Towards High-Speed Energy-Efficient Pulse-Switching Networks Implemented in Carrier-Injection-Based Si-Photonics

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We show that carrier injection based Si-photonics modulators [1] can form the basis for building compact, low-loss and power efficient reconfigurable networks, enabling the switching of ps-pulse trains with sub-GHz repetition rates. The use of pre-emphasis-based activation [2] permits ns-scale switching transitions. Although the steady-state energy consumption in this platform is well studied, the impact of the dynamic energy consumption for these ns switching periods is not well known. Here, we show pre-emphasis-based sub-ns transitions and present a novel large-signal analysis that allows the driving scheme optimization for energy-efficient pulse switching.

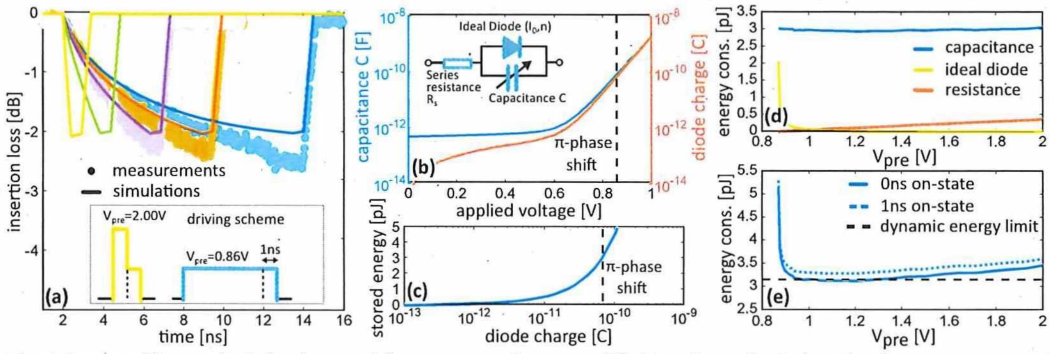

Figure 1: a) Impact of pre-emphasis level on modulator response time exemplified in a 1mm pin-diode with a loss target comparable to a π-phase shift and 1ns on-state. b) Measured capacitance and calculated stored diode charge versus applied voltage. c) Stored capacitive energy in relation to its stored diode charge. d) Contributions to dynamic energy consumption of large-signal model elements. e) Simulated energy consumption per switching operation versus pre-emphasis voltage. The dynamic energy limit equals the stored charge energy at π-phase shift.

The speed of pin-diode based switches depends on how fast charge carriers can be injected and removed from the diode. We studied these dynamics by monitoring the loss of 1mm long pin diodes (Fig.1a). We targeted a loss of 2dB, equivalent to a π-phase shift in these devices [3]. Five driving schemes are generated with constant 1ns on-time and increasing pre-emphasis voltage level V_{pre} (0.86 to 2.00V). As expected, a larger V_{pre} results in a faster response. We expect the same high-speed response in a switching network.

We compared these measurement results with simulations based on the large-signal model [4] shown in Fig.1b (inset). The resistance, diode and capacitance properties were extracted from DC-IV and S_{11} measurements. The measured voltage-dependent capacitance and the corresponding stored charge are visualized in Fig.1b. The dashed line denotes the charge required for a π-phase shift in the modulator. Next, to calculate the energy that is stored in the capacitance for a given charge, we integrate charge over voltage ($E = \int_0^V CVdV$). This stored energy corresponds to the energy required to charge the capacitance (dynamic energy dissipation). Fig.1c indicates $\sim$3pJ is needed for a π-phase shift. This energy is independent on the activation scheme and representative for the modulator technology. In comparison, this value is $\sim$6pJ for carrier-depletion and $\sim$4pJ for carrier-accumulation technology [5], attesting the high modulation efficiency of the carrier-injection technology.

Fig.1d shows the additional contributions to the energy consumption, i.e. the charge leakage in the diode and Joule heating in the resistance, as function of V_{pre}. The figure shows the trade-off between these two contributions, yielding a driving scheme with minimum energy consumption. This can be seen in Fig.1e where all contributions are combined. The solid curve, for no on-time, approaches the dynamic energy limit, which corresponds to the stored charge energy at π-phase shift. Thus, an optimized activation leads to energy savings of $\sim$40%. Additionally, we see that the contribution from static-energy consumption is negligible for short activation times (1ns on-state). In conclusion, an optimized driving scheme leads to significant improvement of both speed and energy consumption in carrier-injection-based modulators which makes this platform suitable for energy-efficient pulse switching. *This project has received funding from the European Unions Horizon 2020 research and innovation programme under grant agreement No 713481.*

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