A closed-form expression for pre-emphasis pulses with minimal RC delay time

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1．Introduction

Pre-emphasis pulses are used in transmission line [1], display [2] and memory [3], to reduce the wiring delay time. However, a general optimization method for the pre-emphasis pulses has not been formulated. In this study, we report a closed-form expression to minimize the delay time and the energy-delay product when RC delay lines (Fig. 1) are driven by the pre-emphasis pulses (Fig. 2).

2. Formulation and verification

(a) Minimal delay time

Parameters used for the calculation are defined as follows. T: pre-emphasis time, E: target voltage, α: ratio of E to the pre-emphasis voltage, β: error rate to E, x: delay line position (x=0 for the nearest, x=l for the farthest), r: resistance per unit length, c: capacitance per unit length, $e(x,t)$: voltage at a position x and a time t, t_{delay_min}: minimal time for the slowest node voltage to reach βE. First, we calculated $e(x,t)$ to be (1), (2) using the basic equation of the transmission line, where τ is a time constant given by $4rcl^2/\pi^2$ and ξ is a normalized position x/l . Next, using (2), we approximately calculated T_{opt} as (3) to have the minimal delay time as shown by (4).

$$T_{opt} \fallingdotseq \tau \, ln \frac{\alpha}{\alpha - 1} \qquad (3)$$

$$t_{delay\_min} \fallingdotseq \frac{\tau}{9} ln \left[\frac{4\alpha}{3\pi\beta} \left(\frac{\alpha}{\alpha - 1} \right)^8 \right] \qquad (4)$$

One can easily determine T_{opt} when α, r and c are given. Fig. 3 shows t_{delay_min} as a function of α for β =0.01, which is normalized by t_{delay_min} with α = 1 in case of a step pulse. (4) is in good agreement with SPICE simulation results within an error of 8% for $\alpha \leqq 2$. For example, by setting α = 2, the delay time can be reduced to 1/4.

(b) Energy delay product

When a pre-emphasis pulse is generated by a linear regulator, the extra charge accumulated in the delay line is discharged to the ground without returning to the power supply. Therefore, the energy consumption E_{en} is expressed as the product of the power supply voltage V_{ext} and the stored maximum charge Q_{max}.

$$E_{en} \fallingdotseq V_{ext} \times Ecl \left[\alpha - \frac{8}{\pi^2}(\alpha - 1) \right] \qquad (5)$$

(5) agrees with SPICE simulation result within an error rate of 1% for $\alpha \leqq 2$. A pre-emphasis pulse with α=2 only increases the energy consumption by 20% in consumption with a step pulse. The energy delay product (ED) is expressed by (6).

$$\mathrm{ED} = t_{delay\_min} \times E_{en} \qquad (6)$$

Fig. 4 shows ED as a function of α, which is normalized by ED of a step pulse. Fig. 4 suggests the energy delay product becomes the minimum of 0.25 when α = 2.86. Even with α = 1.3, ED is as small as 0.4.

3．Conclusion

We formulated a pre-emphasis pulse to reduce the RC delay time, and identified the minimal delay condition (3), the delay time (4), and the energy consumption (5). One can easily design pre-emphasis pulses for RC delay lines by using these equations.

4．References

[1] A. Fiedler, et al., ISSCC, pp. 238-9, 1997.
[2] J. Bang, et al., ISSCC, pp. 212-213, 2016.
[3] W. Jeong et al., IEEE JSSC, Vol. 51, No. 1, pp. 204-212, 2016.

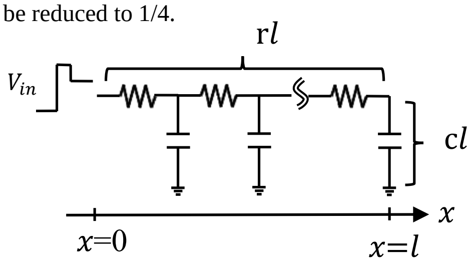

Fig. 1. Equivalent circuit of RC delay line

$$e(x,t) = \alpha E - \frac{4\alpha E}{\pi} \sum_{k=0}^{\infty} \frac{1}{2k+1} e^{\frac{-(2k+1)^2}{\tau}t} sin \frac{(2k+1)\pi}{2} \xi \qquad 0 \le t \le T \qquad (1)$$

$$e(x,t) = E - \frac{4E}{\pi} \sum_{k=0}^{\infty} \left\{ \alpha - (\alpha - 1) e^{\frac{(2k+1)^2}{\tau}T} \right\} \frac{1}{2k+1} e^{\frac{-(2k+1)^2}{\tau}t} sin \frac{(2k+1)\pi}{2} \xi \qquad T < t \qquad (2)$$

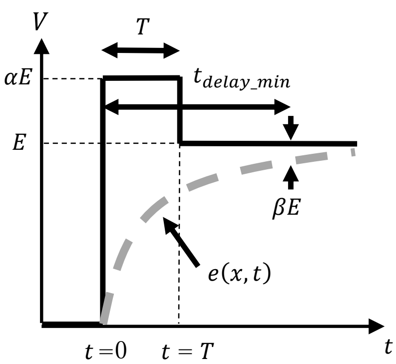

Fig. 2. Pre-emphasis pulse

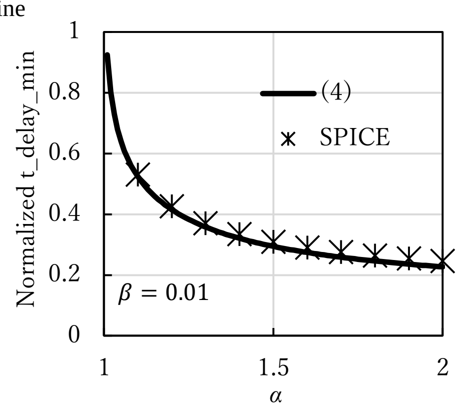

Fig. 3. $\alpha - t_{delay\_min}$

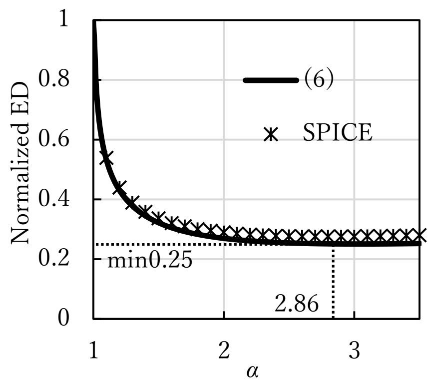

Fig. 4. α-ED

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