

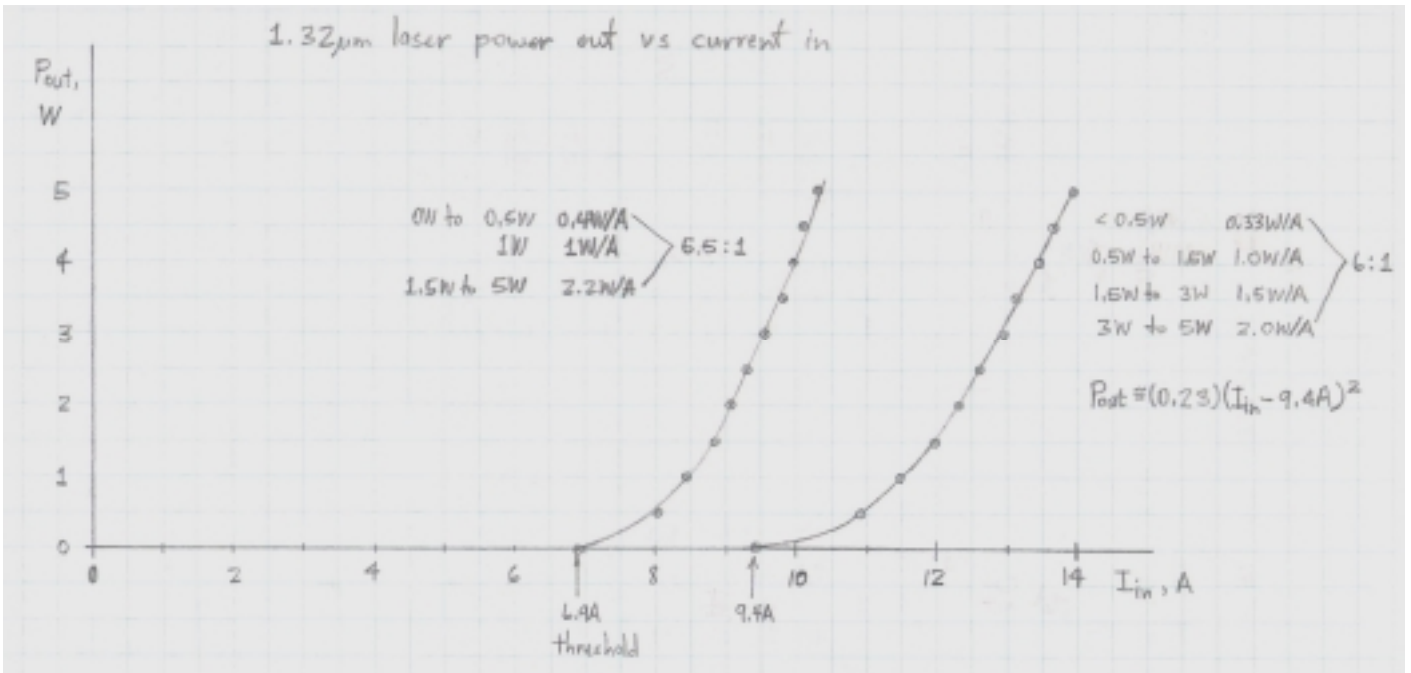
Mixed-Technology Laser System
by Dennis L Feucht

Problem: Two digital engineering partners were consulting for a company designing a medical laser. It contained three microcontrollers, each a commercial product on a single board. One controller ran the main functions and commanded the other two. One of the others ran the user interface and the third controlled the laser system. The RS-485 interfaces between the slave controllers and the main one were via serial ports on a motherboard. At power-on, they were seeing unreliable start-up activity. Sometimes the user interface would be unresponsive. The software engineers could not find any clues to the malfunction in their programming. The hardware design partners would repeatedly test each of the controller boards and they performed flawlessly. By swapping in different controller units, the behavior would change, but the unreliability of the start-up did not go away.

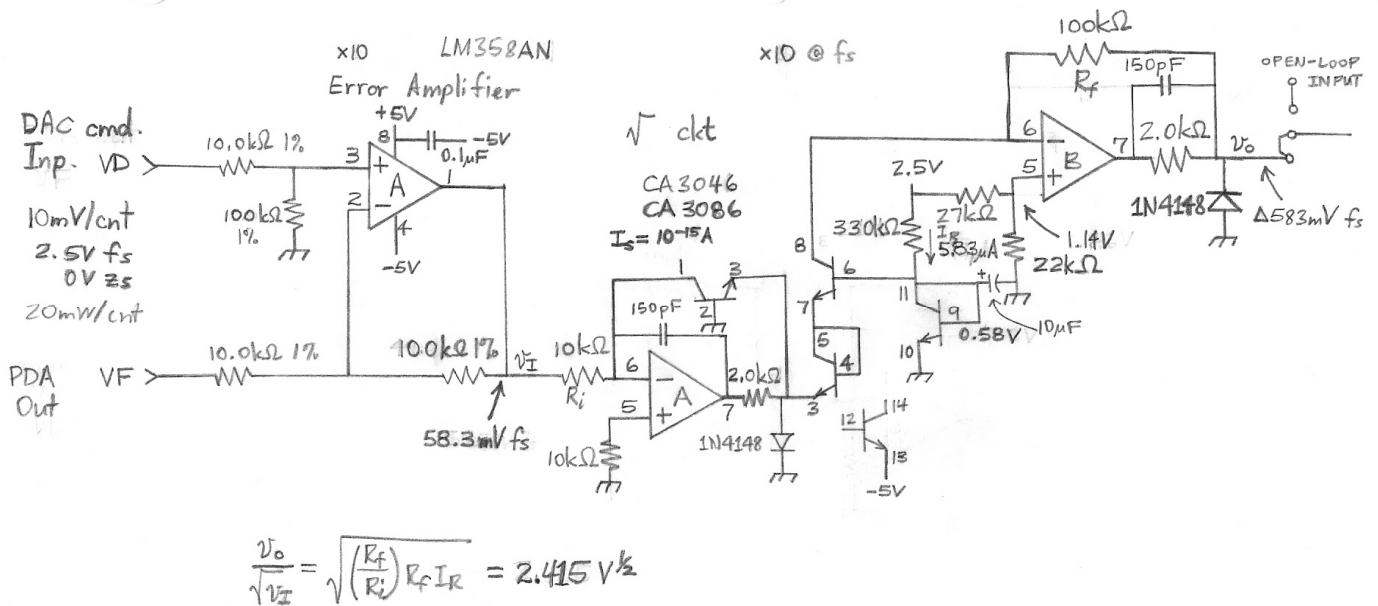
Solution: The fact that power-on behavior was not repeatable was the key clue. Each of the controllers worked correctly and each had their own power-on, power-off circuitry. However, the controller power-on reset timing had some variability among controller units. This is unavoidable and normally it is not a problem if a controller takes t versus $t + \Delta t$ μ s to negate the reset waveform to the controller after the power-on threshold has been crossed by V_{DD} . This variability will mainly be due to the varying threshold voltage values in the controllers.

In this case, it was essential that the main controller not start sending commands to the slave controllers before they were properly booted up. By placing a start-up delay in the main controller, variations in reset times among the controllers would be accounted for by making this delay long enough to ensure that the slave controllers were always ready and waiting for a serial-port command string.

Postscript: the software delay quickly solved the problem after the hardware designers had been wrestling with it for some time. I chuckled to myself when one of the partners grinned as he said to me: "Beginner's luck."



To fix this problem, a square-root circuit was introduced in the loop circuitry, in the forward path, after the error amplifier. The simplified circuit is shown below.



By introducing a function that was the inverse of the flashlamp-laser transfer function, the loop gain became relatively constant over the dynamic power range of the laser, with similar loop-gain error and stability margins over the power range.

The square-root circuit is based on the translinear principle (as covered in *Analog Circuit Design*; see <http://www.innovatia.com>). A CA3086 IC of 5 matched npn BJTs was used to implement it, as shown above. The basic equations of its operation are as follows, where subscripts correspond to CA3086 pin numbers:

$$v_3 = -V_T \cdot \ln\left(\frac{i_l}{I_S}\right)$$

$$v_6 = V_T \cdot \ln\left(\frac{I_R}{I_S}\right)$$

$$v_6 - v_3 = 2 \cdot V_T \cdot \ln\left(\frac{i_O}{I_S}\right) = V_T \cdot \ln\left(\frac{i_O}{I_S}\right)^2 = V_T \cdot \ln\left[\left(\frac{I_R}{I_S}\right) \cdot \left(\frac{i_I}{I_S}\right)\right]$$

The coefficient of 2 follows from having two $p-n$ junctions in series -- the $b-e$ junctions of BJTs with base pin numbers 4 and 6. Then:

$$\left(\frac{i_O}{I_S}\right)^2 = \left(\frac{I_R}{I_S}\right) \cdot \left(\frac{i_I}{I_S}\right)$$

When simplified, and for matched junctions with the same values of I_S , this leads to:

$$i_O^2 = I_R \cdot i_I$$

or:

$$i_O = \sqrt{I_R \cdot i_I}$$

As a voltage amplifier, $v_I = i_I R_i$ and $v_O = R_f i_O$. Substituting, the voltage gain of the square-root circuit is:

$$\frac{i_O^2}{i_I} = I_R = \frac{(v_O / R_f)^2}{(v_I / R_i)}$$

Then:

$$\frac{v_O^2}{v_I} = \left(\frac{R_f}{R_i}\right) \cdot R_f \cdot I_R$$

and:

$$\frac{v_O}{\sqrt{v_I}} = \sqrt{\left(\frac{R_f}{R_i}\right) \cdot R_f \cdot I_R} = \sqrt{\left(\frac{100 \text{ k}\Omega}{10 \text{ k}\Omega}\right) \cdot 100 \text{ k}\Omega \cdot (58.3 \mu\text{A})} = 2.41 \text{ V}^{\frac{1}{2}}$$

Problem: After the previous (and other) problems were solved, the aforementioned laser was showing a drift in output power. The drift was causing the laser to be "out-of-spec" somewhat and hard to characterize. That is, it seemed rather random. Each functional block in the optoelectronic feedback loop was scrutinized in some detail, especially the feedback photodiode and its amplifier in the feedback path.

Solution: This problem was not solved during my involvement in this project but the cause of it was almost certainly identified. It was not electronic but optical. The dichroic mirror used to pick off a small fraction of the output light for the photodiode had a different transmittance through the mirror depending upon the polarization of the light. This ordinarily would not be a problem with a stable light source of fixed polarization. However, upon closer examination it was discovered that a Nd YAG (neodymium yttrium aluminum garnet) laser can oscillate in various modes, in a similar way to the modes possible in a microwave waveguide. Furthermore, which mode of oscillation actually occurred was determined chaotically (as in mathematical chaos) and was a highly nonlinear phenomenon. The different modes had different output polarizations. No amount of electronic compensation would have been of help.

This is the kind of problem that design engineers most want to avoid: a problem in which a foundational element of the system will not perform satisfactorily and for which there is no

practical method of compensation for its limitations. I do not know what course of action the company took in response to this problem, though they are still around. Perhaps the specs were changed to allow for the power variations and different medical applications sought for it. The last I had heard, this was the case. The lesson to be learned from this problem is: be sure you understand well the critical elements of your system before embarking upon a product design that uses them.

