A New Distortion Mechanism in Class B Amplifiers*

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Mutual inductance between power-supply wiring and signal wiring in class B amplifiers introduces even-harmonic distortion. A circuit technique is described for constraining harmonic currents in power-supply wiring to well-defined loops, and these loops can be physically located so as to minimize mutual inductance.

1 THE PROBLEM

During some recent experiments with class B audio power amplifiers, an even-harmonic distortion mechanism was encountered which, to the author's knowledge, has not previously been described.

In an ideal class B stage (Fig. 1) the current in each transistor is a half-wave-rectified sine wave. It matters not whether the transistors are used in the common-emitter or common-collector configuration, or are *n-p-n* or *p-n-p* types. If the peak output voltage is V_O, the angular frequency ω, and the load resistance R_L, the Fourier series for the currents in the transistors are

$$I_1 = \frac{V_O}{R_L}\left[\frac{1}{\pi} + \frac{1}{2}\sin\omega t - \frac{2}{3\pi}\cos 2\omega t - \frac{2}{15\pi}\cos 4\omega t + \cdots\right] \quad (1)$$

$$I_2 = \frac{V_O}{R_L}\left[\frac{1}{\pi} - \frac{1}{2}\sin\omega t - \frac{2}{3\pi}\cos 2\omega t - \frac{2}{15\pi}\cos 4\omega t + \cdots\right]. \quad (2)$$

Inspection of the circuit shows that all components of current except the fundamental circulate around the loop formed by the output transistors and the power supplies. If there is mutual inductance M between this loop and the signal output loop after the point at which negative feedback is derived, a distortion voltage is induced in the output:

$$V_d = M\,\frac{dI}{dt} = \omega M\,\frac{V_O}{R_L} \times \left[\frac{4}{3\pi}\sin 2\omega t + \frac{8}{15\pi}\sin 4\omega t + \cdots\right]. \quad (3)$$

Expressed as percentages of the signal output, the harmonic distortions are

$$D_2 = \frac{\omega M}{R_L}\left[\frac{4}{3\pi}\right] \times 100\ \% \quad (4)$$

$$D_4 = \frac{\omega M}{R_L}\left[\frac{8}{15\pi}\right] \times 100\ \% \quad (5)$$

$$D_{2n} = \frac{\omega M}{R_L}\left[\frac{4n}{(4n^2-1)\pi}\right] \times 100\%. \quad (6)$$

Notice that these percentages are independent of the actual output amplitude and of the rated maximum output amplitude; they depend only on load resistance and frequency. For a typical audio power amplifier having $R_L = 8\ \Omega$, then at ω corresponding to 10 kHz,

$$D_2 = 0.33\%\ \text{per}\ \mu\text{H}.$$

Admittedly, 1 μH would be a very large mutual inductance between power supply and loudspeaker wiring, and the distortion does fall in proportion to frequency. However, the mutual inductance could easily be tens of nanohenrys. The first amplifier in which this distortion mechanism was actually noticed by the author had D_2 = 30 ppm (parts per million) at 10 kHz, corresponding to 10 nH.

If the mutual inductance is between the power supply and the signal input loop, the percentage distortion is increased by the voltage gain of the amplifier at the frequency of the harmonic concerned.

If the amplifier includes a preamplifier with equalization for disk recordings, the problem is further compounded. To a crude approximation the RIAA equalization is an integration, and therefore the distortion

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mechanism becomes independent of frequency. As a numerical example, if the input sensitivity is such that 1 mV produces 50 W output into 8 Ω at 1 kHz (typical for a moving-coil pick-up), then

$$D_2 = 0.33\% \text{ per nH between power supply and input}$$

$$D_4 = 0.067\% \text{ per nH}$$

$$D_{2n} = \frac{1}{4n^2 - 1} \; \% \text{ per nH}$$

independent of signal frequency.

2 A SOLUTION

In principle, the solution is easy: reduce the mutual inductance. However, the layout of power-supply wiring is not ordinarily well controlled, and the last numerical example shows that tiny mutual inductances can be significant. For what the statistic is worth, in a group of fifty 50-W 8-Ω power amplifiers built to the same circuit but with individual layouts, the median second-harmonic distortion of 10 kHz was about 30 ppm, and five (10%) had 100 ppm or higher. The amplifiers were constructed by electronics engineers who had been alerted to the problem and took common-sense precautions like twisting wire pairs that carried forward and return currents.

The author's approach is to force the harmonic current into a figure-of-eight path on the amplifier printed circuit board. Because the path is printed, its layout is reproducible; because it is figure-of-eight in shape, its mutual inductance with signal loops is small. Fig. 2 shows a typical circuit, and Fig. 3 shows the corresponding circuit-board layout. Note the figure-of-eight shape of the loop formed by the two 500 μF capacitors, 0.5-Ω resistors, and the power transistors in Fig. 3; the tracks leading to the power transistors are spaced so closely that the area between them is negligible, and therefore they do not contribute to any mutual inductance. In extreme cases the input and feedback tracks can also be laid out as a figure of eight to reduce magnetic coupling into this most sensitive part of the circuit.

The 500 μF, 15 μH, and 0.15 Ω constitute a critically damped low-pass filter which forces components of transistor current above 1.5 kHz to flow into the on-

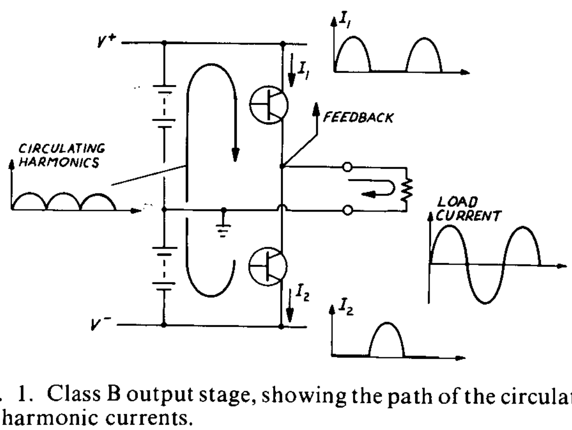

Fig. 1. Class B output stage, showing the path of the circulating harmonic currents.

board bypass capacitors with their controlled figure-of-eight layout rather than into the main power-supply wiring with its uncontrolled layout. Typical 500-μF capacitors have a series resistance of the order 0.1 Ω; if the 15 μH and 0.15 Ω were not present, a substantial part

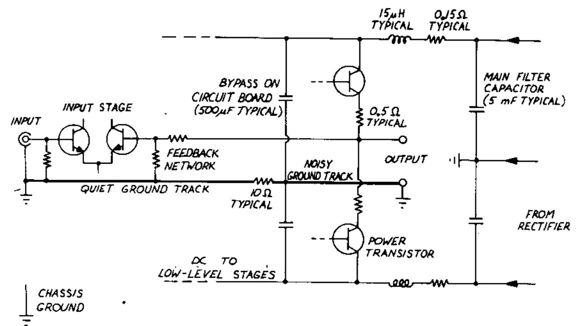

Fig. 2. Power-supply filtering and separate ground tracks for forcing the harmonic currents into the on-board bypass capacitors.

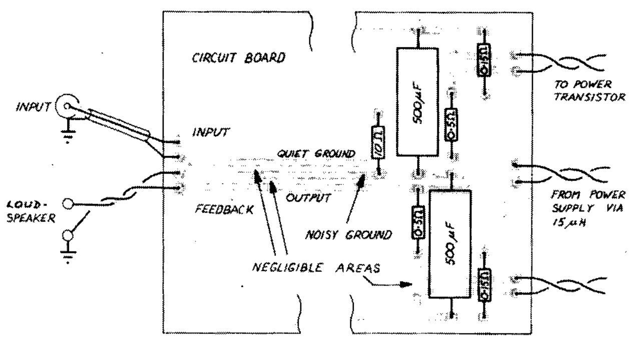

Fig. 3. Suggested circuit-board layout. Note the figure-of-eight shape of the loop formed by the 500 μF capacitors and 0.5 Ω resistors. The area between the tracks to the power transistors is negligible.

of the current at all audio frequencies would flow into the main filter capacitors.

At frequencies below 1.5 kHz the loudspeaker current enters the circuit board via the (twisted) power-supply leads; the return path is via the chassis ground at the loudspeaker terminals. Above 1.5 kHz the loudspeaker current is confined to the bypass capacitors and the output and noisy ground tracks on the circuit board; the small area between these tracks minimizes signal induction into the low-level circuits and also minimizes inductive voltage drops along the tracks.

The bypass capacitors carry 5–10% of the power-supply ripple current, and perceptible hum voltage is developed across the resistance of the noisy ground track and associated wiring. Therefore a completely separate quiet ground track is provided for all low-level circuitry. The 10-Ω resistor provides a high-frequency connection between the quiet ground track and the ground ends of the bypass capacitors; 10 Ω is less than the reactance of a 100-nF bypass at frequencies up to 1 MHz, but is large enough to reduce hum current in the quiet ground track to the order of a milliampere.

Dr. Cherry's biography was published in the March issue.