Yamaha Professional Audio Products

EEEngine and HED (High Efficiency Drive) circuit explanation

Several Yamaha Professional Power Amplifiers and Powered Mixers make use of a circuit configuration that increases the efficiency of the basic Class B amplifier output stage. Depending on the specific model, the marketing terms “**EEEngine**” and “**HED**” and their respective logos are used to promote the technology. Since its method of operation may not be immediately obvious on examination of the circuit diagram, an explanation of the technology will assist in the repair of applicable products.

1. Power supply efficiency of Class B output stage

The conventional Class B audio amplifier output stage (Figure 1) requires a value of power supply voltage that allows the amplifier to deliver its maximum undistorted power output. The power dissipated as heat by the output devices (transistors, MOSFETs, etc) when they are driving a load (ie. a loudspeaker) reduces amplifier efficiency. The amount of heating will depend on the load current and difference between the signal output and power supply voltages. We cannot control the load current (the load impedance and instantaneous signal level determine this), but if the supply voltage available to the output devices can be reduced to the minimum required to accommodate the output signal, an improvement in the efficiency of the output stage can be achieved. This can be implemented in several ways.

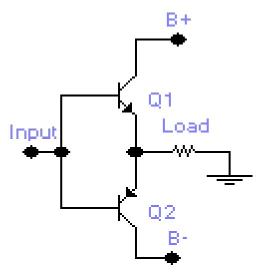

Figure 1

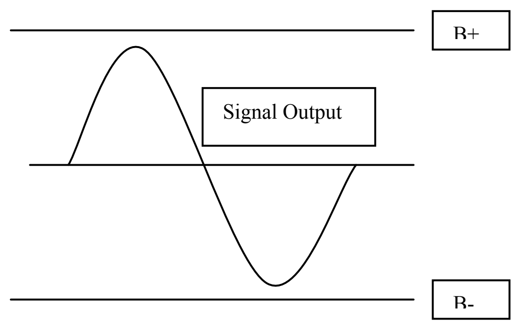

Figure 2

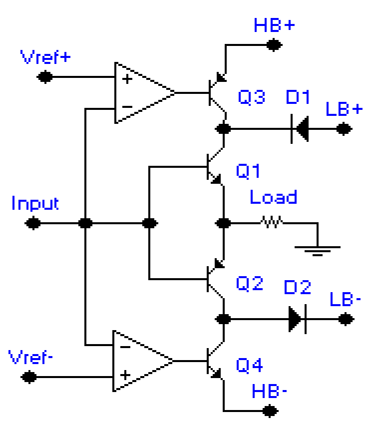

Figure 3

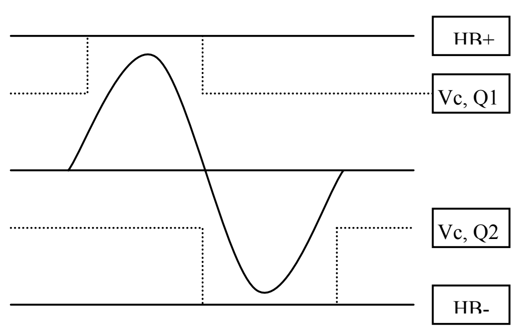

Figure 4

2. **Reduction of output stage heating**

One method to achieve this (Figure 3) is by providing multiple supply rails, each of a different voltage that are switched into and out of circuit depending on the required audio signal level. Comparator circuitry monitors the difference between the signal and reference voltages and switches in the appropriate supply rail. Efficiency increases with a greater number of supply voltages but a practical limit exists beyond which the added cost and complexity outweigh any efficiency gains. Additionally, the circuitry must be designed to accommodate very fast signal rise times otherwise small "notches" will be taken out of the waveform as the supply voltage tries to "catch up". Figure 4 illustrates how the collector voltages of the output devices are switched abruptly between low and high-level power supply voltages.

A second method to reduce output stage heating is by use of a cascode device inserted between the supply rail and the output device (Figure 5). The difference between this method and the one just described occurs after the transition from low to high supply voltage. In this case, the cascode device provides the output device with a constant collector to emitter (or drain to source) value of about five to ten volts (figure 6), which improves the linearity of the output device. The circuit is inherently capable of handling fast signals because no switching is involved. However, at high signal amplitudes both devices are operating linearly, which reduces the overall efficiency of this method compared to that in Figure 3.

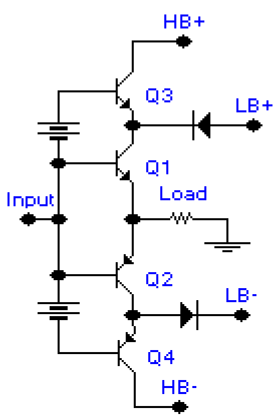

Figure 5

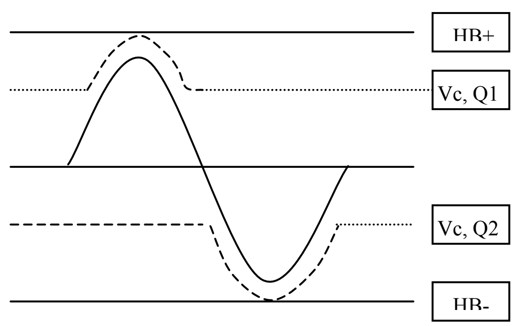

Figure 6

A third method uses a switching power supply whose output voltage (the amplifier's supply rails) is controlled by the audio signal at the amplifier's output. By phase controlling the incoming 240VAC mains using Triac devices, a very high overall amplifier (and power supply) efficiency is achieved. The same applies to pulse wave modulating the output of a conventional transformer/rectifier/ capacitor type power supply. With both methods however, there is a limit to the rate at which the large power supply filter capacitors can be charged, so there again exists the possibility that fast signal transients at the amplifier's output may not be accommodated.

Several other methods exist but in general, a compromise exists between efficiency and signal transient capability. Yamaha's High Efficiency Drive system overcomes the disadvantages of the aforementioned methods.

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3. **Yamaha HED (High Efficiency Drive) system**

This method of reducing amplifier output stage dissipation is best described as a combination of a linear, cascode circuit in parallel with a self-oscillating, switching power supply. The cascode section ensures signal transient capability and the switching section improves efficiency. Both load current and signal rise time determine which of the two sections will provide the supply to the output devices. Refer to the simplified output stage shown in Figure 7. For clarity, only the positive side of the amplifier output stage is shown - the negative side operates in exactly the same way.

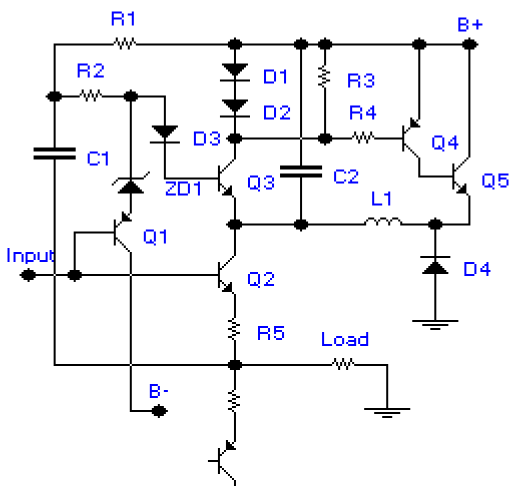

Figure 7

Transistor Q2 is the output device and R5, its emitter resistor. The driver transistor normally used in a Darlington output configuration has been omitted from the diagram for clarity. If, for the moment, we neglect all of the circuitry to the right of Q3 and with no load connected, we can see that a conventional cascode output stage exists. The current through R1 and R2 splits into two paths – the first through ZD1 (a 6.8-volt zener diode) and Q1, the other through D3 and Q3. This results in Q3's emitter being 6.8 volts above the voltage at the speaker output. For any positive value of output signal, Q2 therefore operates with a constant collector-emitter voltage of 6.8 volts with Q3 taking up the difference between Q2's collector and the positive supply. With or without a load connected, the dissipation in Q2 is very low - much lower than if its collector was connected directly to the positive supply rail. However, without assistance, Q3's dissipation is quite high when passing load current.

Now consider the effect of the additional switching circuitry around Q5. At low values of load current, the voltage developed across R3 is insufficient to bias on Q4, and the switching circuitry remains unused. As load current increases, the voltage across R3 will turn on the Q4 / Q5 combination, which then applies the supply voltage directly to the junction of L1 and D4. Due to the integrating effect of L1 and C2, the voltage at Q3 emitter will start to ramp upward and reach a value that will both reverse bias Q3 and remove from it, the burden of load current. When this occurs, the voltage drop across R3 falls to zero (because the load current is now flowing through L1 via Q5) and turns off Q4 and Q5. The current through L1 decreases, resulting in a negative ramp at Q3's emitter, which eventually results in Q3 being forward-biased and the cycle repeats. The circuit acts as a current-controlled oscillator and the value of load current that initiates Q5's contribution is wholly determined by the value of R3.

Diodes D1 and D2 limit the voltage drop across R3, and D3 prevents damage to Q3's base-emitter junction when reverse-biased by Q5. D4 allows the stored energy in L1 to maintain a current flow when Q5 turns off. Capacitor C1 ensures the R1/R2 combination acts as a constant current source irrespective of signal amplitude. Without it, the drive available to Q3 would reduce as the signal amplitude increases, limiting the output swing. One could view Q3 as an "error amplifier" that constantly attempts to maintain a 6.8 volts differential between its emitter and the speaker output line.

Typical music and program signals may contain waveforms whose rise and fall times are of shorter duration than the L1/C2 integrator time constant. The presence of Q3 ensures that in the intervening period before the switched ramp voltage "catches up" to the requirements of the signal waveform, the full supply voltage is still available via D1 and D2, eliminating signal distortion due to supply limiting. The fact that Q3 operates linearly during this period does mean that the efficiency of the HED circuit technique reduces at the higher audio frequencies. However, typical program material has relatively little high frequency content, so in practice, only a slight reduction in overall efficiency results.

4. **Servicing precautions and checking the operation of the HED system**

It is important to understand that a number of components will each at some point be passing output load current. These are Q2, Q3, Q5, D1, D2, D4, L1, R3 and R5. Use only the originally specified components when repairing a faulty amplifier. A failure in any of these components will affect the operation of the HED action in different ways. For example, if Q3 or Q5 were to short circuit, the full supply voltage would appear at Q2's collector. While this would not affect Q2's ability to act as an output transistor, its dissipation would be much higher. As a further example, any fault that prevents Q5 from switching will result in excessive dissipation in Q3.

The easiest way to check the switching operation is by monitoring Q2's collector with an oscilloscope while the amplifier is driving a load. As the output signal progresses away from zero volts, Q2's collector will follow with a 6.8 volts (approximately) differential and as the load current increases, switching ripple will appear, superimposed on the collector waveform. As the NPN and PNP halves of the amplifier each have independent switching circuits, it is necessary to check both (see Figure 8).

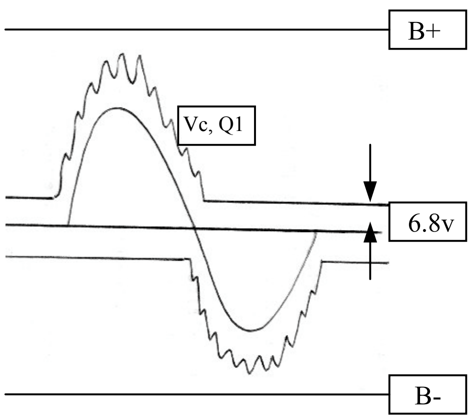

Figure 8

Note that when checking an *unloaded* amplifier with any non-sinusoidal waveforms, (ie. those that contain "edges"), it may be observed that the output devices' collector voltages do not follow the emitter (output) voltages. This is due to the fact that the waveform edges represent high frequency content and, when applied to the amplifier's Zobel network, will draw current that may initiate a cycle of the switching oscillation.

Amplifiers using this circuit technique *may* exhibit a tendency to "sing" audibly in use. This is due to current transients from the applied signal causing mechanical vibration of the switching coil and capacitor. This characteristic will vary between units and even between channels in a unit and will be most noticeable when the amplifier is operating in a different acoustic space to the loudspeaker(s) it is driving. At the time of writing, this is NOT considered to be a fault, and units should not be needlessly serviced for this reported symptom. Alternative components from later models may eventually be specified as a means of reducing the noise in units exhibiting this characteristic.

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5. **<u>Yamaha products using HED technology</u>**

- "H" series Professional Power Amplifiers, H3000, H500, H7000
- "P" series Professional Power Amplifiers, P1600, P3200, P4500
- "EMX" series Powered Mixers, EMX620, EMX640, EMX860ST, EMX2000
- "XM" series Multi-channel Power Amplifiers, XM4220, XM6150

The "H" series amplifiers were first to introduce the technology under the "**HED**" marketing title. Later products ("P", "EMX" and "XM" products) use the "**EEEngine**" marketing title and logo.

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