APPLICATION NOTE 4557

Digital Resistor Sets Operating Power for Laser Driver

Mar 31, 2011

Abstract: Adding an op amp and a digital potentiometer to a standard laser-driver circuit produces a driver that varies the laser’s power-set point in response to temperature, generating a photodiode current that is a linear function of the potentiometer value.

A similar version of this article appeared in the March 15, 2007 issue of ED magazine.

The MAX3740 VCSEL laser driver and DS1859 dual, temperature-controlled digital resistor are popular choices for SFP and SFF fiber-optic systems, due to their small size and high level of integration. The MAX3740 uses a monitoring photodiode and automatic power-control loop (APC) to compensate the laser power for temperature effects and aging. Photodiode responsivity can vary as much as 40%, so the system needs some additional compensation. That can be achieved with a digital resistor, which varies the power set-point in response to temperature.

A resistor between the MAX3740 reference pin (REF) and the power monitor photodiode (MD) sets the photodiode current. The power-control loop then drives the laser diode to the intensity that delivers that current. The problem with this approach is a too-low control voltage: the nominal voltage at MD is 1.6V and the nominal voltage at REF is 1.8V, leaving only 0.2V across the resistor for setting the photodiode current.

Digital resistors like those in the DS1859 can have minimum resistances as high as 1kΩ, which in turn gives a maximum current of only 200µA. The resulting current vs. resistance function is very nonlinear, with poor resolution at high currents. You can add a fixed resistor between REF and MD to raise the maximum current, but the adjustment range is still only 200µA. (Nor does the fixed resistor provide any improvement in nonlinearity and resolution.) A graph of photodiode current vs. DS1859 resistance (lower-left trace in Figure 1) shows the response of a circuit with series resistor value of 806Ω, which biases up the response by 248µA.
Figure 1. The MAX3740 laser driver with external photodiode produces a nonlinear control voltage for the laser (lower-left trace). Adding a digital resistor and op amp (Figure 2) produces the linear control voltage shown. The solution to these problems (Figure 2) is to allow the resistor between REF and MD (R1) to set the maximum photodiode current, and then subtract a current proportional to the DS1859 resistance. The subtracted current comes from the op-amp output, which steals current from the photodiode through R2. The op amp shown was chosen for its small size (SC70 package) and low cost. It is powered by the same +3.3V power supply as the digital resistor (DS1859) and laser driver (MAX3740).

Figure 2. An external op amp and digital resistor (DS1859) enable the MAX3740 laser driver to generate the linear control voltage shown in Figure 1.

The op amp generates a voltage ($V_O$) proportional to the value of MD (REF - MD) and the DS1859...
value. In turn, the voltage generates a current through $R_2$ proportional to the difference between the voltages at $V_O$ and $MD$. The effects at $MD$ cancel out, so the current through $R_2$ depends only on $(REF - MD)$, a stable 0.2V, and the DS1859 value. Current through the photodiode equals the current thru $R_1$ (803µA) minus the current thru $R_2$. Thus, photodiode current is a linear function of the potentiometer value, as illustrated in Figure 1. With appropriate resistor values, this circuit works with any value potentiometer and provides current over any range. Its only limitation is the current-drive capability of the op amp. Design calculations are:

Derivation of equations

**Equation for op amp output voltage**

$$
V_{OUT} = V_{REF} \times \left(\frac{-R_{DS1859}}{R_3}\right) + V_{MD} \times \left(1 + \frac{R_{DS1859}}{R_3}\right)
$$

Rearrange terms

$$
V_{OUT} = V_{MD} + \frac{(V_{MD} - V_{REF}) \times R_{DS1859}}{R_3}
$$

Substitute 0.2V for reference voltage - modulation voltage

$$
V_{OUT} = V_{MD} - \frac{0.2V \times R_{DS1859}}{R_3}
$$

**Equation for current through $R_2$**

Substitute in equation for op amp output voltage

$$
I_{R2} = \frac{V_{OUT} - V_{MC}}{R_2}
$$

Modultion voltage terms cancel out

$$
I_{R2} = -\frac{0.2V \times R_{DS1859}}{R_3 \times R_2}
$$

**Equation for current through $R_1$**

Substitute 0.2V for reference voltage - modulation voltage

$$
I_{R1} = \frac{V_{REF} - V_{MD}}{R_1}
$$

$$
I_{R1} = \frac{0.2V}{R_1}
$$

**Equation for current through photo diode**

$$
I_{PD} = I_{R1} + I_{R2}
$$

Substitute equations for $R_1$ current and $R_2$ current

$$
I_{PD} = \frac{0.2V}{R_1} - \frac{0.2V \times R_{DS1859}}{R_3 \times R_2}
$$

Where

- $R_1 = 249\Omega$
- $R_2 = 1240\Omega$
- $R_3 = 10000\Omega$
- $I_{PD} = 787\mu A$, DS1859 resistance = $1k\Omega$
I_{PD} = -3.3\mu A, DS1859 resistance = 50k\Omega

Design procedure

Select desired photodiode min and max current

\[
\begin{align*}
I_{PD\max} &\equiv 800 \times 10^{-6} A \\
I_{PD\delta} &= I_{PD\max} \cdot I_{PD\min} \\
I_{PD\min} &\equiv 0 A \\
I_{PD\delta} &= 8 \times 10^{-4} A
\end{align*}
\]

DS1859 min and max values

\[
\begin{align*}
R_{DS1859\max} &\equiv 50000 \Omega \\
R_{DS1859\delta} &= R_{DS1859\max} \cdot R_{DS1859\min} \\
R_{DS1859\min} &\equiv 1000 \Omega \\
R_{DS1859\delta} &= 4.9 \times 10^4 \Omega
\end{align*}
\]

Op amp output voltage range

\[
\begin{align*}
V_{OUT\max} &= 2.0 V \\
V_{OUT\delta} &= V_{OUT\max} - V_{OUT\min} \\
V_{OUT\min} &= 0 V \\
V_{OUT\delta} &= 2 V
\end{align*}
\]

Modulation voltage min and max

\[
\begin{align*}
V_{MD\min} &\equiv 1 V \\
V_{MD\delta} &= V_{MD\max} - V_{MD\min} \\
R_1 &= \frac{0.2V}{I_{PD\max}} \\
R_3 &= \frac{0.2V \times R_{DS1859\delta}}{V_{OUT\delta} - V_{MD\delta}} \\
R_2 &= \frac{0.2V \times R_{DS1859\delta}}{I_{PD\delta} \cdot R_3}
\end{align*}
\]

\[
\begin{align*}
R_1 &= 250 \Omega \\
R_3 &= 9.8 \times 10^3 \Omega \\
R_2 &= 1.25 \times 10^3 \Omega
\end{align*}
\]

**Related Parts**

<table>
<thead>
<tr>
<th>Part</th>
<th>Description</th>
<th>Free Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS1859</td>
<td>Dual, Temperature-Controlled Resistors with Internally Calibrated Monitors</td>
<td></td>
</tr>
<tr>
<td>MAX4245</td>
<td>Ultra-Small, Rail-to-Rail I/O with Disable, Single/Dual-Supply, Low-Power Op Amps</td>
<td></td>
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</tbody>
</table>

**More Information**

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Application Note 4557: [http://www.maximintegrated.com/an4557](http://www.maximintegrated.com/an4557)
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