

Development of an Automotive HID Electronic Ballast Based Microprocessor

D.H.Wang, K.W.E.Cheng, B.P. Divakar, P.Dong,
W.W.Chan, X.D.Xue, K.Ding, Y.B.Che, C.D.Xu
Power Electronics Research Centre
Department of Electrical Engineering
The Hong Kong Polytechnic University

Abstract--An automotive High Intensity Discharge (HID) electronic ballast based microprocessor is presented along with hardware design, software design and experimental results. The paper discusses some of the vital practical issues on hardware circuit design. According to the start-up characteristics of HID lamp, a timing control is presented. A new control method is proposed on the power mode control by controlling HID lamp current. Experimental results demonstrate the design of hardware and software is successful.

Index Terms--ballast, flyback converter, HID lamp, inverter, igniter, microprocessor

I. INTRODUCTION

In recent years, high intensity discharge (HID) lamp has been accepted as a good lighting source for automotive or high intensity illumination because of its superior performance over the conventional halogen lamp: energy saving, long life, high luminous efficacy and good color rendering. So, HID lamps will be used extensively and to replace other lighting source in future. However, the high cost of automotive HID ballast is the main reason that it has not been used extensively until now. Many electrical engineers have been developing HID ballast. So far, low cost and high performance of HID ballast is still seldom. Its reason is that the control of HID ballast is complex and HID ballast needs high voltage rating and high current rating components. Due to the complexity of the control, control circuit built with the analog is cumbersome resulting in high cost and unstable. So, digital control is better choice. As we know, DSP has superior capacity of data processing that helps to improve the performance of HID ballast. But DSP is very expensive that is not appropriate for developing the low cost of HID ballast. Hence, microprocessor is good alternative. Microprocessor has many advantages over the analog controller, such as cheap, easy to use, robust, flexible. However microprocessor's clock rate is not enough fast in the application of power electronics system. So HID ballast based microprocessor has to rely on additional PWM control chips to accomplish the PWM switching function and an interface a digital-to-analog (DAC) is needed. It is shown in Fig.1.

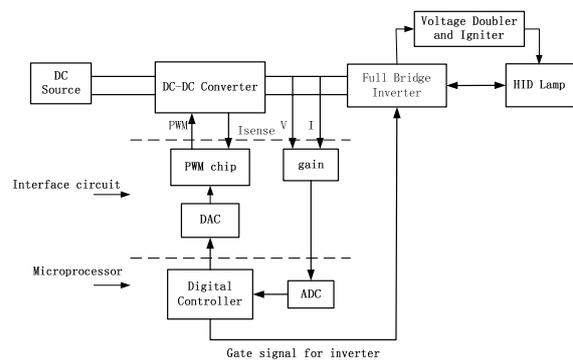


Fig. 1. Block diagram of the HID electronic ballast based on microprocessor

The HID ballast consists of the high frequency (100kHz) DC-DC converter, the low frequency (200Hz) DC-AC inverter, voltage doubler and igniter, and digital controller. The DC-DC converter first boosts DC voltage (9-16v) up to a higher DC voltage about 350V level, for conversion to the high voltage of above 10k to strike the lamp at start-up period, and then provides 85V DC voltage for steady state. The DC-AC inverter drives the HID lamp at steady state. The full bridge inverter converts the DC voltage to a square wave voltage. A high voltage igniter with voltage doubler is needed for striking the automotive HID lamp. Voltage doubler is fed from inverter. Voltage doubler is only used at ignition. After HID lamp is ignited, the output voltage of DC-DC converter decreases immediately. The output voltage of Voltage doubler is not high enough to strike spark gap so that igniter will be not used any longer. The DC-DC converter together with the full bridge inverter is controlled by microprocessor which senses signals of the lamp voltage and current to improve the ignition.

II. THE HARDWARE DESIGN OF THIS HID BALLAST

It is shown in Fig.2. Microprocessor senses the lamp voltage and current by a voltage divider and a resistor respectively, and then processes these feedback signals to regulate the lamp voltage, current, or power when

appropriate. Microprocessor transfers an error signal to PWM chip by DAC. Then, the PWM chip generates PWM to the power switch of DC-DC converter. Meanwhile, microprocessor generates gate signal to full bridge inverter.

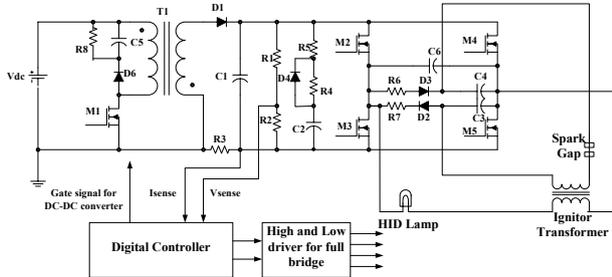


Fig.2. Schematic circuit of HID electronic ballast

A. Active low pass filter

As mentioned above, DC-DC converter works at high frequency of 100kHz. High frequency noise is radiated directly from switching of M1 and D1. If the voltage sense signal or current sense signal with high frequency noise is fed into microprocessor, the resolution of sampling will be affected that results in error between reference and real output. Another noise is from the igniter transformer that generates a very high voltage pulse of above 10kV for hot restrike, and its pulse width is less than 1µs. It is shown in Fig.3. The noise of this type is possible to damage microprocessor. Therefore, an active low pass filter (LPF) as shown in Fig.4 is adopted to filter out high frequency noise and only low frequency passes through. Meanwhile, LPF is needed to adjust the signal voltage to proper level which is limited by the reference voltage of microprocessor.

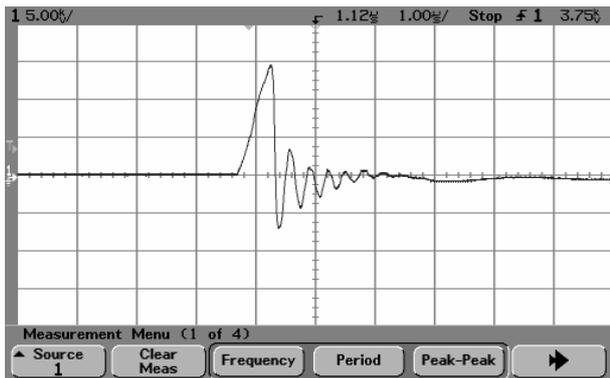


Fig.3. High voltage pulse of igniter

The cross off frequency is defined by the formula as follows:

$$f=1/(2\pi*R11*C7)$$

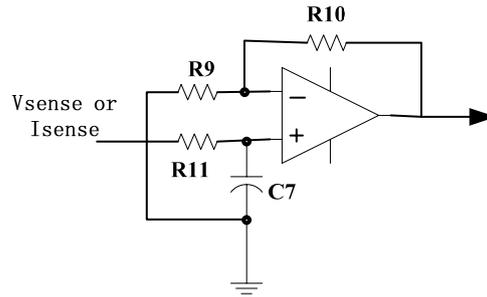


Fig.4. Active low pass filter

B. The full bridge inverter and Voltage doubler

Owing to the output voltage of DC-DC converter is very high at ignition stage, full bridge topology is adopted. When M2 and M5 turn on, DC voltage charges the capacitor C4 through a diode D3 and a resistor R6. When M3 and M4 turn on, DC voltage charges C3 through D2 and R7. Because the duty ratio of inverter is 50%, energy stored in C3 is equal to that in C4. When the sum of voltage of C3 and C4 rises up to 600v, spark gap turns on like a switch. The voltage of C3 and C4 across the primary winding of igniter transformer induces a very high voltage pulse across the secondary winding as shown in Fig.4 by turn ratio.

C. Igniter transformer

The igniter transformer is a very important component in the HID ballast. The igniter transformer must be able to produce enough high voltage pulse during ignition stage. So insulation is a serious problem. For solving this problem, we put 5 insulation tapes between the wires to ensure that transformer can endure so high voltage. A tiny and inexpensive igniter transformer is required for minimizing the HID lamp ballast. The long rod-type core is more effective than other type core, such as EE core.

D. Warm up circuit

Lamp temperature compensation is critical for automobile headlamps, because without compensation, light output varies dramatically from a cold lamp to one that is fully warmed up. The program has had the function that is able to identify the lamp temperature. A warm up circuit is designed as shown in Fig.5. Lamp temperature is anticipated by monitoring charge on capacitor which charge when the lamp is on and discharge when the lamp is off. The program compensates for lamp temperature by driving the lamp with a higher lamp power when the lamp is cold and reducing the power to a normal operating level when the lamp is warmed up. Therefore, the value of R12 and C8 is chose according to the rate of HID lamp cooling.

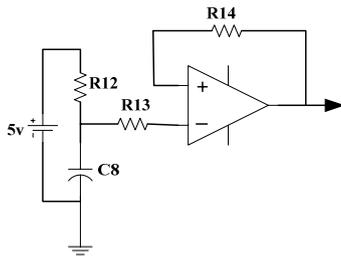


Fig.5. The schematic circuit of warm up

III. THE SOFTWARE DESIGN OF THE HID BALLAST

The key of software design is to identify the most prominent features for transitions between stages. As shown in Fig.6, there are four different control modes (voltage control mode, constant current control mode, variable power regulation, constant power regulation). Therefore, we need to identify all the possible transition points where control mode changes.

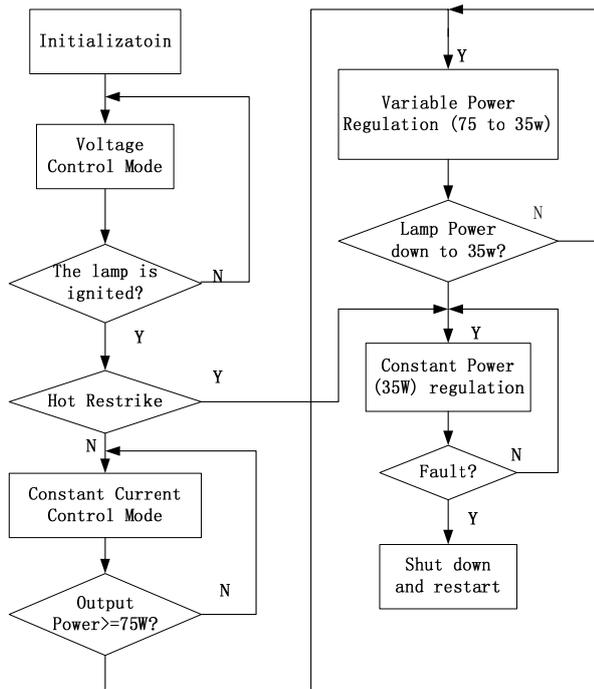


Fig.6. The flow chart of the control

During turn on stage, the DC bus voltage builds up until ignition occurs. This stage adopts voltage control mode. Once the lamp is ignited, the HID ballast must provide enough high current to the lamp in order to maintain the arc. So, instead of voltage control mode, current control mode is adopted. When the lamp power reaches 75w, control mode enters into the variable power regulation that reduces output power gradually. Finally, when the lamp power decreases to 35w, the lamp enter

into steady state and constant power regulation is implemented. The flow chart of the control is shown in Fig.6.

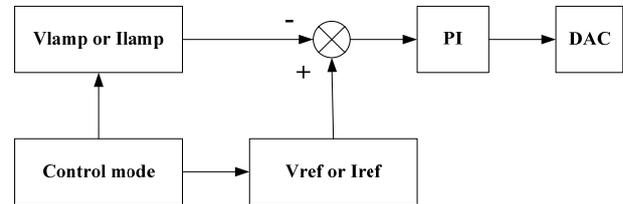


Fig. 7. The block diagram of the control flowchart

Fig.7 shows the control method of voltage mode or current mode. The output voltage sensed or current sensed is fed into error

amplifier. The program compares the output voltage sensed or current sensed with a voltage reference or a current reference respectively. The error value is then processed to calculate a new process signal by PI controller. This process signal will try to adjust the output value back to the desired value. The control of voltage mode and current mode are not difficult to be realized. But it is very difficult to realize constant power control. Because of microprocessor of 8-bit and ADC of 10-bit resolution, power data by the product of voltage and current has to store in the format of 32-bit. A better way is that a table built by calculating current reference according to the lamp voltage sensed are applied by PI controller to regulate the constant power at steady state. From Fig.2, the relation between V_{sense} and I_{sense} can be built as follows;

$$V_{sense} \times I_{sense} = V_{lamp} \times K_V \times I_{lamp} \times K_I \quad (1)$$

where K_V and K_I are the proportionality constants for voltage and current respectively.

$$\text{If } V_{lamp} \times I_{lamp} = 35w$$

$$P_{ref} = 35 \times K_V \times K_I$$

$$V_{sense} \times I_{sense} - P_{ref} = error \quad (2)$$

$$I_{sense} - P_{ref} / V_{sense} = error / V_{sense} \quad (3)$$

$$I_{sense} - I_{ref} = error1 \quad (4)$$

$$\text{where } I_{ref} = P_{ref} / V_{sense}$$

$$error1 = error / V_{sense}$$

From(4), the control algorithm that constant power is regulated by regulating the lamp current is feasible.

IV. EXPERIMENTAL RESULTS

HID lamp is a very complex load to drive. The impedance of HID lamp will drop drastically to a few tens of ohms from infinity if it is ignited by high voltage pulse. Afterwards, the HID lamp enters steady state, at which its impedance remain relatively unchanged. So the transitions between each stage should be properly controlled by HID controller or the parameters of components. Otherwise, the HID lamp may only be ignited, but fail to enter steady state. So there are some factors to be considered in order that the HID lamp will be successfully lighted.

A. The timing control

The HID controller must arrange each function part of HID circuit to work at different time stage. To the inverter, firstly, it must operate in advance to provide a path for charging the capacitor of voltage doubler. Secondly, if the lamp is ignited, DC-DC converter must immediately provide enough current to sustain arc through the inverter. Otherwise, the lamp will extinguish immediately. From Fig.9, there is the current of a positive and a negative platform that sustain arc. It is very important to light the HID lamp successfully. Because, once the HID lamp is ignited, it needs a DC current to sustain the arc. Otherwise, the HID lamp may extinguish. Thirdly, high start-up power is necessary in order to get the light out to 75% of its steady state value rapidly. So a high current has been provided to the HID lamp until output power reach up to 75w. Then the lamp power decreases to 35w gradually. So, the timing control is very important for the automotive HID ballast.

B. Take-over current

As mentioned in previous paragraph, after ignition, the HID lamp requires enough take-over current to sustain arc immediately. Once the HID lamp is ignited, DC-DC converter doesn't respond rapidly. So energy stored previously in a large capacitor C2 will supply enough large current to sustain arc.

C. Insulation

For the igniter transformer, the key issue is to prevent short circuit between windings. Bad insulation can result in serious problem. The igniter transformer should has the capability of generating high voltage pulse ($>15\text{kV}$) to realize hot restrike. If insulation is not good, the high voltage will attenuate which result in failure of ignition. In addition, reasonable insulation can help the HID lamp sustain arc for a longer time.

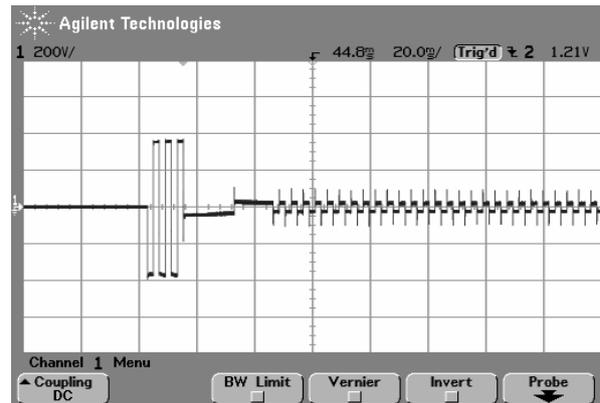


Fig.8. Transition of inverter output voltage

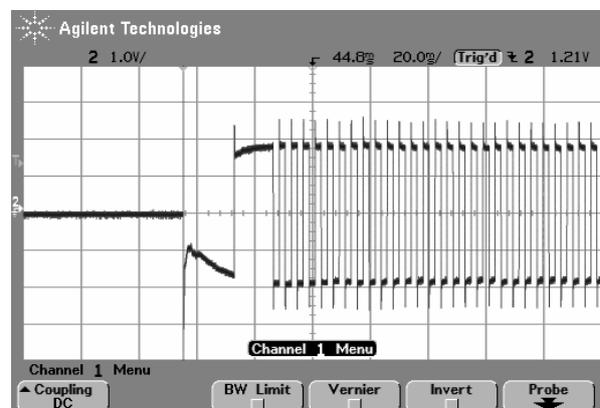


Fig.9. The transition of HID lamp current.



Fig.10. Prototype of the HID ballast based microprocessor

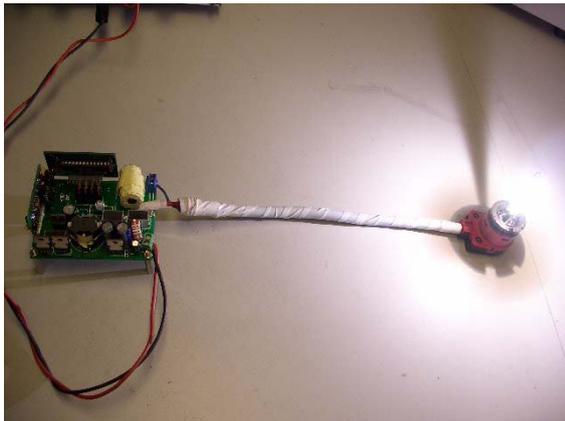


Fig.11. The experimental photo of the HID ballast

Fig.8 is the transition of inverter output voltage. In Fig.8, the transition of inverter output voltage shows that the timing control can meet the start-up characteristics of the HID lamp. The transition of HID lamp current is shown in Fig.9. Fig.10 is the prototype of the HID ballast based microprocessor, the size of which is small and compact (84mm*68mm*35mm). Fig.11 is the experimental photo of the HID ballast.

V. CONCLUSION

A low cost and small size ballast for automotive HID lamp based microprocessor is developed. The HID electronic ballast has been validated by experimental prototype. Because of the cheap and other merits of microprocessor, microprocessor is very suit to use for the HID electronic ballast. Some improvement on hardware and software enhance the performance of HID ballast including ignition, protection, reliability and cost.

VI. REFERENCES

- [1] Ron Fiorello, "powering a 35W DC metal halide HID lamp using the UCC3305 HID lamp controller", Unitrode Application Note U-161.

- [2] Kyu-Chan Lee, Bo Hyung Cho, " Design and analysis of automotive high intensity discharge lamp ballast using microcontroller unit", *IEEE transaction on Power Electronics*, pp. 1356-1364, vol. 18, no 6, Nov 2003
- [3] W.S. Kim, B.H. Cho and K.C. Lee, "Design and analysis of High-Voltage transformer for HID lamp igniter", APEC 2005, pp. 1043-1047, vol 2, march 2005.
- [4] Alberto Reatti, "Low-cost high power-density electronic ballast for automotive HID lamp", *IEEE transaction on Power Electronics*, pp. 361-368, vol. 15, no. 2, March 2000

VII. ACKNOWLEDGMENT

The authors would like to thank the support of the Hong Kong Polytechnic University. This work was supported in ITF for the funding support under the project GHS/073/04.

VIII. BIOGRAPHIES

D.H.Wang received the M.S.degree in Power Electronics & Drives from Shanghai University. Now, he is working on a project on HID lighting for automobiles in Electrical Engineering Department, The Hong Kong Polytechnic University. His research interests include various power electronic converters, power factor corrections and electronics ballast for HID lamp.

Prof. Eric Cheng received his BSc and PhD from the University of Bath in 1987 and 1990 respectively. He then worked in University of Birmingham as Research Fellow then work in Lucas aerospace as Principal Engineer. In 1997, he joined the Hong Kong Polytechnic University where he is now the Professor in the Department of Electrical Engineering and the Director of Power Electronics Research Centre. He has published more than 200 papers. His research interest is all aspects of power electronics and drives.

B.P. Divakar received the M.E. Degree from Annamalai University, India in 1991, in Power Systems and Ph.D. degree from The Hong Kong Polytechnic University in 1998, in power Electronics. He has several years of teaching and research experience. At present he is a research fellow in Department of Electrical Engineering, The Hong Kong polytechnic university. His research interests are in soft-switching of converters, power factor controllers, application of SMES and BESS, EMI and HID lightings.

P. Dong received her Masters degree from South China University of technology, China in 2004. At present she is working towards Ph.D. degree in Electrical Engineering Department, The Hong Kong Polytechnic University.