only ±1%
- But 300V ± 1% is $6V_{pk\text{-}pk}$, and the long-tailed pair has zero rejection to each output
- For a 10W EL84 amplifier, $V_{gk} \approx 11V$, so $6V_{pk\text{-}pk}$ is -11dB referred to full power

Capacitor coupling to the output stage

(100nF to 470kΩ, f_{-3dB} = 3.4Hz)



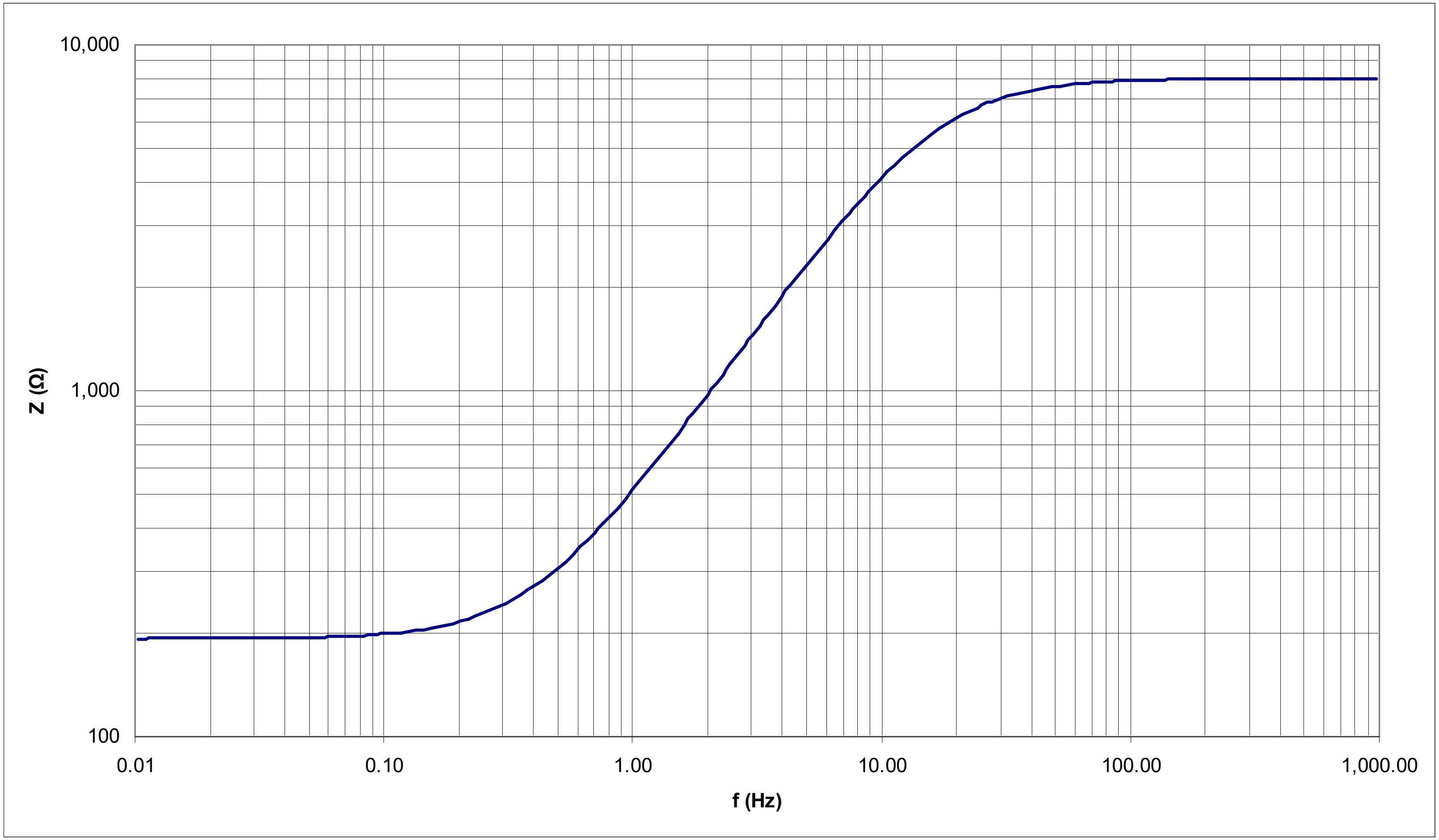
Capacitor choice (τ)

- Low frequency amplitude response
- Stability of feedback amplifiers
- Low frequency distortion (feedback factor)
- Loudspeaker bass alignment (reduced feedback increases output impedance)
- Output stage blocking
- Example attenuated by 20dB at 0.3Hz

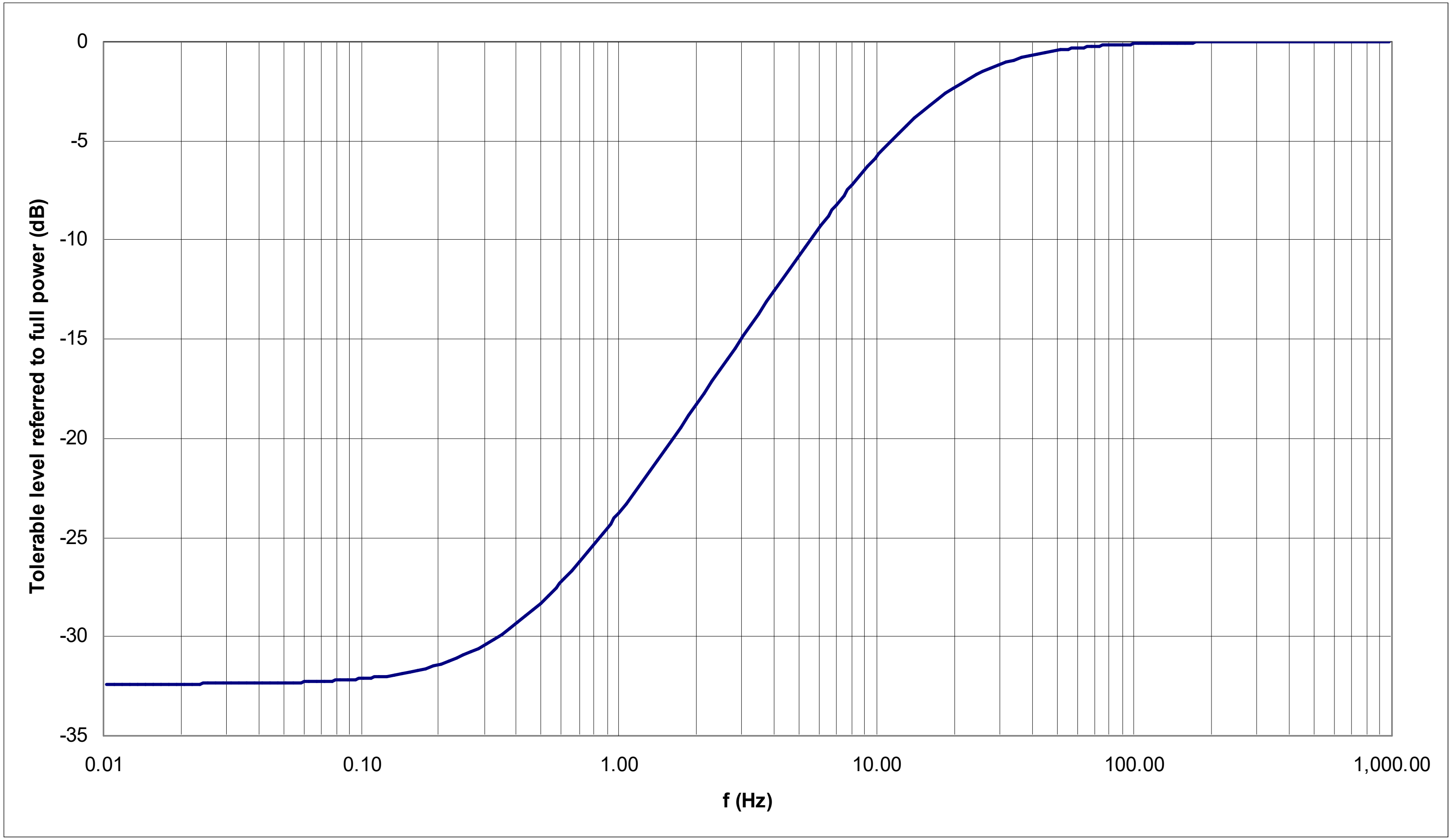
The output transformer

- The output transformer matches the load to the output stage (and removes DC).
- Example $8k\Omega_{a\text{-}a}$ is the load seen between the anodes when the secondary is loaded by the stated resistance
- But that reflected impedance is shunted by primary inductance (≈80H for Hammond 1608)

Modelled primary impedance of loaded Hammond 1608 output transformer



Tolerable level from push-pull EL84 driving loaded Hammond 1608



Conclusions so far

- At each anode, the long-tailed pair has zero +PSRR
- A passively filtered HT supply has zero rejection of frequencies <3Hz
- 1% mains variation represents low frequency noise at -11dB (ref. full power)
- Capacitor coupling example attenuates hostile noise by 20dB at 0.3Hz
- At 0.3Hz, the output stage overloads on signals larger than -30dB (ref. full power)

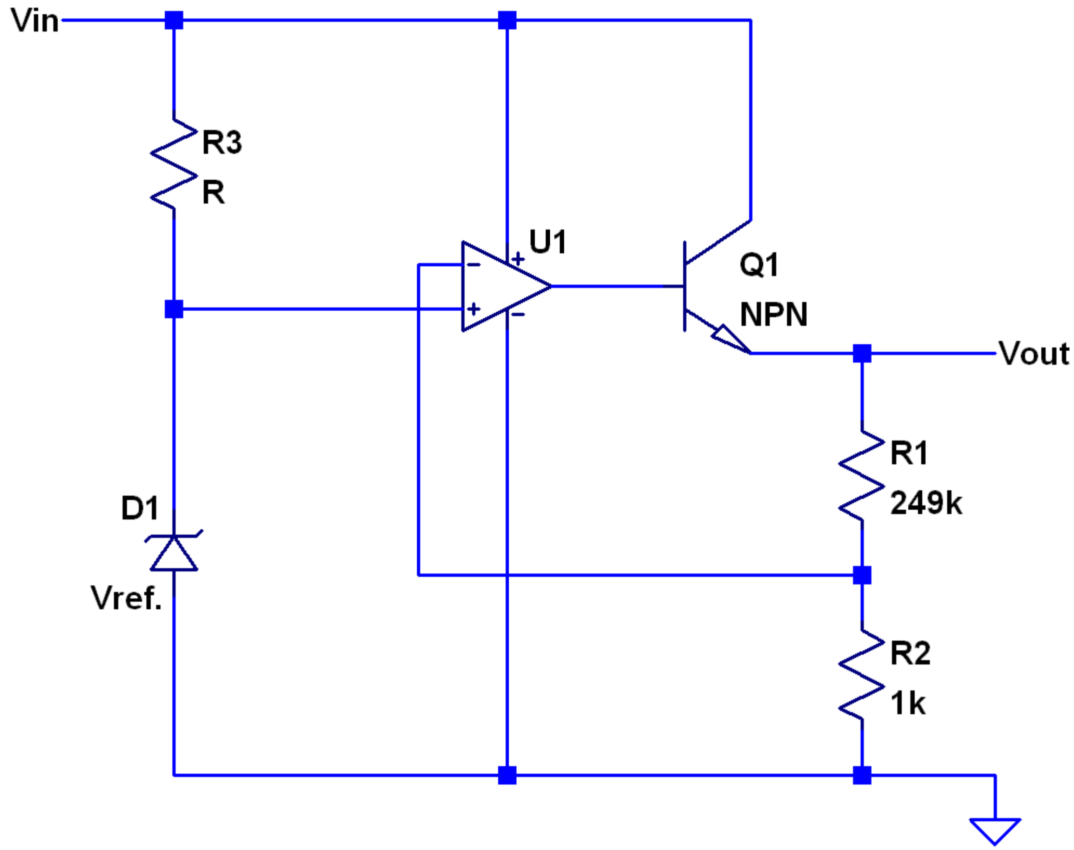
Solutions

- Listen late at night (less mains variation)
- Traditional designs reduced value of coupling capacitor
- Regulate HT to long-tailed pair

Regulators

- Most regulators are a non-inverting op-amp fed by a voltage reference ($V_{ref.}$)
- If $V_{ref.}$ = 1.2V (as in 317 etc.), then to obtain 300V, the gain must be 300/1.2 = 250

Simplified feedback regulator



1/f noise

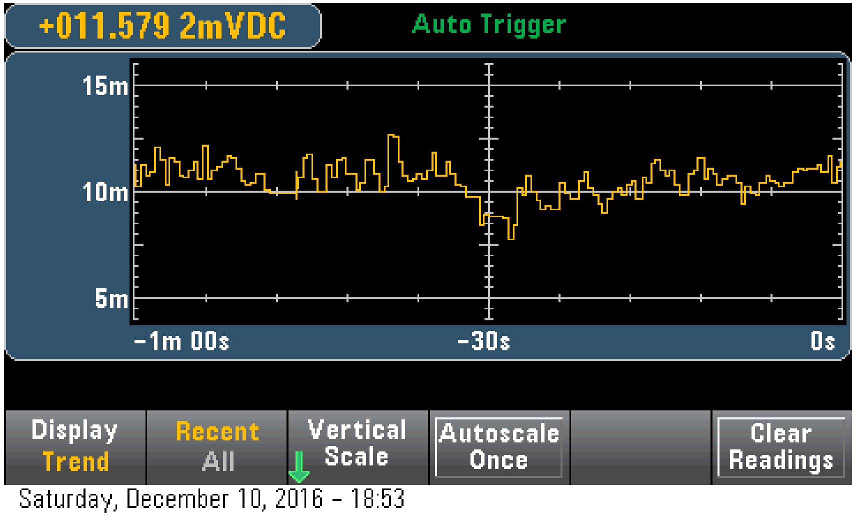
- All voltage references produce 1/f noise
- Feedback regulators add a speed-up capacitor to reduce gain >100Hz
- Feedback regulators have the same gain at 1Hz as at DC, so they apply full amplification to 1/f noise from $V_{ref.}$ and their error amplifier
- Make $V_{ref.}$ large to reduce noise gain

275V regulators

- Traditional valve regulator: Big, techno-pretty, hot, based on 85A2 neon reference. Noisy (≈$0.5mV_{RMS}$ 20Hz – 20kHz, jumps, 1/f)
- Maida regulator: Small, fragile, based on 1.2V reference voltage. Noisy (≈$3mV_{RMS}$ 20Hz – 20kHz, less 1/f noise)
- Statistical regulator: Smallish, provably more robust than Maida, 49 x BZX55C5V6 Zeners. Quiet (≈$0.01mV_{RMS}$ 20Hz – 20kHz)

275V Statistical regulator 1/f noise

- 49 x BZX55C5V6
- Differential voltage measured between two chains using Agilent 34461A 6½ digit DVM
- ≈ $5mV_{pk\text{-}pk}$
- Implies ≈ $3mV_{pk\text{-}pk}$



Conclusions

- Mains voltage variation wastes output stage current, thereby distorting the (wanted) audio signal – more noticeable in small amplifiers
- Regulated HT protects against mains voltage variation, but all regulators produce 1/f noise
- A Statistical regulator is quiet
- I had to find out why it made such a big audible improvement to my Bulwer-Lytton 4W amplifier

Questions?