Novel Switched Current Source for Increasing Output Signal Edge Steepness of Current Switches Without Generating Large Overshoot

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***Abstract*— Shortly switching off the current supplied to a current switch improves edge steepness and reduces overshoot of the output current. This allows higher input voltage swing to achieve yet steeper edges while keeping overshoot reasonably small. An example shows reduction of rise time and fall time to 50% and 70%, respectively.**

I. Introduction

A. Problems Related to Switching-On and Switching-Off a Laser Diode

In high-speed digital optical fiber transmission systems, where laser diodes are driven with up to 50 mA at data rates up to 10 Gb/s [1], transmission with high extinction ratio is desired in order to achieve a high system sensitivity. A high extinction ratio means that the lower level of the optical output power is zero or close to zero, thus switching the laser diode from the near-threshold-region to the higher level of the optical output power and vice versa. For this kind of operation it is a well-known problem that switching-on the laser diode is relatively fast and mostly is combined with a large overshoot of the optical output power, whereas switching-off is comparatively slow [2], [3]. This behavior is simplified shown in Fig. 1. (Figs. 1, 2, 4–6 are not simulation results or the like, but only schematic sketches to illustrate the bacic idea.) The corresponding eye patterns for the same pulse shapes are shown in Fig. 2. It can be seen that for the optical output power—due to the fast switching-on and the slow switching-off—both the horizontal eye opening at half of the maximum output power and the vertical eye opening in the middle between the intersection points of the rising and falling edges are decreased.

For the realization of fast driving circuits the current-switch technique with differential input is commonly used, e.g., [1]. Fig. 3(a) shows the principle of such a driver circuit. The current source I_0 usually is realized by a resistor or by a transistor current source. However, mainly due to charging and discharging the base-emitter junction capacitances of the current-switch transistors, there are some unwanted effects: Rise and fall time of the output current I are not equal (as for sake of simplicity has been assumed in Figs. 1 and 2), but the rise time is comparatively short and the fall time is longer than the rise time. Furthermore, switching-on normally also shows an overshoot. These asymmetrical edges of the output current pulses aggravate the asymmetrical laser response mentioned above.

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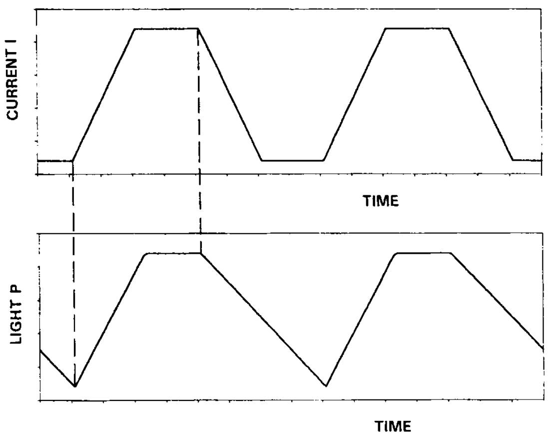


Fig. 1. Driving current and optical output power of a laser diode (schematically).

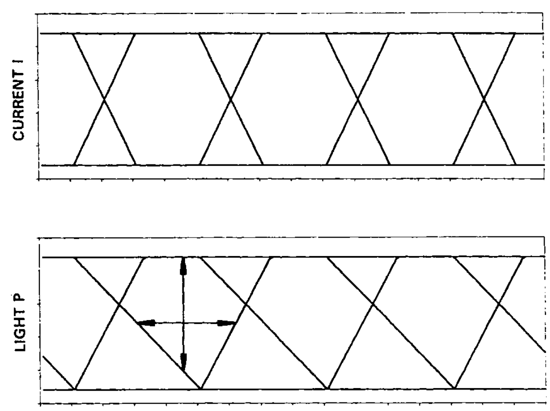


Fig. 2. Eye patterns for driving current and optical output power of a laser diode (schematically).

B. Desired Pulse Shape of the Driving Current

To avoid the degradation of the optical eye pattern due to the asymmetrical switching behavior of the laser diode, the driving current should have a pulse shape which compensates the behavior of the laser diode. This can be achieved, if the intersection points of rising and falling edges in the eye pattern of the driving current are shifted from half the maximum

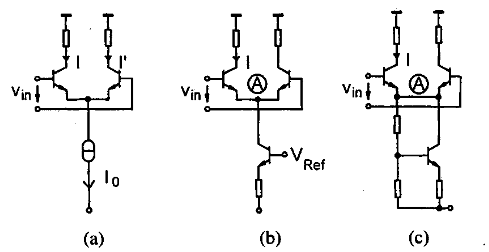


Fig. 3. Current switch with (a) ideal current source I_0, (b) standard transistor current source, (c) novel switched transistor current source.

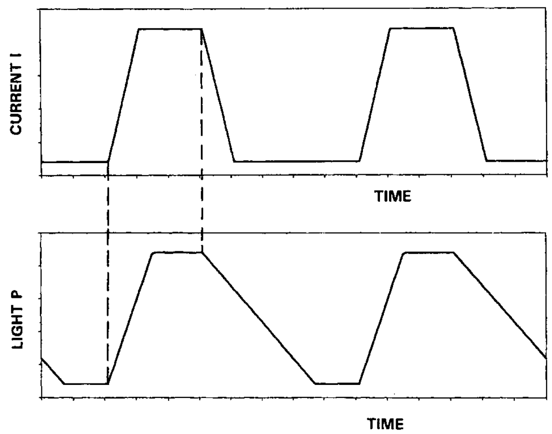


Fig. 4. Improved pulse shape of driving current and resulting optical output power of a laser diode (schematically).

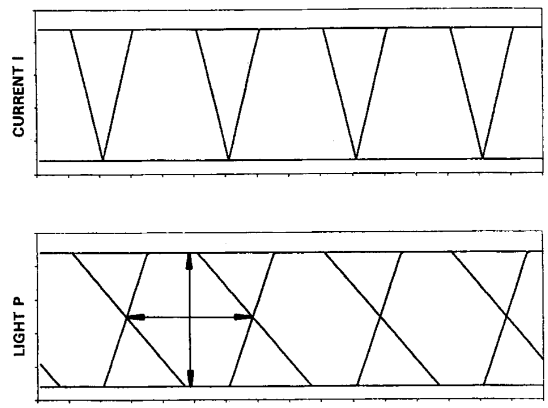


Fig. 5. Eye patterns for driving current and optical output power of a laser diode in the case of the improved shape of the driving current (schematically).

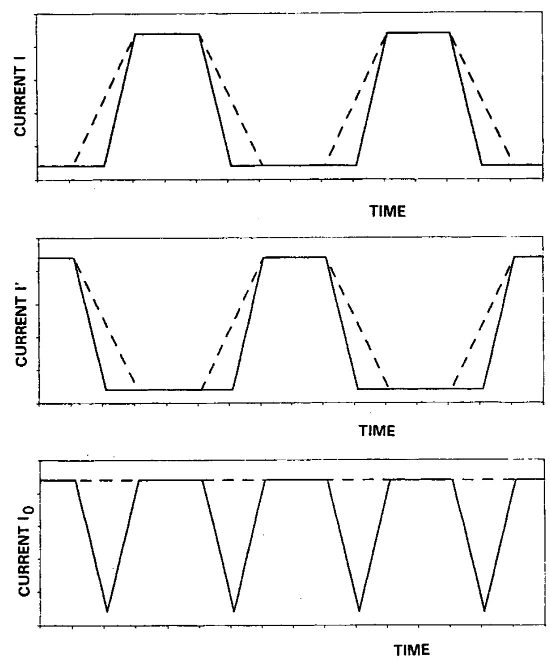


Fig. 6. Currents I and I' (see Fig. 3(a)) for constant (dashed lines) and switched (solid lines) current source (schematically).

current value to very low values of the current. (For this purpose, also externally adjusted offset voltages in a laser driver can be used, as they have been suggested in [4].) Moreover, rise and fall times should be as small as possible, but without having a large overshoot when switching on. The pulse shape of the driving current improved in this way and the resulting optical output power is shown in Fig. 4. Fig. 5 shows the corresponding eye patterns. It can be seen that the eye pattern of the optical output power has been improved by using a driving current with the proposed pulse shape. Now the maximum horizontal eye opening is at half of the maximum optical output power and in the middle between the intersection points of the rising and falling edges the eye pattern is vertically fully opened.

II. Novel Current Source

A. Generation of the Desired Pulse Shape of the Driving Current—In Principle

For the circuit of Fig. 3(a) the equation $I+I' = I_0$ is always valid, if current gain of the transistors and capacitive currents are neglected. Assume the circuit is operated with a constant current source. This results in a pulse shape (in principle) of the currents I and I' as sketched in Fig. 6 with dashed lines. Now assume that the current source is shortly switched off during each transition of the current-switch input voltage [5], i.e., I_0 as shown in Fig. 6 with a solid line. Taking into account $I + I' = I_0$, this yields the desired pulse shape of I and I', see Fig. 6.

Up to now idealized transistors had been assumed to explain the principle of the proposed edge steepness improvement. To demonstrate the effect of employing a switched current source instead of a constant current source if the transistors of the current switch are realistic ones, i.e., with all parasitic resistances and capacitances etc., a simulation has been performed, in which the current-switch transistors are the same as those used in the output stage of a fast laser driver IC [1]. The result is shown in Fig. 7. (Note that in both cases—in contrast to the current-switch transistors—the current source is still an *ideal* one. Simulation results with realistic current sources are presented in Section C.)

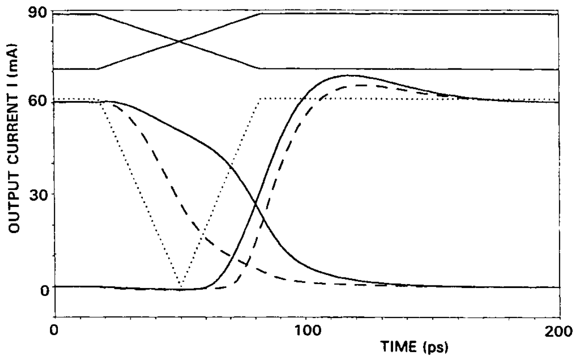


Fig. 7. Output current I for switching-on and switching-off for realistic current-switch transistors and *ideal* current sources: Constant current (solid lines) and switched current (dashed lines). Dotted line: Current of the switched current source. For reference, the corresponding input voltage v_{in} is sketched in the upper part.

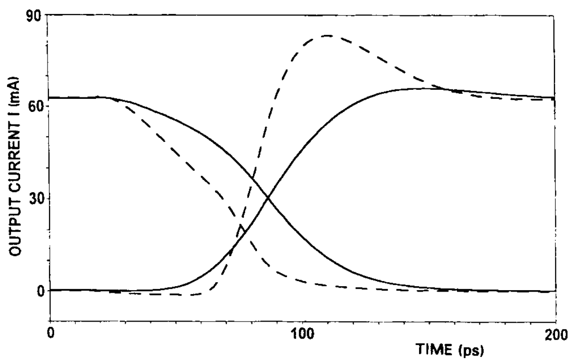


Fig. 8. Output current I for switching-on and switching-off using standard current source for $v_{in} = 2 \times 170\,\mathrm{mV_{PP}}$ (solid lines) and 2 × 500 mVpp (dashed lines).

B. Circuit of the Switched Current Source

Fig. 3(b) shows a current-switch with a standard transistor current source. At the node where the emitters of the current-switch transistors are connected (node "A" in Fig. 3(b) and (c)) the shape of the voltage corresponds to the desired shape of the current I_0. Therefore, this voltage can be used to switch a transistor current source in the desired way, e.g., as depicted in Fig. 3(c): During each transition of the current-switch input voltage v_{in} the voltage at node A is lowered. This signal is simply coupled to the base of the current source transistor by an ohmic voltage divider. Thereby the current of the transistor current source is shortly reduced, resulting in a pulse shape of the current I in the desired way.

C. Simulation Results

As a basis for the simulations of which the results are discussed in the following, a current switch is taken which has been used in the output stage of a fast laser driver IC [1]. This current switch has been dimensioned for driving 60 mA. Using a standard transistor current source as shown in

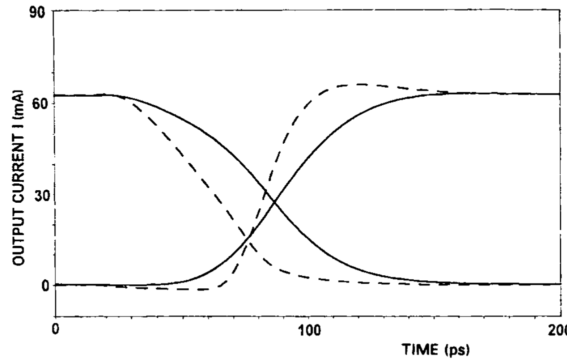


Fig. 9. Output current I for switching-on and switching-off using *switched* current source for $v_{in} = 2 \times 170\,\mathrm{mV_{PP}}$ (solid lines) and 2 × 500 mVpp (dashed lines).

TABLE I
SUMMARY OF RESULTS

current source	V_{in} [mV_{pp}]	fall time	rise time	over-shoot
standard	2 x 170	72 ps	50 ps	5 %
standard	2 x 500	54 ps	19 ps	32 %
switched	2 x 170	70 ps	57 ps	1 %
switched	2 x 500	50 ps	26 ps	5 %

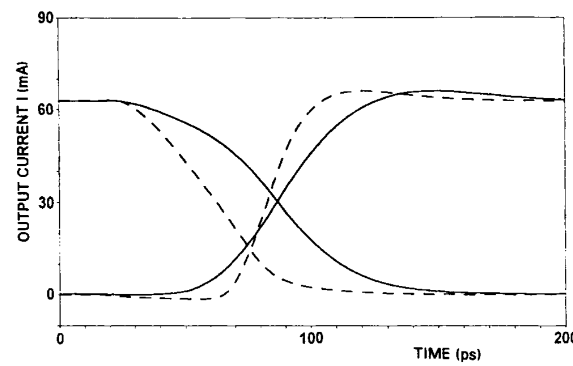


Fig. 10. Comparison of output current I for switching-on and switching-off for same overshoot using standard (solid lines; $v_{in} = 2 \times 170\,\mathrm{mV_{PP}}$) and switched current source (dashed lines; 2 × 500 mVpp), respectively.

Fig. 3(b) yields switching-on and switching-off as shown in Fig. 8. The solid curves show the current I for switching-on and switching-off in the case of using a small input voltage swing ($v_{in} = 2 \times 170\,\mathrm{mV_{pp}}$), thereby limiting the overshoot to a certain amount. (Here the input voltage swing was chosen for an overshoot of 5%.) A decrease of rise and fall time as well as the desired shift of the intersection point can be achieved by simply using a higher input voltage swing—but at the expense of large overshooting, as shown by the dashed curves in Fig. 8.

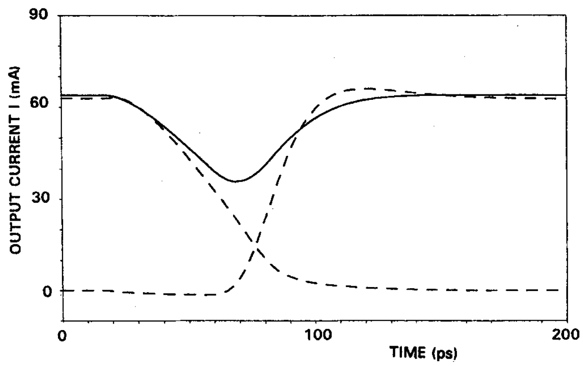
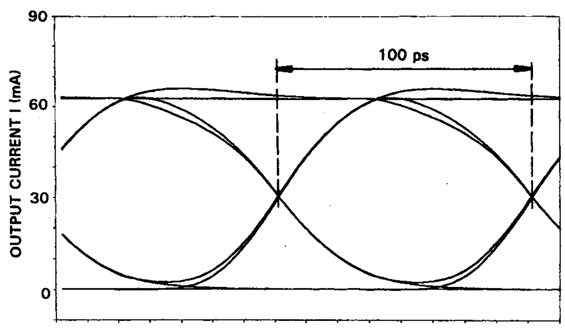


Fig. 11. Output current I for switching-on and switching-off using *switched* current source and $v_{in} = 2 \times 500\,\text{mV}_{pp}$ (dashed lines). Solid line: current of the current source.



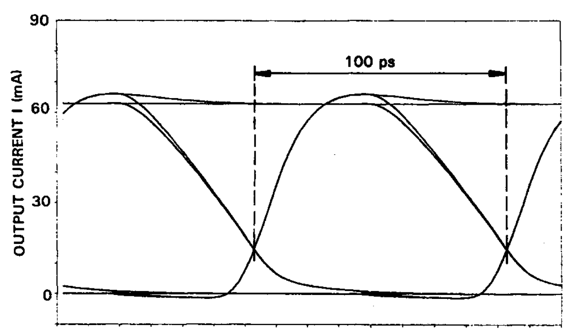


Fig. 12. Comparison of eye patterns of output current I for 10 Gb/s using standard (upper part; $v_{in} = 2 \times 170\,\text{mV}_{pp}$) and switched (lower part; $v_{in} = 2 \times 500\,\text{mV}_{pp}$) current source, respectively.

Fig. 9 shows the results for using the novel switched current source as depicted in Fig. 3(c). The solid curves show, how the current I is switched, when the same small input voltage swing ($v_{in} = 2 \times 170\,\text{mV}_{pp}$) is applied as for the case with the standard current source. The improvement of the fall time is only marginal, the rise time is even a little bit higher. But practically no overshoot occurs (<1%). This allows higher input voltage swing and thereby improving edge steepness. Applying an input voltage swing of 2 × 500 mV_{pp} yields an overshoot of 5%—the same value as for the case with small input voltage and standard current source, but with considerably improved edge steepness (see dashed curves in Fig. 9): Fall time (90% to 10%) is lowered from 72 ps to 50 ps, rise time (10% to 90%) from 50 ps to 26 ps. The results on rise time, fall time and overshoot are summarized in Table I. The both cases with 5% overshoot are compared in Fig. 10. Apart from the improvement of edge steepness, it can be seen that also the intersection point of rising and falling edge is shifted in the desired way. Fig. 11 shows, how the current supplied to the current switch is reduced during the transition. (The current is only reduced instead of completely switched off, since in practice it is difficult to realize the switching-off in a simple way.)

Any kind of pulse shaping might influence the pattern dependent jitter of the output current I. Therefore, also simulations of eye patterns for 10 Gb/s have been performed, using a 60-b word. Again, the both cases with 5% overshoot are compared and the two eye patterns are depicted in Fig. 12. It can be seen that the use of the novel switched current source does not impair the pattern dependent jitter behavior.

III. Other Applications

The application of the novel current source is not restricted to laser drivers, but might be useful generally wherever steep pulses with small overshoot are needed.

References

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