Why do tube amplifiers have fat sound while solid state amplifiers don't

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Oct 21, 2011

Summary

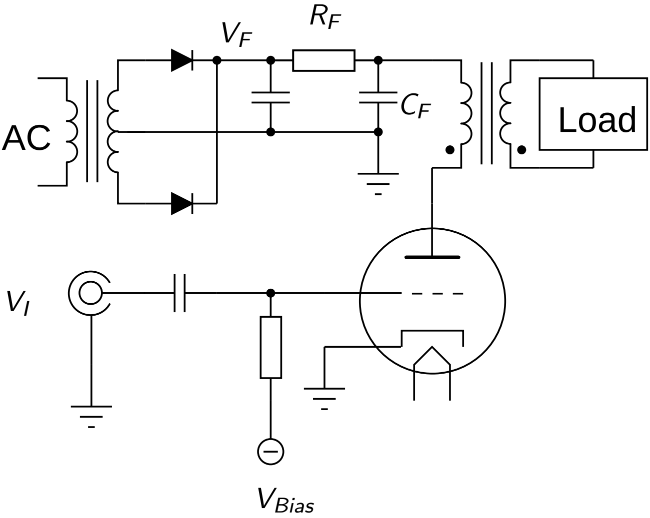
- Tube amplifiers have:
  - "Fat sound": "warm", "clean", "soft", "smooth", "fat", "detailed", "euphonic" ...
  - "Vivid sound": "euphonic", "life like", "vivid" ...
- I show tube amplifiers are speaker cone excursion soft limiters, due to output transformer core nonlinearity
- High frquency signal is not affected by transformer nonlinearity, even when superposed with low frequency signal with excessive amplitude
- I think it can explain "fat sound"
- It calls for validation from listening tests

How the Poster is Organized

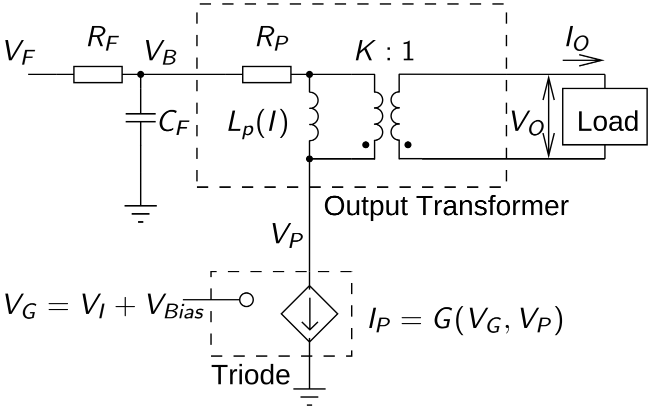
- Part 1. Simulations show tube amplifiers are speaker cone excursion soft limiters
- Part 2. Block diagram manipulation relates tube amplifiers to existing soft speaker cone excursion limiters
- Part 3. Experiments

Part 1, Simulations show tube amplifiers are speaker cone excursion soft limiters

A typical SET amplifier



Equivalent Circuit of the Typical SET Amplifier

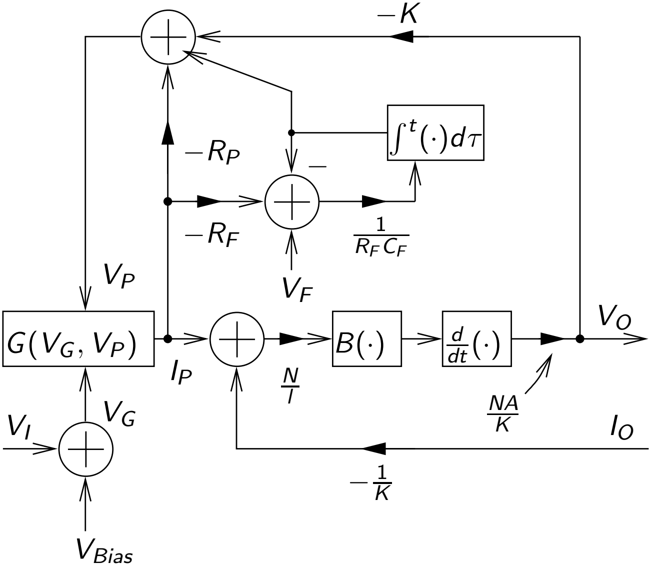


Equations describing the Equivalent Circuit

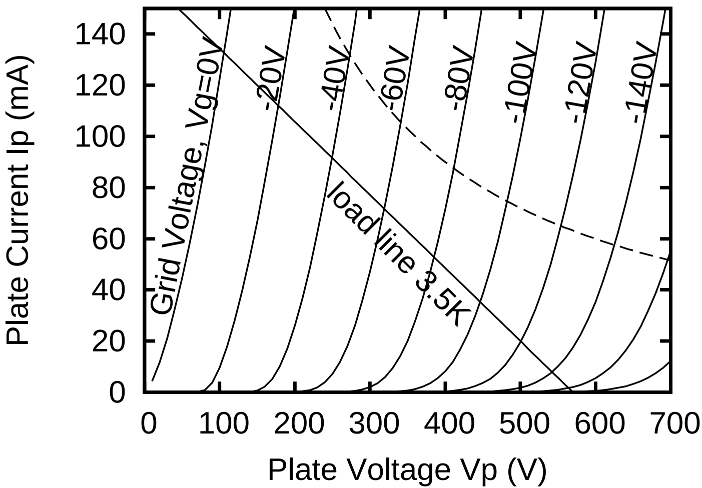
$$
\begin{aligned}
V_B &= \frac{1}{C_F}\int^t \left(\frac{V_F - V_B}{R_F} - I_P\right) d\tau \\
I_P &= G\left(V_I + V_{Bias}, V_B - KV_O - I_P R_P\right) \\
V_O &= \frac{N}{K}\frac{d}{dt}(-\Phi) = \frac{NA}{K}\frac{d}{dt}B\left(\frac{N}{l}\left(I_P - \frac{I_O}{K}\right)\right)
\end{aligned}
$$

- $B(\cdot)$ is core $B(H)$ function
- A is the area of the core
- N is number of turns of primary winding
- l is the length of the magnetic path

Equivalent Block Diagram Derived from the Equations



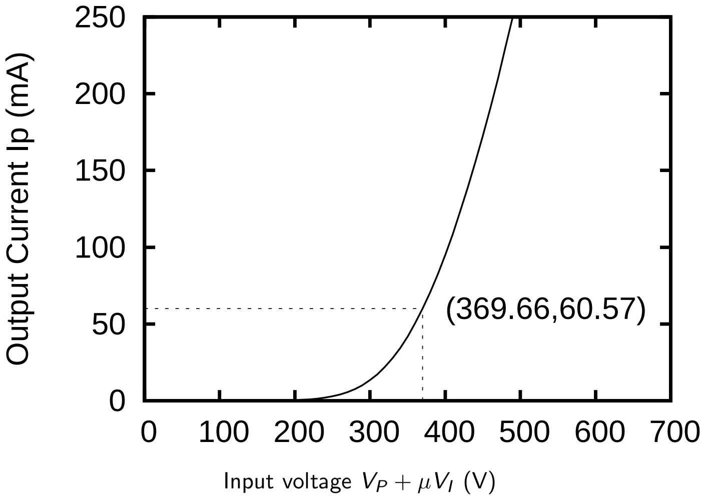
The Function $I_P = G(V_G, V_P)$ of 300B Tube



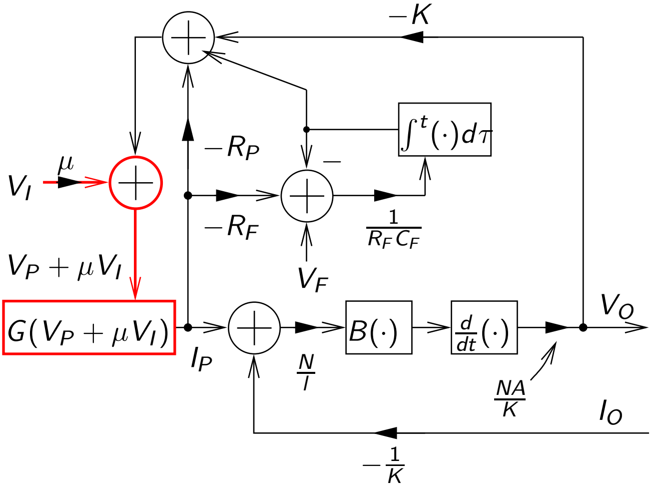
Function $I_P = G(V_G, V_P)$ Can Be Simplified

- The curves with different V_G's are approximately parallel
- It is unlikely that the triode will operate near bottom left corner
- Thus the curve can be simplified (depicted in next Figure).
- An operation point $(369.66, 60.57)$ is shown.

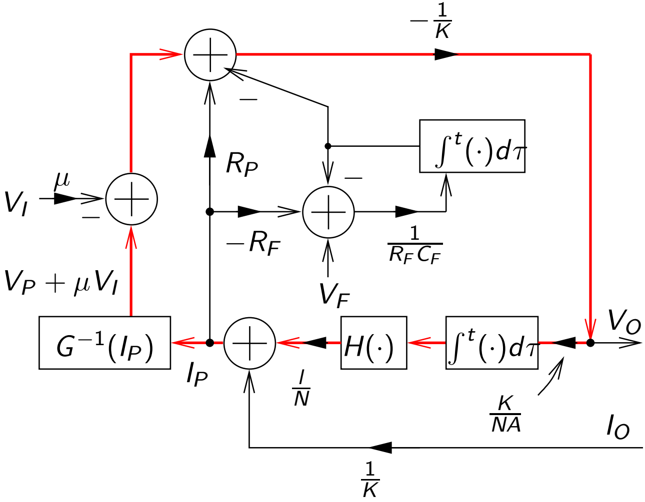
$I_P = G(V_G, V_P)$ Simplified to $G(V_P + \mu V_I)$



Equivalent Block Diagram Simplified

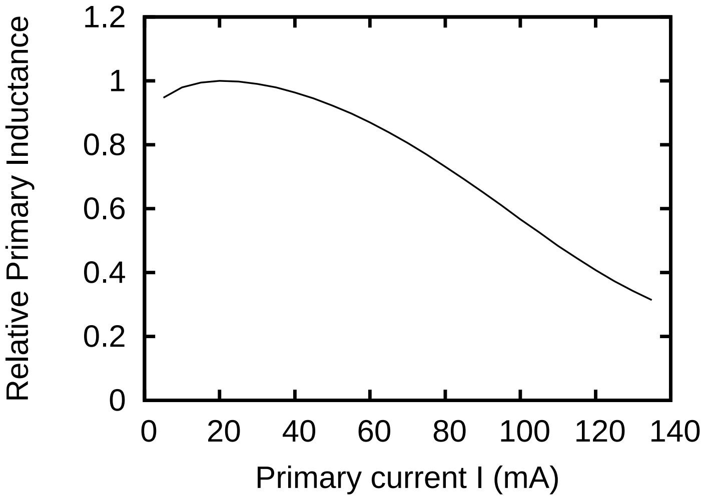


Equivalent Block Diagram w/ a Big Loop Reversed

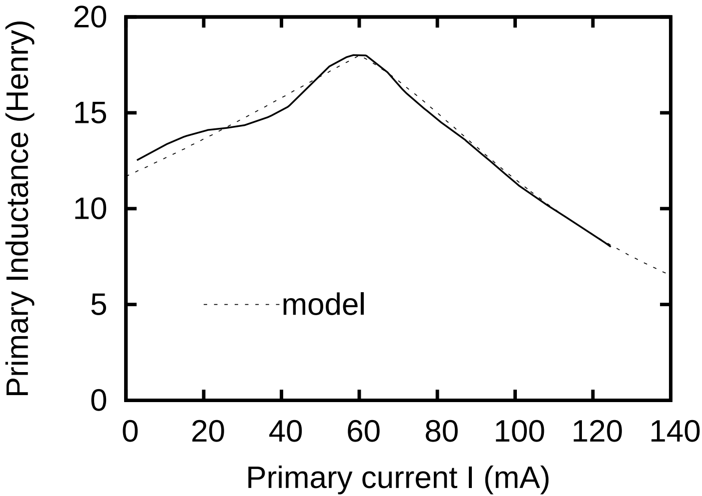


Refer to Shengchao li, "Loop Reversal Technique in Block Diagram or Signal Flow Graph Manipulation", unpublished technical report, 2011

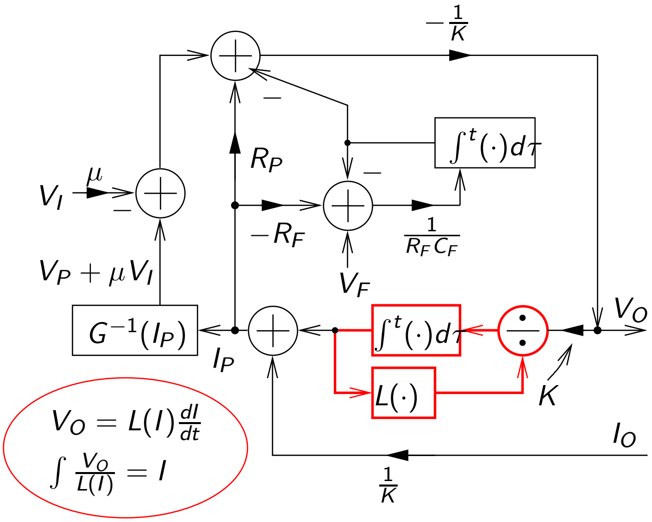
Measured relative inductance of transformer A



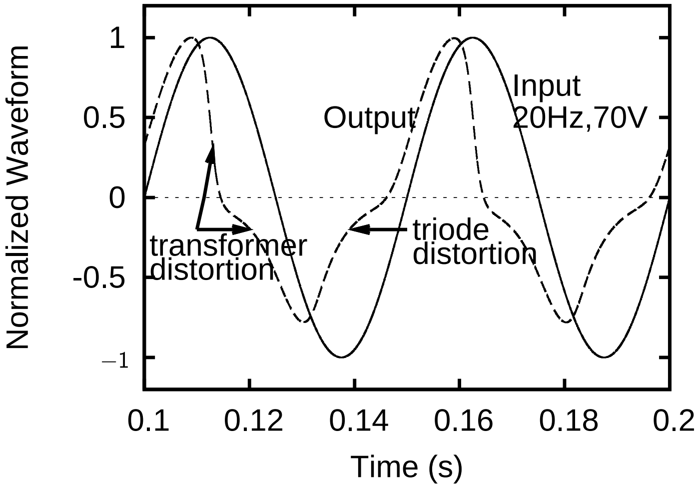
Measured relative inductance of transformer B



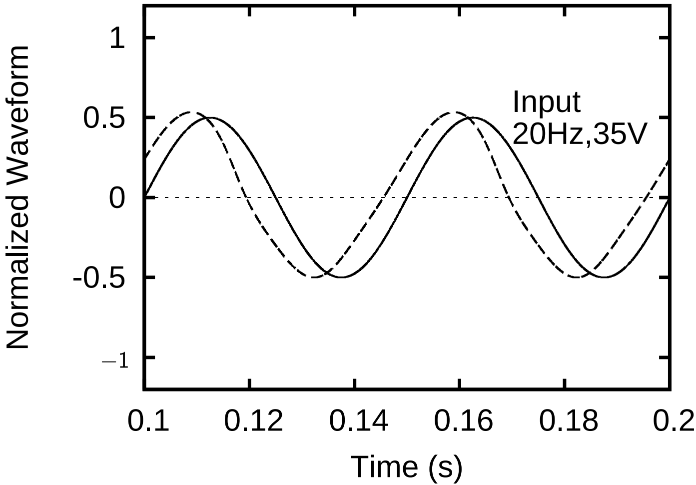
Can Simulate with the Inductance Curve Directly



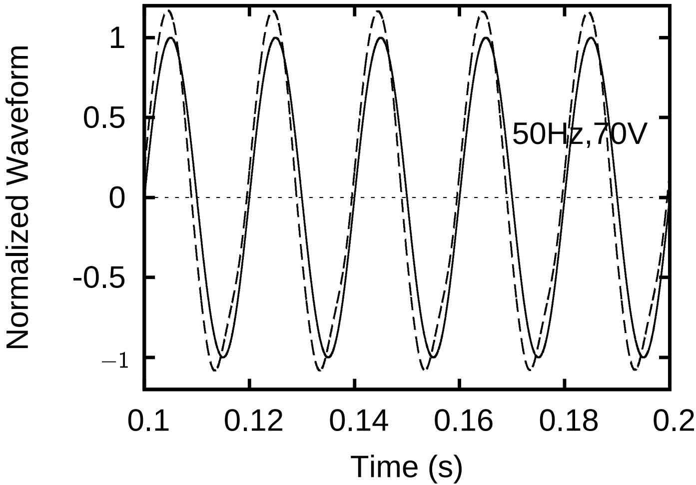
V_O v.s. V_I with low frequency input signal with excessive amplitude: Speaker Cone Excursion Softly Limited



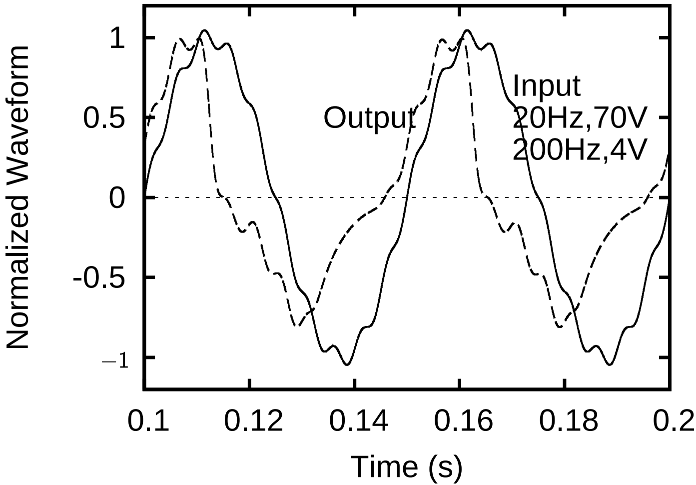
V_O v.s. V_I with low frequency input signal with moderate amplitude: No or little soft limiting



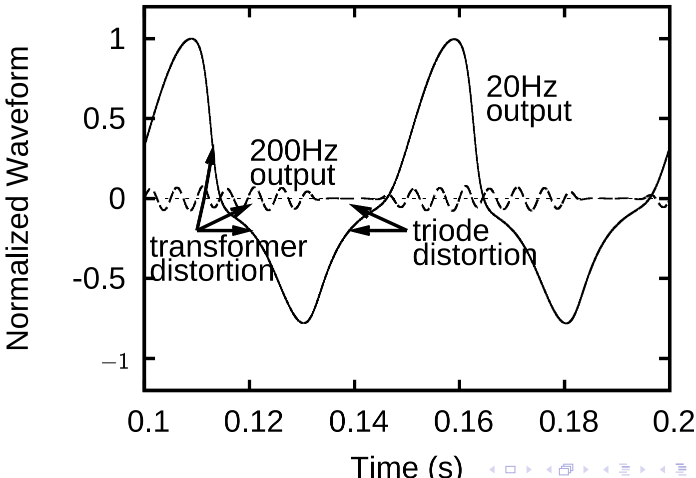
V_O v.s. V_I with moderately high frequency input signal with high amplitude: No or little soft limiting



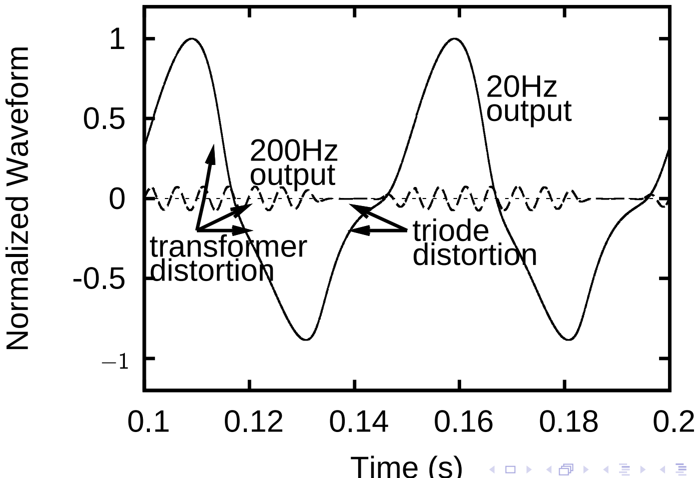
V_O v.s. V_I with input signal having both low and high frequencies



Transformer A, low and high frequencies separated for clarity, Speaker Cone Excursion Softly Limited, high frequency not affected by transformer distortion



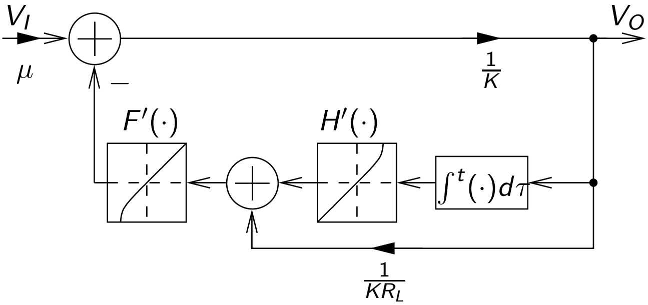
Transformer B, low and high frequencies separated for clarity, Speaker Cone Excursion Softly Limited, high frequency not affected by transformer distortion



Part 2, Tube amplifiers are related to existing speaker cone excursion soft limiters

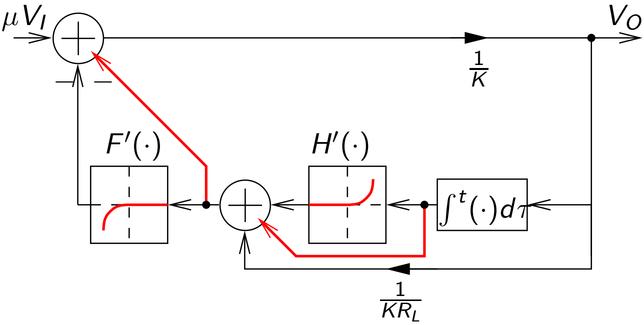
Simplified block diagram

- No power filtering (Assume perfect power supply)
- Non-linear functions approximated with linear and non-linear parts



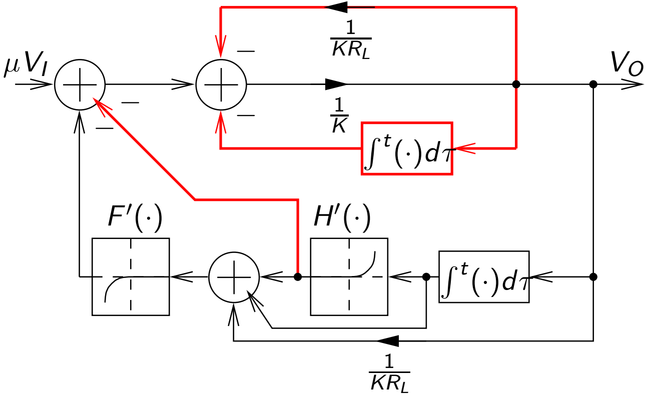
Block Diagram Manipulation...

- Split out linear parts from nonlinear functions



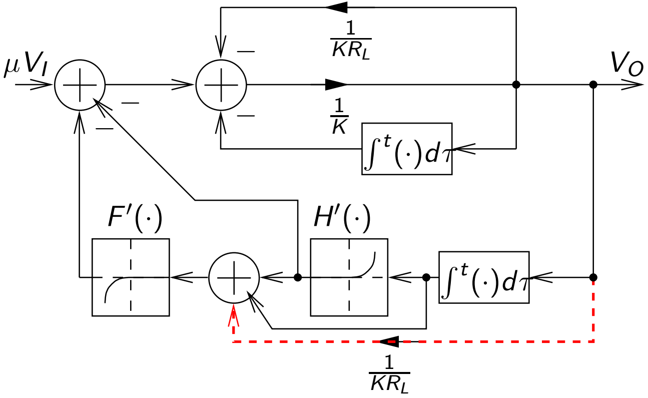
Block Diagram Manipulation...

- Reorganize junctions



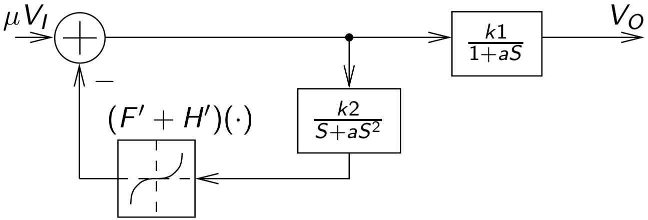
Block Diagram Manipulation...

- Further simplified by removing the speaker feedback
- One example is with interstage transformers



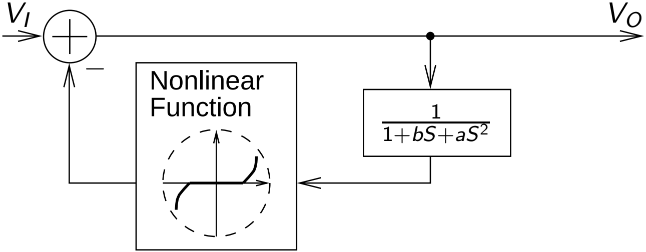
Block Diagram Manipulation...Done

- Combine functions
- How is it compared to the next figure?



Klippel's speaker protector

- This one is typical, other speaker corn excursion limiters exist

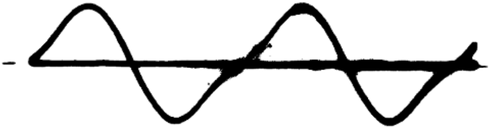


Part 3, Experiments

Block Diagram Manipulation...Done

- Compare Simulation with SET (Mostly done)
- Compare circuit based on block diagrams with SET (Current)
- Listening test to compare Simulator, SET, and Circuit (Future)

photos of SET outputs



photos of SET outputs