Audio Power Amplifiers

History and design of the audio amplifier

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Early High Quality Sound
The Loftin-White amplifier

The Loftin-White circuit as it was published in Radio News issue January 1929
POWER OUTPUT SYSTEMS

A Paper delivered before the New South Wales Division of
The Institution of Radio Engineers, Australia, at Science
House, Sydney, on December 3, 1936.

by
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FIG. 1

FIG. 2

FIG. 3

FIG. 4

6C6

42

6C6

42

6C6

42

6C6

2A3

2A3

2A3

2A3
A 1937 vacuum tube feedback circuit designed by Frederick E. Terman, using current feedback to the low impedance input cathode (adapted from Reference 2).
A 1941 vacuum tube feedback circuit using current feedback

Adapted from: Stewart E. Miller, “Sensitive DC Amplifier with AC Operation,” Electronics, November 1941, pp. 27–31, 105–109
1947 Earlier Williamson

Amplifier employing voltage feedback from the secondary of the output transformer, with push-pull triodes. The amplifier is virtually distortionless up to an output of 11 watts, and has a smooth overload up to 16 watts.
Loop gain and phase-shift characteristics of Williamson main amplifier
1949 Williamson amplifier
1949 Basic principles of McIntosh Amplifier
1949 Complete 50 watt McIntosh amplifier
Quality Sound 1950s
1949 The Leak TL12
1952 The Quad amplifier
1957  Baxandall’s simple amplifier
Circa 1959  Mullard 20W amplifier
### Comparison between Triode, Pentode and Distributed-load Operation of EL34s

<table>
<thead>
<tr>
<th>Valve</th>
<th>Mode of Operation</th>
<th>Total Distortion (%)</th>
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<tr>
<td></td>
<td></td>
<td>10W</td>
</tr>
<tr>
<td>EL34</td>
<td>Triode connection</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Distributed load</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(a) 20% common winding</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>(b) 43% common winding</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>Pentode connection</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Circa 1959 Mullard 3-3 (3 valves and 3 watts)
Circa 1959  General Electric  Class AB2  600-1100 watt amplifier.
Guitar Amplifiers
FENDER “DELUXE” SCHEMATIC
MODEL 26

“Woodies” 1946
Circa 1950's
Early Solid State Amplifiers
Hearing-aid circuit.

Circa 1953
Circa 1954  30 Watts

Fig. 8.11  High-power amplifier.

A Special medium-power transistors.
B Special high-power transistors.
Circa 1958
Transformer coupled amp
4.5-W sliding-bias output stage designed by Pawling and Tharma (based on Mellard Technical Communications, Vol. 4, No. 31). The original OC16 has been replaced by OC26.

Sliding-bias Amplifier. Wireless World May 1962
“Modern” Solid State Amplifiers
Circuit of complete power amplifier. The transistors used are: $T_{r_1}$—40361 (R.C.A.); $T_{r_2}$—BC109 (Mullard); $T_{r_3}$—40362 (R.C.A.); $T_{r_4}$—BC107 (Mullard); $T_{r_5}$—BC125 (Fairchild); $T_{r_6}$—40361 (R.C.A.); $T_{r_7}$—MJ481 (Motorola); $T_{r_8}$—BC126 (Fairchild); $T_{r_9}$—40362 (R.C.A.); $T_{r_{10}}$—MJ491 (Motorola). Note that $C_7$ is a reversible electrolytic and could be made up of two 4000-$\mu$F polarized electrolytics connected ‘back-to-back’. 

+30V supply at 800mA max.

* Non-inductive or very small diameter

* Returns 20s.w.g. enamelled wire 1/2 dia. former, random wound (not critical)

*0V

-30V supply at 800mA max.

1968 Bailey
April 1969  Linsley Hood  Class A  10 watts
1975 Marshall Leach. Low TIM amplifier
Circa 1975  Quad current dumping amplifier concept.
1977 Siliconix VMOS power FET amplifier.
Gain and Distortion vs Frequency
1986  G.J. Cohen
Prototype MOSFET amp for Adelaide Festival Centre (FESMOS)

Hinged upright for service
1993  D. Self  Current displacement amplifier
“Other“
Amplifiers
Class D operation
1993  G.J. Cohen
Transmission line transformers. AES Preprint 3692
1995  G.J. Cohen
Dual Single Ended Amplifier.  AES Preprint 4028

Linear Output
Current
Test Circuit
1995  G.J. Cohen
Dual Single Ended Amplifier.
(Showing Distortion Reduction)
1995  G.J. Cohen
Dual Single Ended Amplifier.
(Showing Distortion Reduction)
Bipolar Characteristics

Ic (amperes)

100°C

20°C

+Vb (volts)

0

0.5

1.0
MOSFET Characteristics
Voltage Output Amplifier

Current Output Amplifier

2010 E. Merilainen
Current Driving of Loudspeakers
2011 G.J. Cohen
Valve - FET Amplifier
1943 Zenith Hearing Aid Amplifier
2012 G.J. Cohen   Headphone Amp
Early High Quality Sound

- Possibly earliest famous amp.
- Direct coupled
- Pentode input, Triode output
- Minimum Components

- Pentode silvering from getter
- Triode: solid metal anode
- Half wave rectifier with mesh anode

- F. Langford Smith presentation
- Pentode input stage
- Triode and Pentode outputs
- 1936 designs common in radios

- F.E. Terman design 1937
- Pentode input, Triode output
- Current feedback to I/P cathode
- Forerunner of later designs
- Direct coupled push-pull design
- Neon tubes for voltage shift
- Current feedback
- Voltage and current output also used for analog computing

- Early Williamson design 1947
  - Triode connected P-P 807's
  - DC coupled input stage
  - Minimal coupling capacitors

- Wide response with no feedback
- Well designed output transformer
- Smooth response with feedback
- Controlled phase shift with feedback

- Later Williamson design 1949
  - Triode connected push-pull KT66's
  - Extra compensation on input anode
  - Extra power supply filter choke

- Bifilar and Trifilar windings
- Screen grids connected to op. anodes
- Cathode windings
- Driver transformer for large swings

- Also 600 ohms from cathodes
- Fixed bias (maximum output)
- P-P feedback from cathodes
- Preamplifier built in
Quality Sound 1950s

- Triode connected KT66's
- "Long tail" phase splitter
- Single pentode input stage
- Compensation on feedback

- Pentode connected KT66's
- Cathode windings
- Unique Pentode phase splitter with screen grids coupled

- Pentode connected EL84's
- Heavy decoupling of output screens
- Feedback from extra tap on O/P T/F
- DC Coupling of I/P with compensation

- "Ultra Linear" connected O/P stage
- Pentode input stages DC coupled to phase splitter
- Minimal coupling capacitors

- "Ultra Linear" or distributed load
- Triode: low power, low distortion
- Pentode: max power, max distortion
- 20% common. winding:- better
- 43% common. winding:- best
- Input Pentode, starvation condition
gives maximum gain
- Both stages DC coupled
- Class “A” operation, 3 watt output

- Class “AB2" operation
- All stages triode connected
- Driver T/F because of grid current
- Equal turns on driver pri & sec with coupling caps. from cathodes to grids

Guitar Amplifiers

- Fender, “first” amplifier for guitars
- ”Woodies” due to polished cabinets
- Input mixing stage, simple splitter
- No Feedback gives soft overload

- Marshall, later & high power
- More complex
- Vibrato/tremelo added

- Vox, later design
- Also complex additions
- Some small sized models
**Early Solid State Amplifiers**

- Brattain, Bardeen & Schockly invented the transistor in December 1947 at Bell Labs.

- Germanium PNP Transistor 1953
- Interstage coupling transformers
- Four only capacitors of same value
- Two of 1.5 volt batteries (+/- supply!)

- High power (30W) Germanium power
- Grounded base stages, except input
- due to poor response of devices
- Therefore coupling transformers

- Germanium with better freq. response
- Common emitter stages
- Still transformer coupled
- High gain, no feedback
- Commonly used in “Tranny” Radios

- Class “A” low to high bias O/P stage
- Bias increased for higher average signal. i.e. Low average dissipation
- Possibly for radio comms use

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**“Modern” Solid State Amplifiers**

- Germanium with better freq. response
- Common emitter stages
- Still transformer coupled
- High gain, no feedback
- Commonly used in “Tranny” Radios

- Class “A” low to high bias O/P stage
- Bias increased for higher average signal. i.e. Low average dissipation
- Possibly for radio comms use
- Early use of symmetrical voltage rails
- Early use of overload protection
- Early bias compensation on input
- Symmetrical output stage and Zobel network

- J.L. Hood 10 watt Class “A”
- NPN output transistors only
- Very high frequency driver transistors so loop gain less than unity at 180°
- No crossover distortion

- Low transient intermod. distortion
- Fully complementary-symmetry
- D.C. coupled
- 20dB or less feedback
- RFI input protection

- Single ended input current switched to P-P output current in class “B”
- Bipolar transistor true LOG operation
- Thermal tracking of this function

- QUAD unique current dumping amp.
- Class “A” at low level & Class “B” at high levels via feedback paths
- The four feedback components are a frequency dependant balanced bridge

- Quasi-complimentary N-Channel VMOS only available at this time
- Hence current mirrors used for drive
- Low feedback approximately 20dB
• Low distortion from 40Hz - 20kHz
• Open loop -3dB to 40kHz
• RFI input filter curve shown

• All FET design, used hybrid
• Single pole response (C1), gate cap.
• Modest feedback
• Balanced input

• Open loop -3dB to 40kHz
• Closed loop -3dB to ~150kHz
• Overall smooth response
• Response to DC. No coupling, feedback or bypass capacitors used

• Hybrids with minimal ext. components
• Used in FESMOS amplifiers
• Ease of servicing (replace hybrids)

• Prototype for FESMOS development
• 500 watts per channel
• Heatsink folds up for servicing
• 2RU for proto., Conv. cooling

• Bias current change with signal
• Similar but opposite to sliding-bias
• Question output current (bias) change under dynamic conditions
"Other" Amplifiers

- Class “D” efficient operation
- Uses pulse width modulation
- Low pass filter before speaker
- Possible radiation of switching noise

- Bifilar auto-transformer (No DC)
- Triode anode and cathode output
- Lower turns, tighter coupling
- Two floating power supplies

- 2 single ended Class “A” per channel
- Test circuit to generate current O/P to compare P-P, and 2 Class “A”, added

- Two single ended transformers showing some distortion reduction

- Individual waveforms approaching overload
- Combined waveforms
- Bipolar junction transistor curves
- Steep gradient due to high gain
- Has sharp turn-on for voltage drive
- Possible thermal run-away

- Field Effect Transistor curves
- Gentle gradient, lower gain
- Gradual turn-on
- Reduced current with higher temp.
- Zero temperature coefficient at “A” to “AB” transition

- Current drive to speakers
- Plus: holds current at resonance
- Minus: has low damping for transients
- Speakers are usually designed for voltage (low impedance) drive

- Valve input & driver with FET output
- Valves for voltage gain
- FETs for current gain
- Valve amp with no O/P transformer
- 2 coupling caps. Min. phase shift
- No bypass caps. in feedback path

- 1943 Hearing aid amplifier
- Valves developed for this in 1942
- Inbuilt mic. above clip for coat pocket
- Separate batteries and earpiece

- Output impedance setable from one ohm up to 120 ohms (DIN Spec)
- Valves are low distortion types