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Subject: Invention

Pulse Class A Audio Power Amplifier

Tutorial

A simplified schematic of a common and modern audio power amplifier is shown in Figure 1. Its front end is modeled by a voltage generator of input signal Vi (Volts). It provides current drive Ib (Amperes) to the bases of the NPN and PNP output silicon transistors. In turn, they supply output voltage (Vo) and current (Io) to the load/loudspeaker. Bias to the transistors is represented by the two batteries. It allows the transistors to conduct/idle collector current (Ic) versus be cut off (Ic = 0). A bias of ~ 0.6Volts is needed across the base to emitter junction of a silicon transistor to cause the onset of conduction. The bias polarity for the NPN transistor requires the base to be more positive than its emitter. The bias polarity for the complementary PNP transistor is the reverse. The bases of the two transistors are effectively tied together because the batteries have ~ zero ohms internal resistance. By universal convention, collector current (Ic) flows from the collector to the emitter of an NPN transistor, and vice versa for its complementary mate. The drive current (Ib) flows in the base of NPN and out of PNP as depicted in Figure 1. The base and collector currents are related by the amplification factor β according to the equation: Ic = β times Ib. Total emitter current (Ie) is the sum of the contributing currents Ib and Ic. The output stage of this type of amplifier has a voltage gain of one (i.e Vo = Vi) and a current gain ~ β for the condition of Ie approximately equals to Ic. (because Ib<<Ic for high β values). This output stage does not invert (flip upside down) the polarity/phase of the input signal as depicted pictorially by the color shading. Loop (global) feedback is normally taken from the output node to the amplifier's input to reduce distortions in the output signal and hence improve the overall performance of the amplifier.

Figure 2 shows a simplified schematic of another modern audio power amplifier. Its output stage has a current gain ~ β like that of Figure 1. However, unlike the latter its output stage has a voltage gain that is greater than one and it inverts the polarity/phase of the input signal as depicted pictorially. The magnitude of the voltage gain is roughly equal to R(load) divided by Re. As in Figure 1, loop feedback from the output junction of the loudspeaker to its input is also used here. The use of this configuration is not as common as that of Figure 1. Nonetheless, it is practiced in the commercial product made by Hafler Model # 9505/US Patent # 4,467,288 to James Strickland.

Modern power amplifiers are energized by dual power supplies as indicated by the plus and minus Vc batteries (e.g. +/-50 Volts). The mid-point of the two power supplies is called common or ground in Figure 1. The junction of the Re resistors in Figure 2 is used instead. Ground/common serves as a reference point for voltage measurements on the internal components of the amplifiers.

Figure 3 represents a model of the alternating input signal Vi. One sinusoidal cycle of an arbitrary 60 Hertz frequency is shown. It is a plot of the amplitude of the voltage drive (Y axis) to the transistors versus time (X axis). The X axis is also the common or the ground reference measurement point for the Y axis. Thus, the signal is positive in the time interval from 0 to 8.3 milliseconds and is later negative between 8.3 and 16.7 milliseconds.

The discussion below applies equally well to the amplifiers modeled in Figures 1 and 2. I'll only use the latter as the prior art working model because it is an easier and a more pertinent comparison with my invention.

The operation of the power amplifier in Figure 2 is as follows. First, establish/define a quiescent or idle collector current for the output transistors. Then, superimpose the input signal Vi on this idle state. Three different magnitudes of quiescent collector current can be enabled:

- Ic = 0. The transistors are cut-off and the operation of the amplifier is called Class B. This is effected by depriving the output transistors from bias voltage. Simply remove the bias batteries from Figure 2 and connect Vi to the junction of the transistors' bases.
- Ic = substantially large e.g. 2 Amperes. This is called Class A operation. A high bias voltage enables this quiescent state.
- Ic = a low level e.g. 0.1 Amperes. This is called Class AB operation and is derived from a bias level that is lower in magnitude than used in Class A.

Consider next the dynamic (with input signal) operation of the amplifier. As the input signal voltage increases from zero to its peak at +Vp, the following events happen/track it smoothly and concurrently:

- The NPN conducts more because this increasing positive signal augments and assists its positive idle bias.
- The PNP conducts less (i.e. moves toward cut off) because this increasing positive signal detracts from/cancels some of its negative idle bias. <u>This transistor must not cut-off at +Vp (i.e. at peak power output) for Class A operation</u>. Its initial high reservoir of quiescent/idle current comes at play here by preempting/counteracting the turn-off action of the positive input signal. If this transistor cuts off (Ic=0) at a Vx between zero and +Vp volts, then the operation of the power amplifier at that moment in time becomes Class B. The magnitude of its idle current was not enough to sustain Class A operation. The

net operation of the power amplifier between zero and +Vp in then called Class AB.

- The phase inverted and amplified output voltage tracks the input voltage. Since there is now a voltage difference across the loudspeaker (-Vo versus ground), the output current Io flows through the load as depicted in Figure 2.

As the amplitude of the input signal decreases from +Vp to zero, the reverse of the above happens (like the analogous chemical microscopic reversibility). The quiescent state of the amplifier is restored at 8.3 milliseconds like it was at time zero.

The operation of the amplifier during the forthcoming negative portion of the input signal is described in a similar way as above. As the input signal voltage now decreases from zero to -Vp, the following events happen/track it smoothly and concurrently:

- The NPN conducts less (i.e. moves toward cut off) because this increasingly negative signal detracts from/cancels some of its positive idle bias. <u>This transistor must not cut-off at -Vp (peak power) for Class A operation</u>. Its initial high quiescent idle current is the reservoir which preempts/counteracts the turn-off action of the negative input signal. If it cuts-off at -Vx between zero and -Vp, then the operation of the amplifier at this point in time becomes Class B. The net operation between zero and -Vp is then termed Class AB.

- The PNP conducts more because this increasingly negative signal augments and assists its negative idle bias.

- The phase inverted and amplified output voltage tracks input voltage. Since there is now a voltage difference across the load (+Vo versus ground), output current (Io') flows through it as depicted in Figure 2.

The reverse of the above happens as the amplitude of the input signal increases from -Vp to zero. The quiescent state of the amplifier is then restored at 16.7milliseconds like it was at time 8.3 and zero milliseconds.

Class A amplifiers are reputed/believed by their suppliers and customers to reproduce the most pleasing sound from loudspeakers compared with Class AB. The sonic excellence of Class A amplifiers is principally attributed to the absence of abrupt cut off in their output transistors. Class A amplifiers inherently dissipate a large amount of standby/idle power. For the above mentioned example, the standby power dissipated by the two output transistors equals 2 Amperes (Ic) times 100 Volts (+ and -Vc) = 200 Watts. This usually requires the use of multiple output transistor pairs for long term reliability. These transistors must be mounted on a heavy and large surface area heat sink so as to dissipate the heat which otherwise will destroy them. Their sonic performance is highest and so is their cost which is actually proportional to their weight. On the other hand, Class AB amplifiers idle at a lower standby power; e.g. 10 Watts for both transistors in the above mentioned example. This lowers substantially their material/production cost and makes them attractive to customers from the standpoint of low cost and a fully acceptable (but not best) performance.

Here are statistics from the October 1997 issue of Audio magazine reporting on the 40th Annual Equipment Directory. There were roughly 217 listed suppliers of power amplifiers. They offered ~ 1000+ unique transistor and vacuum tube models. Roughly, 18% of the amplifiers were Class A, 57% were Class AB, 0.7% Class B and the balance was a mix of Class H, G or unlisted. Class H and G embody "smart and variable (i.e. dynamic) dual power supplies" which efficiently manage the power dissipation of the output transistors (for reliability and more output power) working in either a low power Class A or AB modes. The data reflect a customer need for sonic excellence, low cost and (with) efficient/reliable operation.

Where's The Technical Problem?

- The bases of the transistors are "effectively" tied together in the prior art design(s).
- The input signal (Vi) is connected to the junction of the power output transistors' bases. It turns on and cuts off in a synchronous manner the transistors during Class AB operation.
- The output transistors cut off abruptly to cause and then add distortion to the output signal. This detracts from and compromises sonic excellence.

Prior Art Solutions

Past inventors have devised/found "clever" solutions to prevent the output transistors from cut off in Class AB audio amplifiers. Their objective was to make a Class AB or even a Class B amplifier sound/perform like that of Class A amplifier, but without its attendant high cost and added expense to operate. Examples of these solutions are grouped below under the broad topic of Dynamic Class A operation. As viable products, they have been accordingly advertised (but not as Class AB or B), for the purpose of competitive differentiation. This improved mode of operation has been called "sliding/dynamic bias". An example is US Patent number 3,995,228 to Nelson Pass. Japanese suppliers have also contributed to this effort/solution. JVC dubbed it Super A (model #   ),and Sony Corporation called it Legato Linear A (model # STR-GX99ES). In this age of digital audio processing, here's a recount of a newer solution from a Japanese supplier? which I've read in a past issue of Audio magazine. Several seconds of a music signal in digital format are first stored in a RAM. A built in microprocessor analyzes these data, and calculates the "right bias level for the output stage of the amplifier" based on the peak voltage value of the signal. It then instructs the bias circuitry to adjust the bias accordingly before it downloads the data to a Digital to Analog Converter for processing by the power amplifier. Talk about elaborate. These inventors "walked the extra mile" to further the cause of sonic excellence in their attendant power amplifier.

Dynamic Class A type amplifiers have a common mode of operation. A smart circuit is put/placed ahead of the output stage transistors. It senses, measures, and can possibly anticipate the cut off and/or movement in that direction by the output transistors due to the input signal Vi. It then counteracts in real time the cut off condition by increasing (sliding) the bias to the output transistors. The bottom line is that this smart circuit reacts to the input signal and then makes a suitable correction. In my opinion, a better solution will be to act on rather than react to this problem.

My Invention.

My approach is to "transform" the input signal (Vi) to a different format before offering to the transistors of the output stage. This acts on rather than reacts to the input signal in order to completely eliminate their problem of cut-off. It does not "manipulate" bias in any form or fashion. My objective is to improve the sonic excellence of prior art Class A, Class B and Class AB amplifiers by using a simple, effective, and novel way. Here's the conceptual cascade of steps to my solution.

- Separate faithfully the positive segment (+pulse) from the negative segment (-pulse) of the input signal. Take a pair of "virtual" scissors and cut in half the graph of input signal Vi along the X axis. Separate fully the two pulses as shown in Figure 4. Note their " relative relationship" with respect to time. This scission process must be faithful; i.e. exact. It must not distort the resultant signal pulses, and/or add distortion to the point of compromising the high fidelity premise of this solution. The "intelligent" circuit which does all this (re-formatting) is a phase inverting dual output precision (exact) half-wave rectifier. Figure 5 shows a simplified schematic of this circuit.

- Offer the NPN output transistor the positive signal pulse for amplification. After all, NPN is tailor made to process/amplify positive signals only.

- Offer the PNP transistor the negative signal pulse for amplification. After all, the PNP output transistor is tailor made to process/amplify negative signals only.

- Splice faithfully the positive and negative signal pulses at the power output junction to the loudspeaker. This generates output voltage Vo which is an amplified replica of input signal Vi. This will be shown in Figure 6.

The exact scission or precise rectification of input signal Vi by the circuit of Figure 5 is a switching process. Switching is an abrupt on to off and vice versa transitions very much like that of the Class AB operation described above. The switching process in the circuit of Figure 5 also generates the undesired and critical distortion similar to that from Class AB. Except that in this situation, this and any other distortion is automatically reduced to a magnitude that is next to nil by feedback around a high gain operational amplifier therein Figure 5. Consequently, the positive and negative pulses will have negligible distortion due to such "abrupt transitions, and hence will not entrain this distortion to the output stage transistors for amplification. Feedback also ensures that the resultant positive and negative pulses are exact replicas of their counterparts in the parent alternating signal Vi. This means that when the positive and negative pulses are spliced, the reconstituted alternating signal (Vi') will be an exact replica of the alternating input signal Vi.". For all practical purposes, the positive and negative signal pulses are a "transformed/formatted " form of input signal Vi. The transformation of signals is common in electronics. An example is the reversible Analog to Digital signal conversions used in compact disc players and others. The inter-convertible formats essentially spell out the same signal. The key elements and operation of the circuit in figure 5 are as follows:

- An Operational Amplifier (OA) of inherent high open loop voltage gain. It can be a readily available integrated circuit, or assembled from "discrete" components. It is powered by a dual power supply; e.g. +/- 15 Volts. It has an Inverting (-) and a Non Inverting inputs (+), plus an Output node (O). The (-) unlike the (+) input inverts the polarity/phase of the input signal Vi. The inversion of polarity/phase is pictorially depicted at the output node O. A typical open loop voltage of an OA ranges between 10,000 to 50,000 Volts at output node O per every input volt Vi at either of its inputs. In Figure 5, the OA may be needed to amplify the input signal Vi by a factor of 10 (R' divided by R=10). Its remaining "reserve " open loop gain of 1000-5000 Vo/Vi is automatically used and/or invested to reduce the errors from its own operation and from the switching process. This means that its amplified output signal is an exact replica of the input signal Vi and further contains a negligible amount/magnitude of distortion.

- Switching Diode A steers only the "positive going" portion of the output signal O (i.e. rectifies it) to generate a positive signal pulse at the auxiliary output Point A for offering to the NPN power output transistor. A voltage bias of magnitude Vd (~ 0.5 V; note its polarity) is used to barely turn on diode A; similar to Class AB operation. This improves the linearity of diode A and further ensures that its frequency response extends to greater than 20,000 Hz to embody the audible range.

- Switching Diode B steers only the "negative portion" of the output signal O to generate a negative pulse at the auxiliary output point B for offering to the PNP power transistor of the output stage. A bias voltage of magnitude Vd' of similar and opposite polarity to Vd is used also for the same purpose and consequent effect.

- The positive and negative signal pulses are also fed back to the (-) input via the resistors R' for error correction. This basically splices both polarity signal pulses to reproduce or reconstitute an exact and inverted replica of alternating input signal Vi. This returning inverted replica of signal Vi, and error components (i.e. distortion from switching in diodes A and B, and from the OA), and the parent/virgin (non inverted) input signal Vi must algebraically add up at the (-) input to a voltage equal to zero like that present at the (+) input (ground/common). This is a simple description of the closed loop operation for this (any) inverting operational amplifier. Consequently, the precise rectification of the output signal O around the 2 feedback loops of this operational amplifier provides a dual polarity and a faithfully reproduced signal pulse replicas of the input alternating signal Vi. The pulses contain at best a negligible distortion/error from the operation of the circuit.

Figure 6 shows a simplified schematic of the amplifier which embodies the teachings of my invention. It differs from the "prior art" of Figure 2 only by inserting the circuit of Figure 5 between the input signal Vi and the bases of the output transistors. Here's the description of its operation. First, let's put the amplifier of my invention and the prior art on a level "playing/working" field.

Let the idle collector current of the output stage transistors for either amplifier be equal to 0.1 Amperes via adequate biasing. Offer each amplifier the same level alternating signal Vi such that it invokes Class AB operation in the amplifier of the prior art to compromise its sonic excellence.

- During the time interval from 0 to 8.3 milliseconds, the circuit of Figure 5 inverts the positive polarity of the input signal Vi and presents/steers the resulting negative pulse to the base of the PNP. This negative pulse augments/assists the negative bias of PNP. The conduction of this transistor is increased and basically follows/tracks this pulse signal found at its base port. PNP inverts the polarity and amplifies this negative pulse to give a positive polarity output signal pulse +Y at the power output junction (Vo). The output positive pulse +Y is impressed across the load. It causes current Io to flow through it as depicted.

- During the same time interval above, the NPN was idling at 0.1 Amperes. It did not cut off like its counterpart in the prior art amplifier because it was not offered and was intentionally deprived from the negative pulse given to PNP.

- During the time interval from 8.3 to 16.7 milliseconds, the circuit of Figure 5 inverts the negative polarity of the input signal Vi and presents the resulting positive pulse to the base of the NPN power output transistor. This positive pulse augments/assists the positive bias of NPN. The conduction of this transistor is increased and basically follows/tracks the input pulse signal. NPN inverts the polarity and amplifies this positive pulse at its base terminal to give a negative polarity output signal -Yo at the power output junction (Vo). The output negative pulse -Y is impressed across the load. It causes current Io' to flow through it as depicted.

- During the same time interval of 8.3 to 16.7 milliseconds, the PNP was idling at 0.1 Amperes. It did not cut off like its counterpart in the prior art amplifier because it was not offered and was intentionally deprived from the positive pulse given to NPN.

- The output junction is the means to merge/splice the positive and negative pulses to reproduce an amplified replica of input signal Vi. The output signal Vo does not have the distortion due to abrupt cut off in the power output stage unlike that of the prior art. Consequently, the performance of my amplifier is better than the state of the art, and further advances the cause of its sonic excellence.

The output transistors of my amplifier operated in Class A without sliding the bias and without using a heavy and "brute force" quiescent idle of the base Class A types. The name ascribed to this mode of operation is Pulse Class A. It is superior to the prior art amplifier because its output stage was not allowed to produce "distortion" from abrupt cut off which compromises sonic excellence.

Claims

- Process and/or circuit(s) to faithfully scission the input signal into positive and negative pulses. It does not add any distortion to either signal pulses. This process/circuit further offers the positive pulse to NPN only, and presents the complementary negative pulse to PNP only.
- A means to splice the output positive and negative pulses to reconstitute an amplified replica of input signal Vi. In my example above it is the output node to the loudspeaker; i.e. the junction of the dual power supply as depicted in Figure 6. Other means of splicing are mentioned below.
- The whole amplifier.
- The output stage devices include semiconductors like bipolar NPN and/or PNP transistors, N and P channel enhancement and depletion MOSFETs and vacuum tubes.

Prototype according to the Invention

The entitled was built/reduced to practice using the teachings of Figures 5 and 6. It works as taught and performs very well.

Other prototypes

Other prototype amplifiers were built to study the scope of this invention. All performed as predicted and sounded very well. I'm including their simplified schematics for completeness.

- Figure 7 shows an opposed collector complementary output stage. The bases of the NPN and PNP transistors are driven respectively by positive and negative pulses which are now referenced to the power supply rails instead to common/ground like in Figures 1, 2 and 6. This configuration works because the power supply rails are effectively at ground level since their internal resistance is close to zero ohms. The prior art comparative is an Onkyo amplifier Model A-9911.

- Figure 8 shows the use of only a single polarity NPN output transistor to implement the invention. Often, the electrical characteristics of the so called complementary NPN/PNP and/or P/N channel MOSFET pairs are practically approximate. This mismatch invokes its own brand of distortion and hence causes degradation in performance. By contrast, the characteristics of the same type polarity semiconductors are essentially similar because of tight quality control in their production. The impact then is to eliminate the mentioned distortion from complementary pairs. How about vacuum tubes which are inherently unidirectional conductors of electricity as depicted?. The circuit of Figure 8 is also adaptable for use with vacuum tubes for two reasons. First it uses a power output transformer like the counterpart prior art designs. The transformer is a requirement in the output stage of a vacuum tube amplifier. In my invention it is also the means <u>to splice</u> the pulses to generate the output signal Vo at the secondary transformer winding. Secondly, the power output stage of a Class AB vacuum tube is also burdened by distortion due to the abrupt on/off transitions of solid state devices. Pulse Class A operation will improve it like for solid state designs. Note the use of a positive only polarity signal pulses to drive the NPN transistors and/or the vacuum tube triodes. It has to be so because either device is designed to use positive signals only. Simply track the color coded signals from the input to the output to see how it was done. The circuit using the NPN transistors was built with the dual purpose of demonstrating feasibility with it and vacuum tubes but without the high lethal plate voltage of the latter.

- Figure 9 shows the use of a pair of prior art power amplifiers in place of discrete output transistors. Note that one amplifier does not invert the phase/polarity of one polarity pulse while the second one does invert it for the complementary input pulse to the first. The loudspeaker is now the means to <u>splice</u> the pulses. It works quite well. Its full potential is under study.

<u>Finally.</u> Inventors think the unthinkable.