TB053

Generating High Voltage Using the PIC16C781/782

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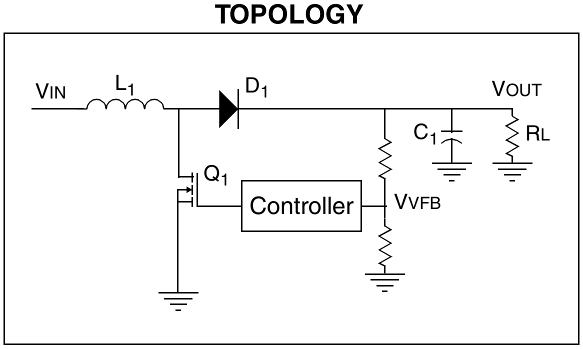
INTRODUCTION

The Nixie tube is a device born out of the middle twentieth century, used to display digital information in a human readable format. Basically, it is a high-voltage numerical display. Today, the Nixie tube has been replaced by more efficient, more durable, and longer lasting devices, such as LED displays and LCDs. However, for this technical brief, the Nixie tube serves as an excellent visual feedback of the PIC16C782 device's ability to generate high voltage from a low-voltage source.

This technical brief introduces the boost converter topology operating in Discontinuous mode. As an example, a simple 9V to 170V DC-DC converter is designed based on this topology, and is used to provide power to a three-digit Nixie tube display. The PIC16C782 is used to control the DC-DC converter and provides data decoding for the display. To make the display useful, the PICmicro® MCU samples a temperature sensor and displays the results.

THE BASIC BOOST TOPOLOGY (DISCONTINUOUS MODE)

FIGURE 1: BOOST CONVERTER TOPOLOGY



In the basic boost topology shown in Figure 1, the input voltage (V_{IN}) is always less than the output voltage (V_{OUT}). Initially, energy is stored in inductor L_1 when Q_1 is turned on. From the electrical characteristics of the inductor, the current ramps up linearly according to Equation 1 (assuming inductor series resistance and switch on resistance are negligible).

EQUATION 1:

$$V_{IN} = L_1 \frac{di_L}{dt} \rightarrow \frac{V_{IN}}{L_1} t = i_L$$

The peak current is achieved the moment before Q_1 turns off. Equation 2 shows the peak current, where D is the duty cycle and T is the period for Pulse-Width Modulation (PWM).

EQUATION 2:

$$\frac{V_{IN}}{L_1} DT = I_{PEAK}$$

The current in an inductor cannot change instantaneously. When Q1 is switched off, the current in L1 continues to flow through D_1 to the storage capacitor, C_1, and the load, R_L. Thus, the current in the inductor decreases linearly in time from the peak current. In discontinuous operation, the inductor current actually falls to zero. Equation 3 shows this relationship.

EQUATION 3:

$$\frac{di_L}{dt} = \frac{V_{IN} - V_{OUT}}{L_1} \rightarrow i_L = \frac{V_{IN} - V_{OUT}}{L_1} t + I_{PEAK}$$

During this linear decrease in current, the energy stored in the inductor is transferred to C_1. The result is a simple relationship between input and output voltage shown in Equation 4. This equation is derived from the simple concept: power in equals the power out. Refer to the publications listed under **"REFERENCES"** for more details.

EQUATION 4:

$$V_{OUT} = V_{IN}\sqrt{\frac{R_L DT}{2L_1}}$$

A HIGH-VOLTAGE DISPLAY EXAMPLE

The Nixie tubes used in this design require 170 VDC, at a peak operating current of approximately 4 mA or 0.68 Watts per tube. For a three-digit display, the peak operating power is slightly over 2 Watts. The input to the supply is 9 VDC. Thus, the desired power supply design is a 9V to 170V DC-DC converter, with a maximum output operating power of 2 Watts.

The programmable functions of the PIC16C781/782 are considered together with the design of the boost power circuit. The following options in the PIC16C781/782 are selected which affect the DC-DC converter operation:

- Internal 4 MHz oscillator is selected
- PWM clock set to FOSC/128
- Maximum duty cycle set to 75%

Essentially, this means the on time of the MOSFET, Q1, is about 24 µs. Using Equation 4, a function for power in terms of inductance is easily derived:

EQUATION 5:

$$170 = 9\sqrt{\frac{\frac{(170\ Volts)^2}{(P)Watts}\ 24\ \mu S}{2L_1}} \rightarrow P = \frac{(24\ \mu S)(9\ Volts)^2}{2L_1}$$

The desired peak output power of the DC-DC converter is 2 Watts. To achieve this, the output power must be greater to overcome losses in the voltage conversion. Therefore, an inductor size must be chosen to achieve a power output of 2 Watts, plus some power loss. The inductor chosen for this design is 330 µH. This means the maximum power is 2.945 Watts, assuming no power loss. With power loss, the lowest allowable efficiency for the chosen inductor is 67.9%. Efficiency in the 70% region is a reasonable assumption for this design and should not be a problem.

The peak current, from Equation 2, for the 330 µH inductor is:

EQUATION 6:

$$\frac{9}{2L_1}\ 24\ \mu S = I_{PEAK} = 0.655\ Amps$$

Power inductors, in the range of 330 µH @ 0.655A, are common and readily available.

This design is intended to run in Discontinuous mode and should stay in Discontinuous mode throughout the load range. Therefore, the rise and fall time of the current in the inductor for maximum load is compared with the switching period. The rise time of the inductor current is already known to be 24 µs. The fall time is calculated using Equation 3.

EQUATION 7:

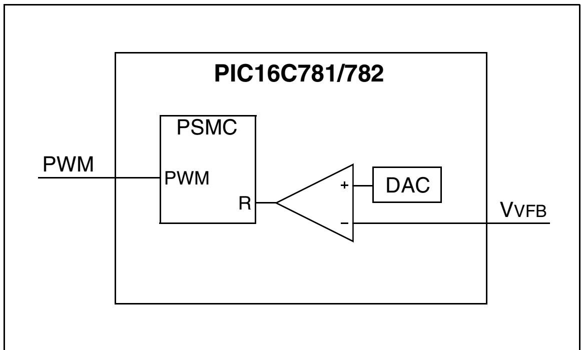
$$0 = \frac{(9 - 170)\ Volts}{330\ \mu H}\ t_{fall} + 0.655\ Amps \rightarrow t_{fall} = 1.34\ \mu s$$

The inductor has current flowing through it for a total of 25.34 µs. The period T is 32 µs, which is much larger than the total time the current is flowing. Thus, the supply is sure to stay in Discontinuous mode for the given input and load conditions.

CLOSING THE LOOP WITH THE PIC16C781/782

The control loop is closed with the PIC16C781/782. Figure 2 shows the configuration within the PIC16C781/782. Essentially, the voltage feedback is compared to a fixed voltage. The Digital-to-Analog Converter provides the fixed voltage reference. When the feedback voltage crosses the voltage reference, the Programmable Switch Mode Controller (PSMC) output is reset. Thus, changing the reference voltage provided by the Digital-to-Analog Converter (DAC) changes the output voltage, VOUT.

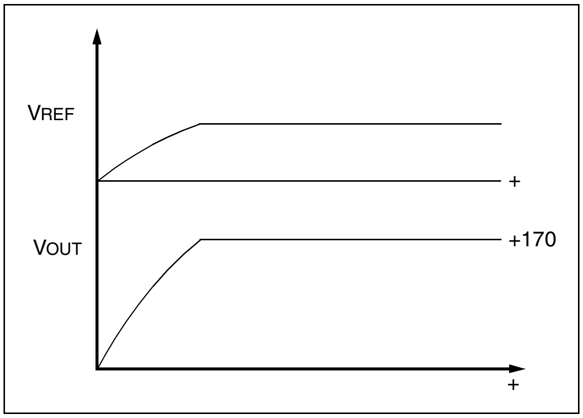
FIGURE 2: PIC16C781/782 CONTROL LOOP CONFIGURATION



This feedback method is unusual for this topology. Energy is transferred from the inductor when the Pulse-Width Modulation (PWM) is in its negative (low output) portion of the duty cycle. However, the PSMC has acting feedback control only during the positive portion of the duty cycle. Thus, energy is transferred to the output on the cycle prior to the control portion. The net result is a pseudo pulse-skip operation, while the PIC16C781/782 PSMC is in the PWM mode. Refer to the *"PIC16C781/782 Data Sheet"* (DS41171) for information about the PSMC and its standard modes of operation. To smooth the output ripple due to pulse skipping, the minimum pulse width in the PIC16C781/782 is set to 25%.

Soft start is provided in the software. By slowly increasing the voltage reference, the output voltage ramps up linearly over several hundred milliseconds (Figure 3). Gradually ramping up controls the current drawn during start-up. This prevents saturating the inductor, thus, preventing excessive current through the switch. As a result, a smaller FET can be used safely.

FIGURE 3: VOLTAGE OUTPUT REFERENCE



CONCLUSION

Nixie tubes are very much out of date in terms of technology and have passed into history. However, there are some applications that still require high voltage, for example, EL backlighting and low-current fluorescent lighting. This application demonstrates the ability of the PIC16C781/782 to perform a simple DC-DC voltage boost and have additional control for other system functions.

REFERENCES

1. Ross, J. N., *The Essence of Power Electronics*, Prentice Hall, New York, 1997.
2. Pressman, Abraham I., *Switching Power Supply Design*, McGraw-Hill, New York, 1998.

APPENDIX A: SCHEMATICS

FIGURE A-1: HIGH-VOLTAGE DRIVER DISPLAY CONTROL

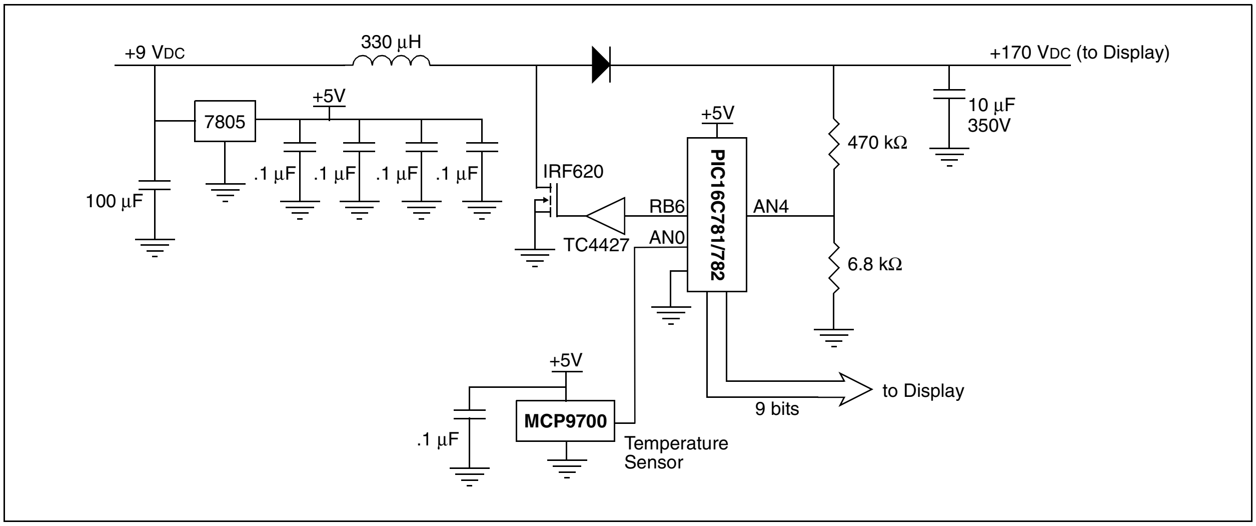
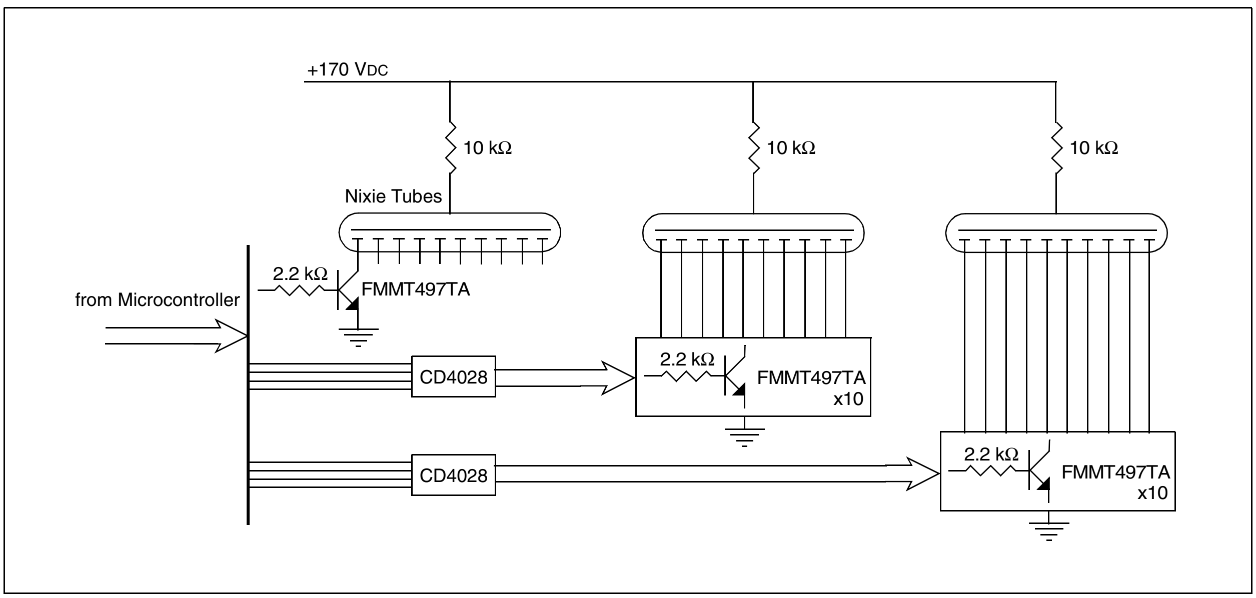


FIGURE A-2: NIXIE TUBE DISPLAY



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