

## A MHz Electronic Ballast for Automotive-Type HID Lamps

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**Abstract** - The compatibility of the Current Sourcing Push-Pull Resonant Inverter (CS-PPRI) with the driving requirements of HID lamps designated for automotive headlight applications was investigated theoretically, by simulation and experimentally. The study reveals that a based ballast (CS-PPRI) complies with the automotive requirement of very fast warm up. The experimental ballast was run under Zero Voltage Switching (ZVS) at a nominal switching frequency of 1.29MHz while the pre-ignition switching frequency was 124KHz. Warm up time to 80% after cold ignition was about 10 seconds.

### I. INTRODUCTION

High Intensity Discharge (HID) lamps and in particular Metal Halide Discharge (MHD) lamps are considered to be one of the most effective light sources [1]. These lamps have high electrical to lumen efficiency (efficacy), long life, good color rendition and good focusing capability when the arc is made short. These favorable characteristics, and in particular the very high brightness and color temperature of commercial HID lamps, make them good candidates for sophisticated applications such as automotive headlights. Indeed, some auto makers are already offering a HID lamp option to replace the conventional 'halogen' type headlights. Unfortunately, application of HID lamps in such demanding environments is far from being straightforward due to the many peculiarities of these light sources. The main difficulty with present day HID lamps is their need for special electrical circuits, electronic ballasts, to drive them [2, 3, 4].

The conventional design of an automotive HID lamp ballast involved two stages [5, 6]: a DC-DC converter to boost the battery voltage to the value required by the lamp (around 80V) and a DC-AC full bridge inverter that converts the DC bus to a low frequency square wave (in the range of 50-500Hz). This two stage design is further complicated by the need to pump high power to the lamp during warm up.

The nominal (electrical) power required to drive a headlight HID lamp is 35W [5, 6]. Assuming a nominal lamp voltage of 80V, the nominal current is about 0.44A. To ensure quick rise to nominal light intensity, the power level during warm up should be about 75W [5] which is more than twice than

the nominal power. However, since the lamp voltage during warm up is low (about 20V), the current drive during warm up should reach about 7-8 times the nominal current, i.e. about 3-4 A. Considering the fact that the warm up time lasts few seconds, the ballast must be designed to current levels which are much higher than the nominal ones.

The objective of this study was to examine and evaluate the potential application of the Current-Sourcing Push-Pull Parallel-Resonance Inverter (CS-PPRI) topology [2] as a ballast for low wattage HID lamps designated as automotive headlights [5, 6]. Special attention was paid to three major points:

1. To permit the application of an external igniter (rather than using a multiresonance ignition scheme [2]) so that ignition pulses of very high voltage can be realized.
2. Ensuring soft switching of the inverter during ignition, warm up and normal operation.
3. Exploring the capability of the inverter to deliver high power to the lamp during ignition.

The operating frequency of the ballast was chosen to be above 1 MHz to overcome the acoustic resonance problems [2, 3, 4]. The study includes analytical investigation, simulation and an experimental evaluation of a 1.5 MHz ballast designed for a 35W automotive MHD lamp.

### II. BALLAST TOPOLOGY

The proposed ballast (Fig. 1) is built around a CS-PPRI [2] and includes two switches ( $Q_1$ ,  $Q_2$ ) with inherent anti-parallel diodes ( $D_1$ ,  $D_2$ ), an input inductor ( $L_{in}$ ), integrated-magnetics element ( $T_2$ ), resonant capacitor  $C_r$  and a serially connected ignition transformer ( $T_{ig}$ ) with a secondary inductance of  $L_{ig}$ . A simplified equivalent circuit of the inverter is given in Fig. 2. The inverter operates in two modes: a voltage-source mode that is in effect prior to ignition and a current-source mode that prevails as soon as the lamp ignites and during steady state operation. The operating switching frequency of the ballast during the voltage-source mode and the current-source mode is designated  $f_{vss}$  and  $f_{css}$  respectively. The two mode operation is facilitated by applying different resonant frequencies of the circuit. The low resonance frequency ( $f_{r_{vss}}$ ), which is

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