Boost Converter Provides Temperature-Controlled Operation of 12V Fan from +5V Supply

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The temperature controlled pulse-width-modulator (PWM) boost converter shown in Fig. 1 allows operation of a 12V brushless DC fan from a +5V supply. The circuit is based on the Unitrode UCC2805, a single chip BiCMOS PWM controller which contains all the necessary circuitry (voltage reference, error amplifier, comparator, MOSFET gate drive, and oscillator) for closed loop PWM power supply control. At maximum boost, a voltage of +10V is provided to the fan, which operates at about 80% of its rated (12V supply) speed. Fan speed is controlled by sensing the ambient temperature in the system enclosure, and reducing the fan supply voltage when maximum cooling is not necessary. Reducing the operating speed of the fan not only saves power but also extends operating life and reduces acoustic noise.

The UCC2805, which can be configured for either voltage-mode or current-mode feedback, is used here in a voltage-mode configuration controlling the boost converter formed by Q1, D1, L1, and C1. The switch element, Q1, is a logic level MOSFET that can be driven from the 5V-swing gate drive signal OUT at pin 6. As shown in the timing diagram in Fig. 1, the duty cycle of the switch drive signal is determined by on-chip comparison of the control voltage COMP (pin 1) to a sawtooth waveform CS (pin 3). The R3/R4 network attenuates the charge/discharge waveform on the oscillator timing capacitor C2, to develop a sawtooth waveform at CS of the proper amplitude for comparison with the control voltage COMP. The frequency of the on-chip PWM oscillator is set to 120kHz by R2 and C2. The oscillator uses the on-chip +4V reference to keep the frequency independent of variations in the +5V supply voltage.

For this boost converter with a +5V input, the approximate relationship (assuming the voltage drop across Schottky diode D1 to be negligible) between output voltage and duty cycle D is given by

$$V_{OUT} = \frac{5V}{1-D} \qquad \text{(Eq. 1)}$$

Thus as duty cycle increases, V_{OUT} increases. At the minimum duty cycle of zero, V_{OUT} reaches its minimum value of +5V . This ensures that stalling of the fan (which occurs at a fan supply voltage of about 4V) cannot occur. An on-chip control block limits the minimum duty cycle to 50%, corresponding to a maximum fan voltage of 10V. This limit is necessary since the V_{OUT} of the boost converter deviates significantly from Eq. 1 for duty cycles near unity, causing the control loop to become unstable.

When V_{OUT} is within the 5V to 10V range, the system acts as a closed loop controller, increasing fan voltage (and thus fan speed) if an increase in ambient temperature is detected. The loop uses proportional control, since the long thermal time constant associated with sensing ambient temperature makes it difficult to compensate an integral control loop.

Resistor R_T, a negative temperature coefficient (NTC) thermistor located in the fan airflow path, acts as the sensor that incorporates temperature information into the control voltage COMP at the input of the comparator. The on-chip reference is used in the R_T/R5/R6 temperature sensing network, so that the temperature control characteristic is unaffected by supply variations.

The negative feedback loop that controls fan speed based on temperature can be seen by following the control signal around the loop from R_T to the fan supply voltage. When the ambient temperature increases, the value of R_T decreases, increasing the current in R_T, and increasing the value of the control voltage COMP at the output of the error amplifier. This changes the duty cycle of the comparator output and MOSFET gate drive such that the amount of time when Q1 is "on" increases. This in turn increases the output voltage of the boost converter supplying the fan, which increases the fan operating speed.

The fan speed vs. temperature profile is characterized by two temperature points: T1 (below which the fan runs at a supply voltage of 5V) and T2 (above which the fan runs at the maximum of 10V). The desired temperatures

for T1 and T2 determine the values of resistors R5 and R6, which scale and shift the control voltage at the output of the error amplifier. The resistances are determined from the values of the thermistor $R_{T(T1)}$ and $R_{T(T2)}$ at temperatures T1 and T2:

$$R5 = \frac{1.2}{\frac{2.2}{R_{T(T2)}} - \frac{1}{R_{T(T1)}}} \qquad \text{(Eq. 2)}$$

$$R6 = \frac{0.3}{\frac{1}{R_{T(T2)}} - \frac{1}{R_{T(T1)}}} \qquad \text{(Eq. 3)}$$

The system shown in Fig. 1 was designed for an enclosure containing circuitry with power dissipation that varied from 5W to 30W. The values chosen for the temperature profile were T1=77 °F and T2=86 °F, at which the thermistor had values of $R_{T(T1)}$=200 kΩ and $R_{T(T2)}$=154 kΩ respectively. Measurements on the circuit showed an actual full output voltage of V_{OUT}=+9.83V, with corresponding DC fan current of I_{FAN}=117mA and 5V DC supply current of I_{CC}=258mA. At the minimum measured fan voltage of V_{OUT}=+4.91V, the fan current was I_{FAN}=60.4mA, and the 5V supply current was I_{CC}=63.5mA.

If a different temperature profile is required (for example, in a different enclosure or power dissipation range), the new values of R5 and R6 are given by substituting the thermistor values at the new T1 and T2 into (Eqs. 2, 3).

To use this circuit with a load requiring a higher operating current, it's necessary to change the values of C1 and L1. The value of C1 needs to be increased in proportion to the increase in current, to keep the same ripple amplitude. The value of L1 needs to be decreased (changed in inverse proportion to the increased current), since the maximum output current is inversely proportional to the inductance. For large increases in current, Q1 and D1 may need to changed as well.

Finally, a note of acknowledgment and appreciation for the work of Luis Menezes, Jeff Kulesza, and Nina Tjoa, who completed the detailed design of the circuit and built and tested the prototype.

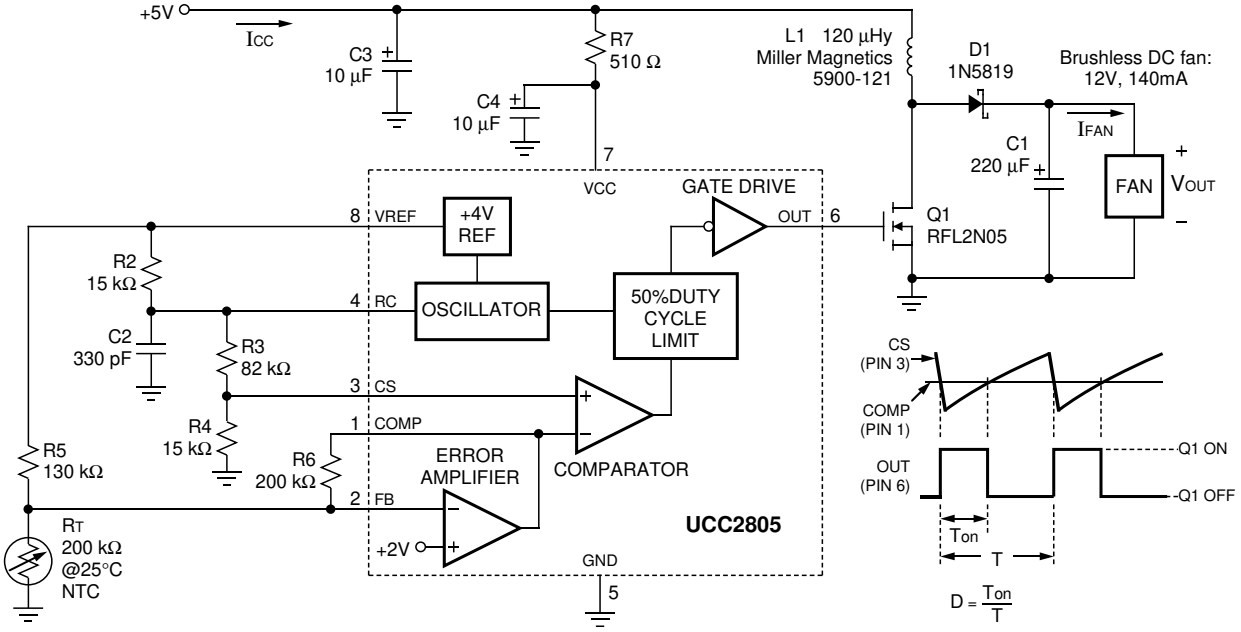

Figure 1.