Texas Instruments

Application Report
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Audio Power Amplifier Operation with Transformer Load

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ABSTRACT

A Class-D audio power amplifier (APA) driving an output transformer with inadequate low-frequency performance may sometimes shut down because of saturation of the transformer core. This paper explains the cause of this sort of shutdown and provides strategies for avoiding it.

Introduction

A product with a Class-D audio power amplifier (APA) driving an output transformer with inadequate low-frequency performance may shut down when its output is stepped from zero to maximum at the start of a sine cycle. Shutdown is triggered by short circuit protection (SCP), after the first half cycle of the sine output. The root cause is saturation of the transformer core.

If shutdown is avoided the transformer input and output voltages and currents settle to steady-state levels after a few cycles, as expected. But with or without shutdown there is a large transient in the primary current of the transformer during the second quarter cycle after transformer primary signal is applied.

To demonstrate this problem a TPA3123D2 in bridge-tied-load (BTL) mode was used to drive the primary of a transformer that has this sort of saturation. The input to the TPA3123D2 was a sine from a function generator at 50Hz, the transformer's minimum rated input frequency. To demonstrate the transient as clearly as possible it was first generated with the load disconnected, as shown in Figure 1.

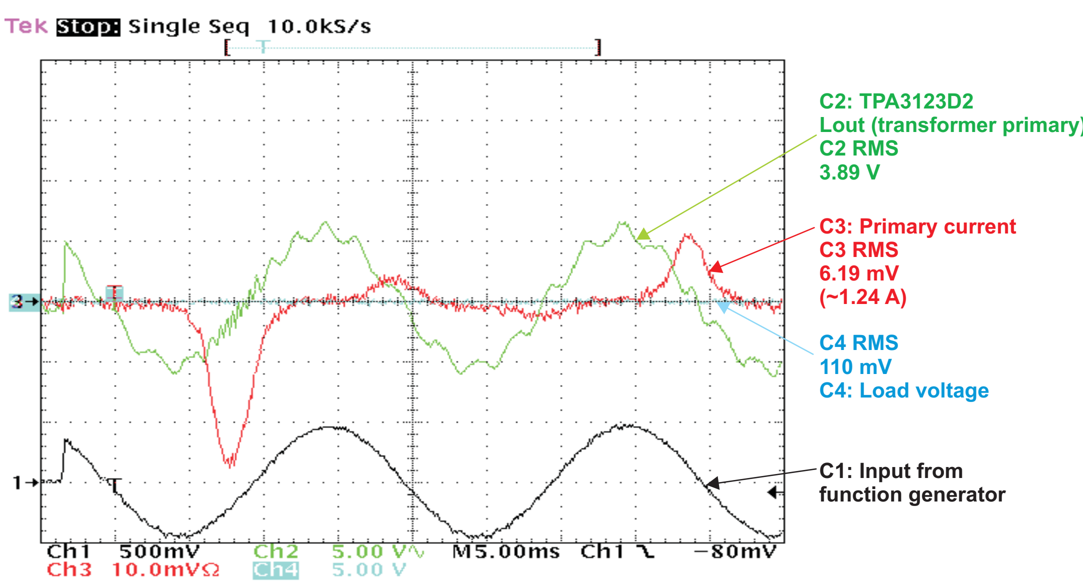

Figure 1. Transformer Primary Voltage and Saturation Current Without APA Shutdown

Ripples in TPA3123D2 Lout are aliased ripple from the switching signal after the LC filter.

In cases like the preceding case the product avoided shutting down. In others it shut down as shown in Figure 2. (Nominal SCP threshold for TPA3123D2 is 6A, with a range from 4A to 8A.)

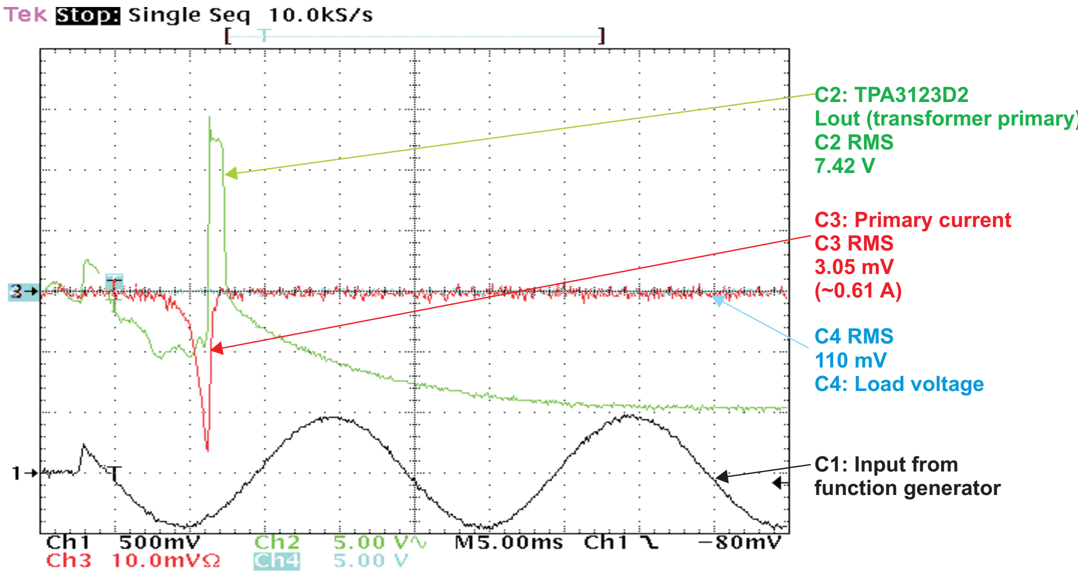

Figure 2. Transformer Primary Voltage and Saturation Current With APA Shutdown

SCP shutdown was a function of magnetizing current, and it did not depend on loading on the transformer secondaries.

With a load the initial transient is still clearly apparent, as shown in Figure 3. (The load in this case is a parallel pair of 5-Ω resistors fed through bridge rectifiers, one on each secondary of the transformer; see the schematic, Figure 4).

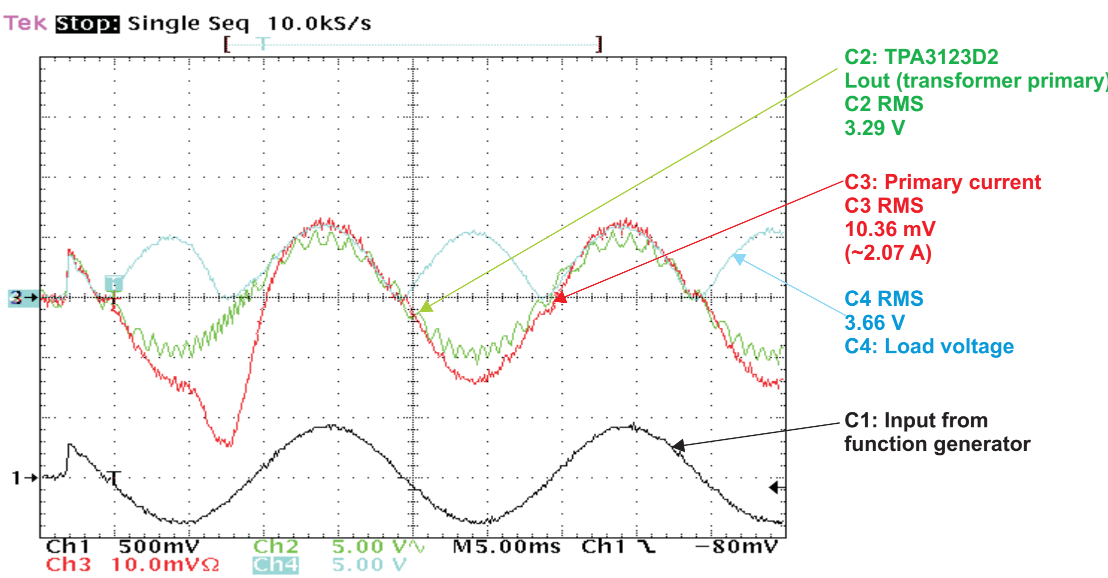

Figure 3. Transformer Primary and Load Voltages and Saturation Current Without APA Shutdown

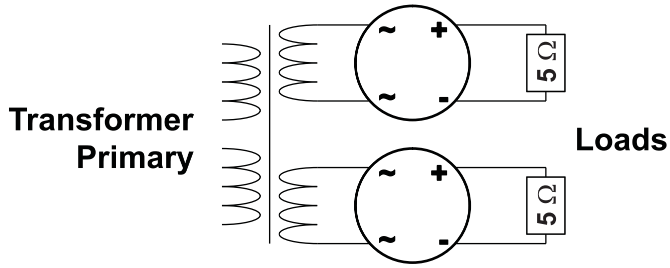

Figure 4. Transformer and Load Circuit Schematic

The reason for transformer core saturation during the first quarter to half cycle is that the transformer is exposed to unipolar volt-seconds during that interval, so magnetizing current builds up to a level above its steady-state value. In steady-state operation the input is bipolar, and magnetizing current lags primary voltage and avoids this effect.

Note that the input signal in graphs above does not start exactly at zero crossing but anticipates it by a fraction of a cycle. The function generator used in these measurements does not permit exact control over signal starting phase, and its starting point has some drift. At the start of these measurements the typical starting point was closer to the zero crossing, and shutdowns were more frequent. This appears to mean that an initial period of primary volt-seconds with opposite phase from the first full half cycle tends to compensate that half cycle, reducing the depth of saturation and so making shutdown less likely.

This suggests a possible cure for the problem. The existing program makes the transition from the low level input to the high level input precisely at a zero crossing. Making the transition a fraction of a cycle before the zero crossing, perhaps a quarter cycle, might compensate just as the initial fraction of a cycle produced by the function generator seems to.

Another alternative is to make the transition from zero to maximum output in more than one step, allowing the magnetizing current to stabilize each time to avoid saturation.

A third alternative is to design the transformer to avoid saturation under these conditions. A simple criterion for achieving success may be to design the transformer so it will not saturate in steady-state operation with full rated primary voltage at a frequency that is half the minimum input frequency that will be applied. Magnetizing current is essentially proportional to both magnitude and frequency of driving voltage. Then, when primary voltage is stepped from zero to maximum at the start of a cycle at the minimum applicable input frequency, peak magnetizing current during the first half cycle will be equal to peak magnetizing current in steady-state operation at half the minimum applicable input frequency, and saturation will be avoided.