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# Large Input-Capacitance Compensation Method Employed in a CSA Designed for EMCs in HIEPA

Ran ZHENG, Chao LIU, Jia WANG, Xiaomin WEI, Feifei Xue, Yongcai HU

*School of Computer Science and Engineering, Northwestern Polytechnical University, 710072 Xi’an, P.R. China*

zhengran@nwpu.edu.cn

## Readout System Performance Degradation Induced by Large Input Detector Capacitance

In nuclear sensing and high-energy physics experiment area, more and more detectors (detector arrays) with large-input capacitance are employed, in order to obtain large sensitive area as well as high-image resolution. For example, silicon photomultipliers (SiPMs) needs to comprise thousands of Geiger-mode avalanche photodiodes (GM-APDs) connected in parallel to realize large sensitive area, which results in large detector capacitance. Charge Sensing Amplifier (CSA) is an important unit which can convert input charges into corresponding voltages, whose gain is theoretically fixed and decided by the feedback capacitor. CSA followed by Gaussian shapers can be regarded as a general readout system, which can be seriously influenced by the large-input capacitance.

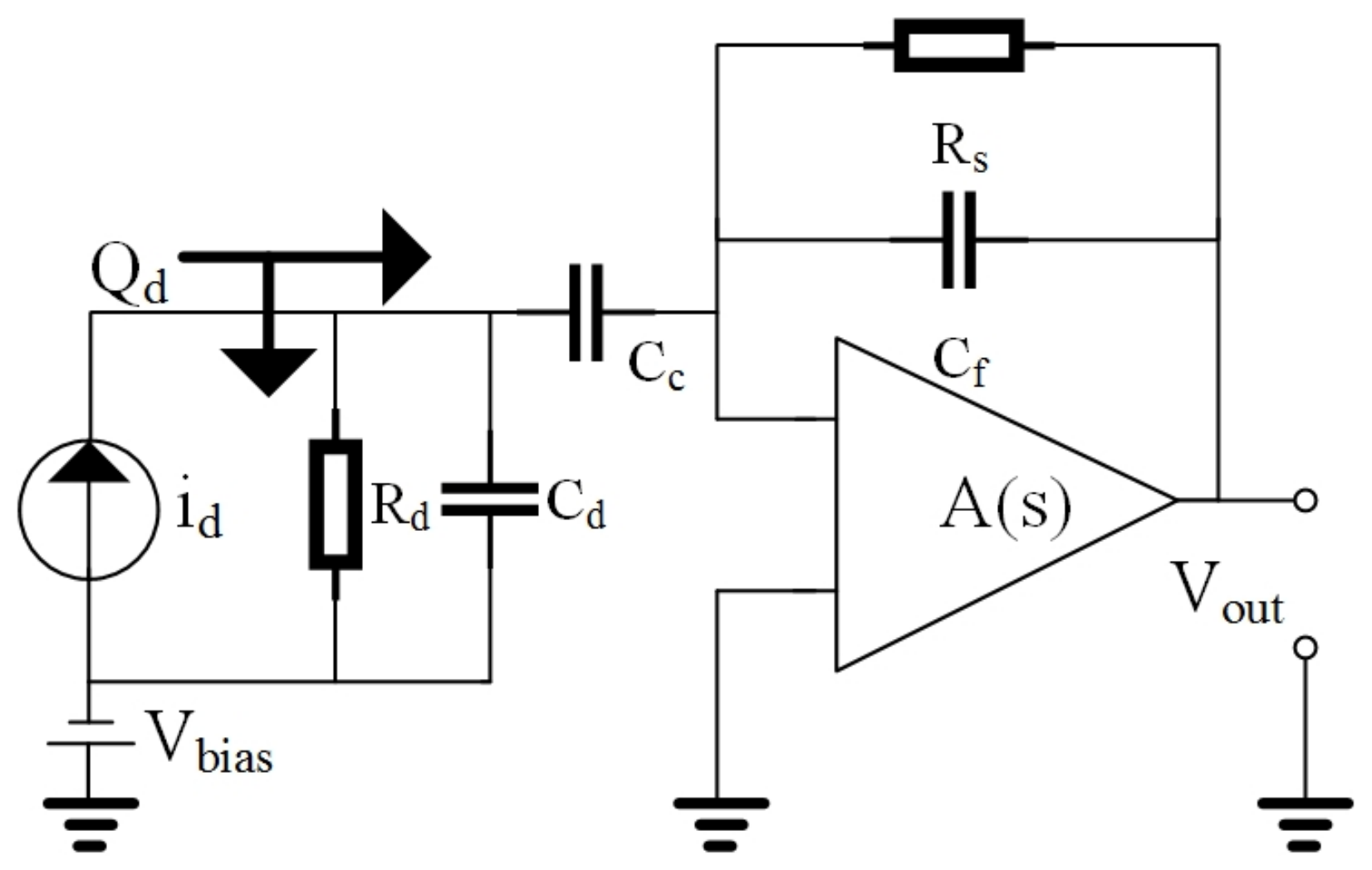

Fig.1. Signal charge shunted by detector capacitance

A CSA based front-end readout system is illustrated in Fig.1, in which, $i_d$, $R_d$ and $C_d$ represent for detector’s signal current, stray resistance and capacitance respectively; A(s), whose DC gain, output resistance and capacitance are assuming to be $A_o$, $R_{out}$ and $C_{out}$, is the open-loop transfer function of the CSA; $C_f$ is the feedback capacitor which decides the C-V gain of the CSA; $C_c$ is the AC coupling capacitance and $R_s$ is the reset resistor, both of which are large enough to be regardless in AC analysis. Thus, the transfer function of the readout system can be written as Eq.1.

$$\frac{V_{out}(s)}{i_d(s)} = \frac{A_o R_d}{[1 + s \cdot R_d(C_d + A_o C_f)](1 + s \cdot R_{out} C_{out})} \qquad \text{(Eq.1)}$$

We are now engaged in a readout system design for electromagnetic calorimeter employed in high intensity electron-positron accelerator (HIEPA). The stray capacitance ($C_d$) of the APD Packaged with CsI is as big as 270pF, as a result of which, the frequency response of the function in Eq.1 is dominated by a low-frequency pole $1/2\pi R_d C_d$, noting that the $C_f$ is generally set to femto farad. In this scenario, the rise time of the $V_{out}$ is badly retarded. Besides, the signal charge $Q_d$ is partly shunted to ground before flowing into the CSA input, which degrades the system gain as well as the SNR.

## Shunt Bootstrap Method For Capacitance Compensation

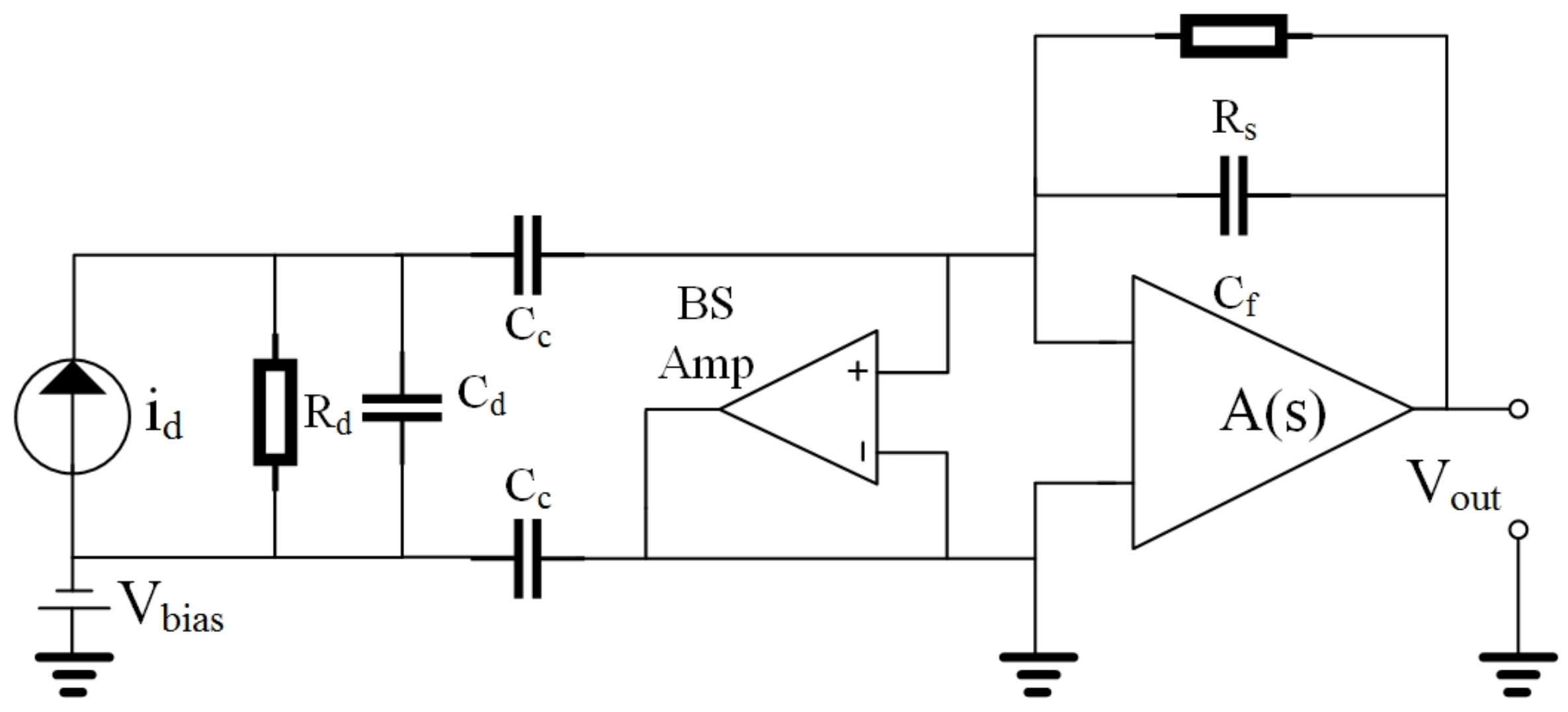

Fig.2. Topology of the CSA with shunt bootstrap amplifier

Capacitance bootstrap method is early used in optic receivers to obtain wide bandwidth. CSA with shunt bootstrap amplifier (BS Amp) is shown in Fig.2. BS Amp are configured to be a unit gain buffer that makes the small signals on both upper and lower nodes of $C_d$ vary the same. Thus, theoretically, there will be no charge integrating on $C_d$ and according to (Eq.2), the $C_d$ effect can be cleared up by miller equalization.

$$C_{eq} = (1 - A_{buf})C_d \quad (A_{buf} = 1) \qquad \text{(Eq.2)}$$

In which, $A_{buf}$ is the gain of unity buffer configured using BS Amp

## Bootstrap Amplifier Design and Simulation Results

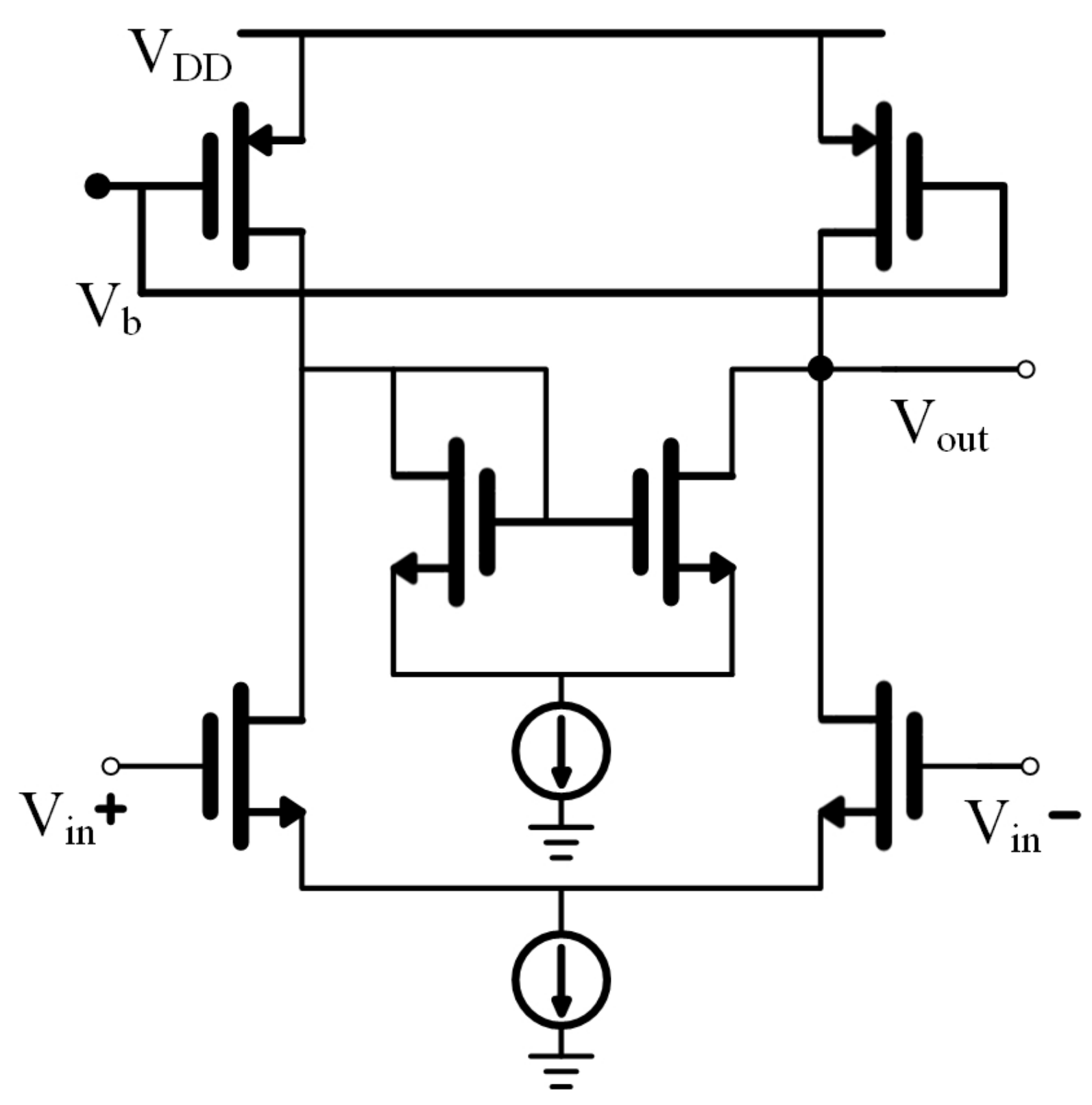

Fig.3. Topology of BS Amp with drain current compensation

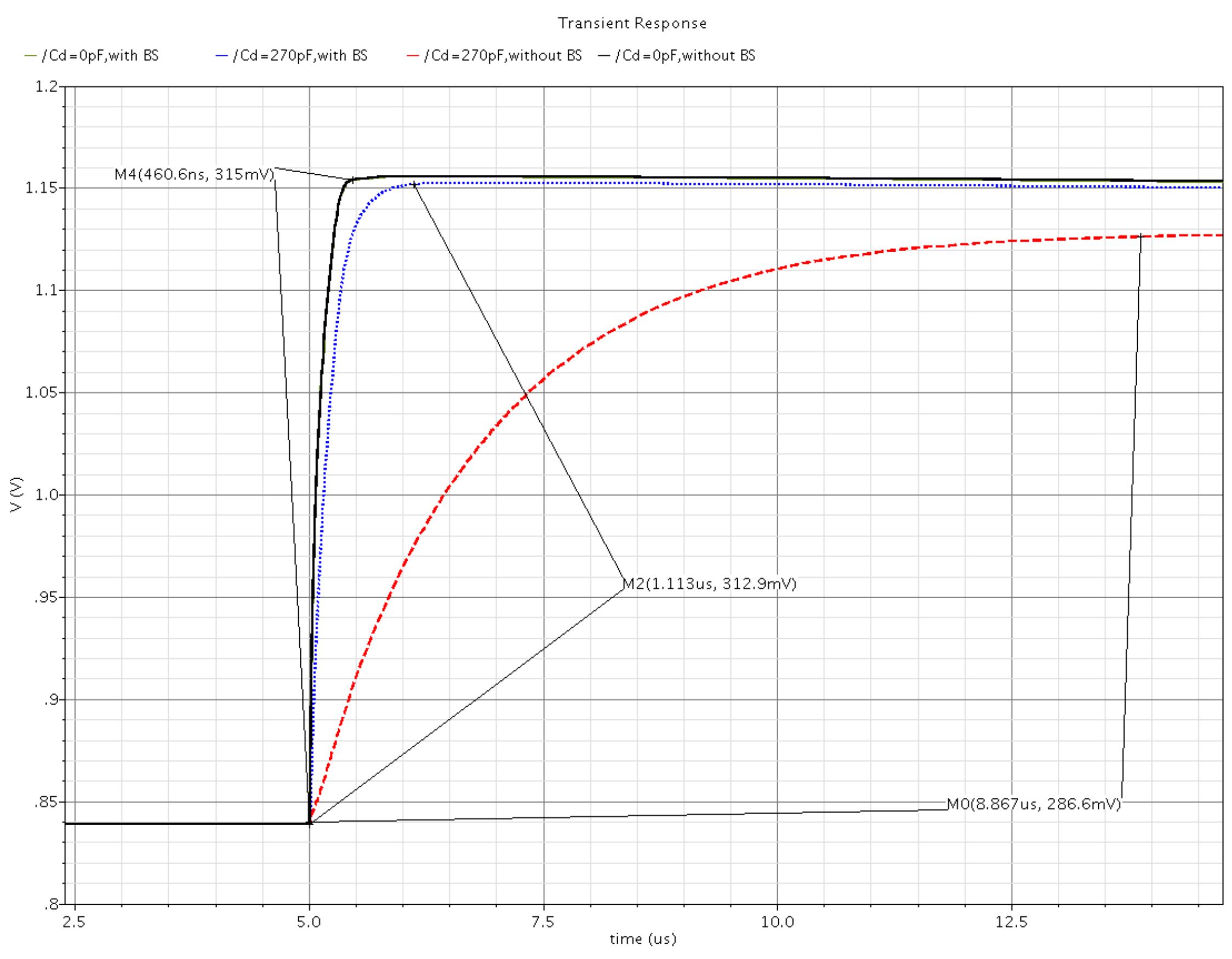

Fig.4. Rising time of the CSA outputs with and without BS.

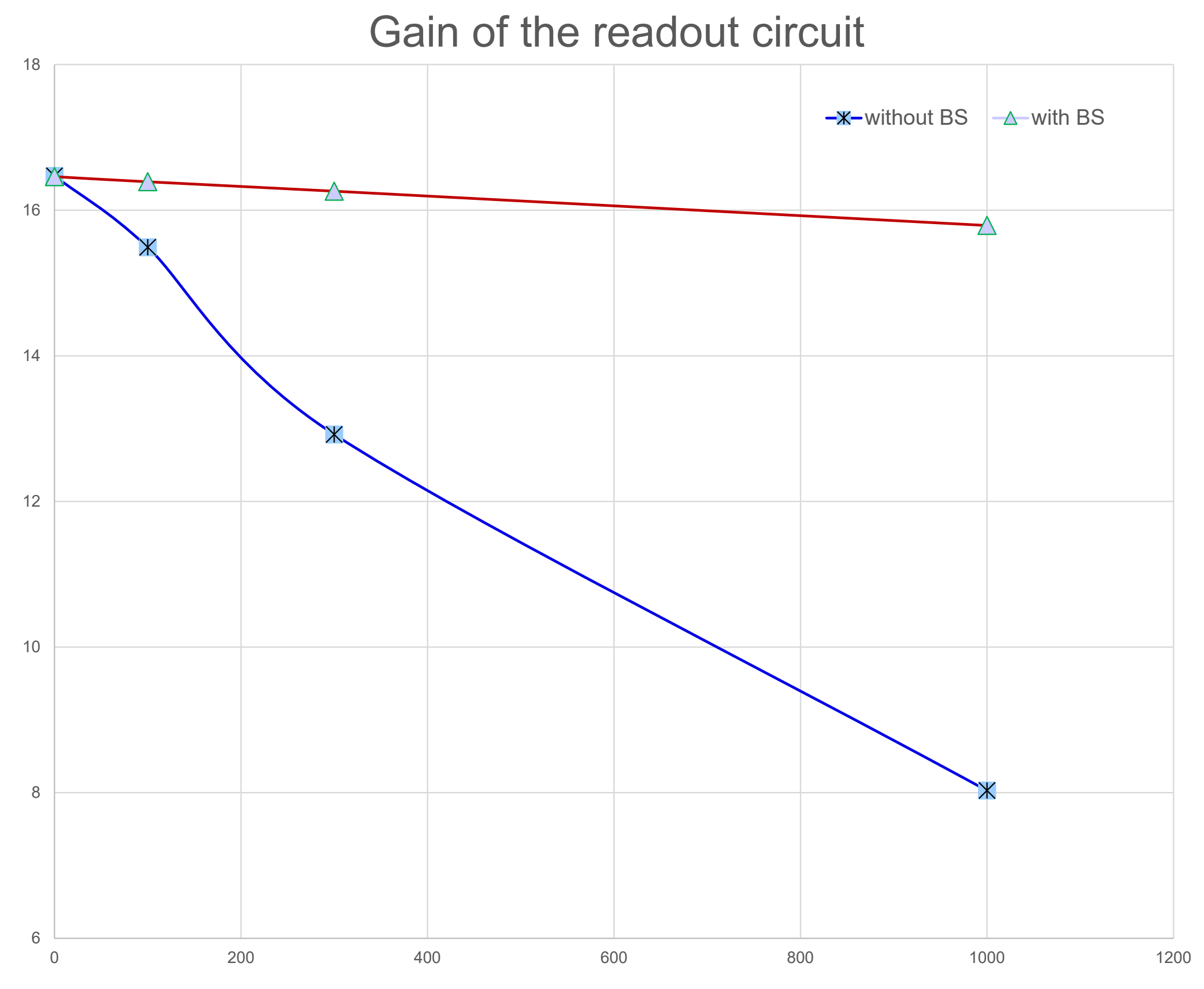

Fig.5. Gain of the readout system after shaper.

As illustrated in Fig.4 and Fig.5, the rising time and C-V gain benefits much from the proposed method. However, the BS amp contributes a lot of noise to the CSA output, as a result of which, SNR degradation (Table.1) remains a problem. It seems whether the BS amp can work as a SNR booster relies on the amounts of input charge as well as the whole readout system design.

Table.1 CSA performance with/without BS

| | Cd | 0pF | 100pF | 270pF | 300pF | 1nF |
|---|---|---|---|---|---|---|
| without BS | Gain (mV/fC) | 16.47 | 15.49 | 13.28 | 12.92 | 8.03 |
| | ENC(e-) | 192.7 | 1209 | 3255 | 3629 | 12560 |
| | RMS.(mV) | 0.5077 | 2.997 | 6.915 | 7.503 | 16.15 |
| | SNR(@30fC) | 973.2 | 155.06 | 57.6 | 51.67 | 14.92 |
| with BS | Gain (mV/fC) | 16.46 | 16.39 | 16.28 | 16.26 | 15.79 |
| | ENC(e-) | 449.5 | 5224 | 14080 | 15650 | 52580 |
| | RMS.(mV) | 1.184 | 13.7 | 36.7 | 40.74 | 132.8 |
| | SNR(@30fC) | 416.98 | 35.89 | 13.31 | 11.96 | 3.567 |