Analog and Telecomunication Electronics

Audio Amplifiers

An overview of the most commonly used class of amplifiers in audio applications.
SUMMARY

- Output stages: class-A, class-B, class-AB
  - Class-A schematic example
- Output stage: class-D
  - How it works
  - PWM circuit
  - Class-D topology
  - Efficiency
- Class-XD: Crossover Displacement
- References
To project a fully efficient and with very low distortion levels amplifier requires more than just some electronics basics.

Sometimes, to design and build an amplifier is considered even an art.
An audio amplifier is divided in a series of intermediate blocks defined ‘stage’.

The output stage, or ‘power stage’, is the one able to highly amplify the input signal in order to pilot a certain load (i.e. a speaker).

An output stage can be of multiple levels (single, double, triple, etc.), depending on the desired output.

The technology used to build the output stage depends on the designer choices: BJT, MOSFET, vacuum tubes, etc.
**OUTPUT STAGE: CLASS-A, CLASS-B, CLASS-AB**

- **Class-A**
  - Able to pilot for the entire signal’s period (360°)
  - Low output distortion
  - Current flows even when $V_{in} = 0$
  - Low efficiency (c.a. 25%)

- **Class-B**
  - Able to pilot for half the period of $V_{in}$
  - Uses two piloting devices
  - Current flows only when $V_{in} = 0$
  - Higher efficiency than Class-A (c.a. 78%)
  - Cons: crossover distortion

- **Class-AB**
  - Apply a constant voltage to the B-E junctions to remove crossover distortion
  - Obtained by using diodes or a more precise $V_{BE}$ multiplier
  - Both transistor always in conduction, but with low quiescent current
  - Efficiency slightly lower than B (almost 70%)

*In clockwise order*
- Class-A
- Class-B
- Class-AB
Death of Zen Class-A amplifier

It is necessary to apply a biasing voltage to output transistors to half of the power supply.
Earliest documentation regarding Class-D amplifiers goes back to 1930, in an article published in ‘63 by D. R. Birt in Wireless World, entitled ‘Modulated Pulse AF Amplifiers’.

First working Class-D amplifier design appeared in April 1965 in the same magazine.

Sinclair X-20: one of the first Class-D amplifier put in commerce
- THD around 5% (not very encouraging)
- Reason for high THD: use of bipolar transistor instead of MOSFETs
- With the introduction of MOSFET devices, Class-D became a really practical proposition for audio applications
Class-D: HOW IT WORKS

- Class-D does not operate in linear mode (as A and B did)
- Signal is modulated to generate a PWM (Pulse Width Modulation)
- The modulated signal drives the series of an NMOS and PMOS
- Output signal (which is still a modulated square wave) is filtered using an LC filter to reconstruct the amplified signal
CLASS-D: PWM CIRCUIT

- A very precise triangle wave samples the input signal, generating the actual PWM.
- Sampling → Nyquist theorem
  \[ f_{\text{triangle}} = f_s > 2B \]
- To reduce distortions, consider \( f_s \) much higher (5 to 50 times the signal bandwidth)
- Alternative: digital input (SP/DIF), Delta-Sigma modulator (reduces distortion)
CLASS-D TOPOLOGY

- Half-bridge: classic topology, higher efficiency when powered at \( \pm V_{DD} \)
- Full-bridge: twice the number of transistors, but removes the need of dual-rail supply

Left figure: half-bridge topology
Right figure: full-bridge topology
CLASS-D: EFFICIENCY

- Operating in ON-OFF condition, ideally the Class-D amplifier can reach 100% efficiency. This is not true.
  - In ON state, voltage drop on between Drain and Source is not zero; same goes for the current when in OFF state
  - Non-zero output resistance when MOSFETs are turned ON (which increases with the device’s temperature)
  - Intermediate resistance of MOSFETs when switching between ON and OFF (minimize parasitic inductance between Drain and Source)
  - Flyback pulses caused by inductive load (prevent with Schottky clamp diode between output and supply lines)
  - ‘Shoot-through’: both MOSFETs are in conduction.
- Efficiency can increase with an opportune filtering choice
  - Butterworth filter gives maximal flatness of frequency response
• Typical Class-D efficiency: up to 90%!
• TAS5261 from Texas Instruments (315 W on 4Ω mono channel)
Is it possible to create an amplifier that has the pure linear behaviour of a Class-A and the high efficiency of a Class-AB?

Crossover Displacement: move the zero-crossing position that causes the crossover distortion; while the output voltage keeps below this new crossover point, the behaviour of the amplifier will have the linear performance of the class A. If output goes higher this voltage level, the amplifier will perform as an optimal Class-B.

How to realize Crossover Displacement: adding a Displacer block between the output and the load, which sources/drains current from the positive/to the negative power supply.

Lower efficiency (between Class-A and B), but THD becomes almost nullified!

Developed by Cambridge Audio
REFERENCES