

# Preethi's ROIC analysis

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# 1 setup

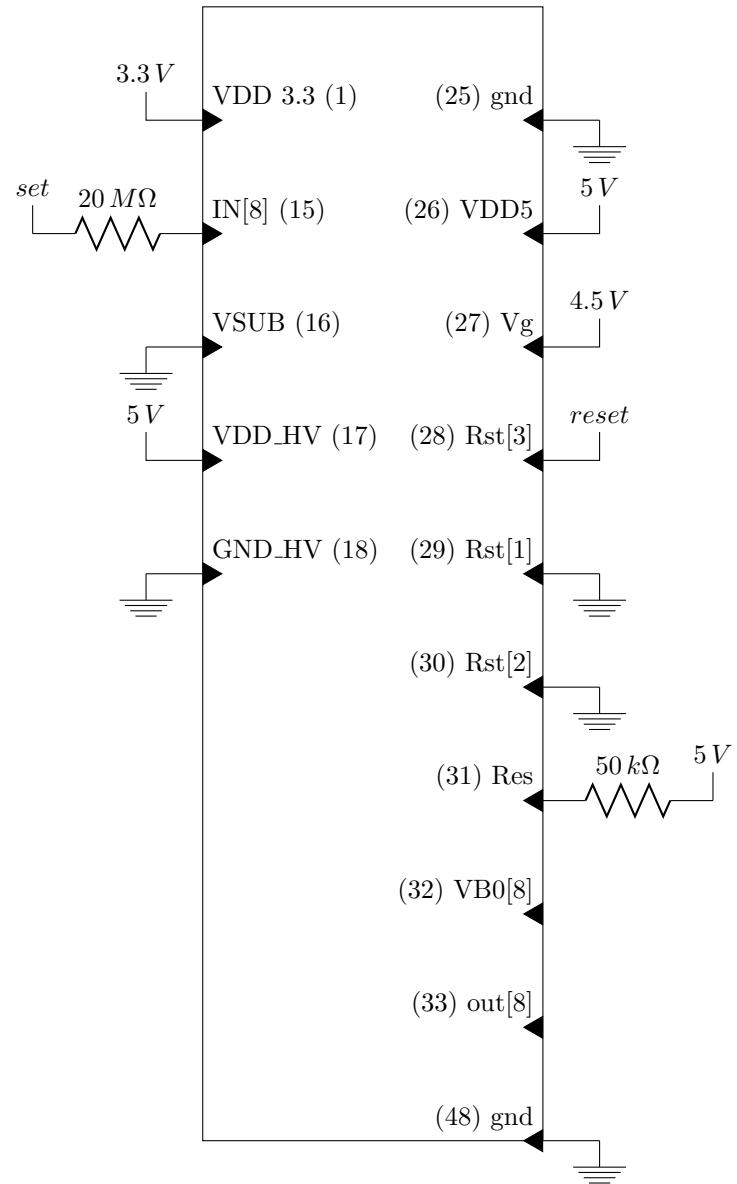


Figure 1: Schematic of breadboard

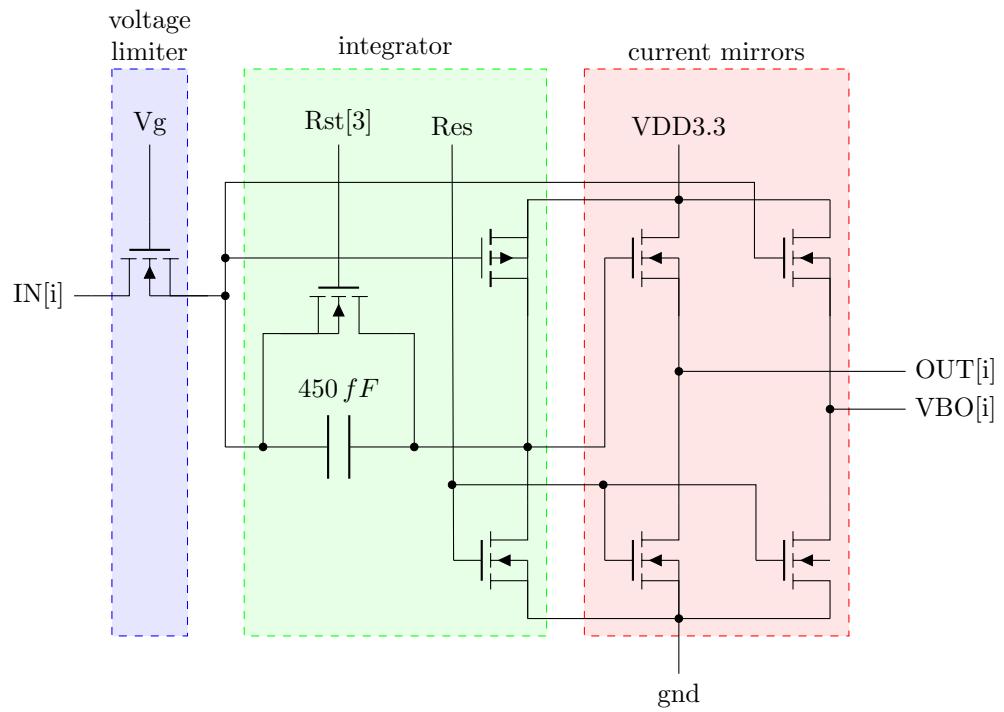


Figure 2: Schematic of ROIC channel

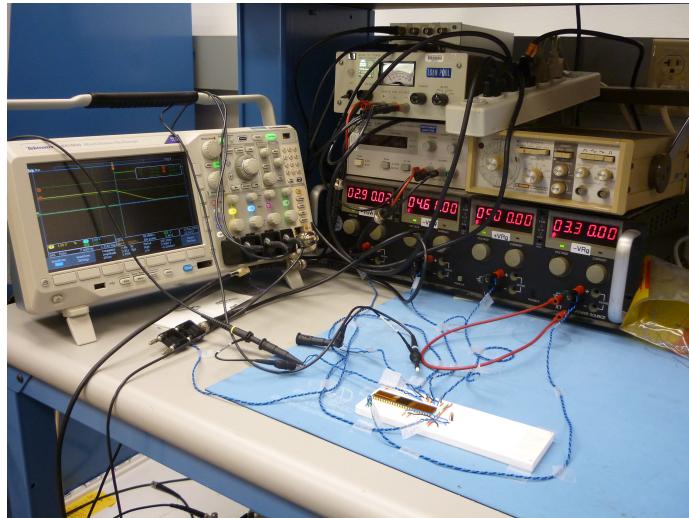


Figure 3: setup overview

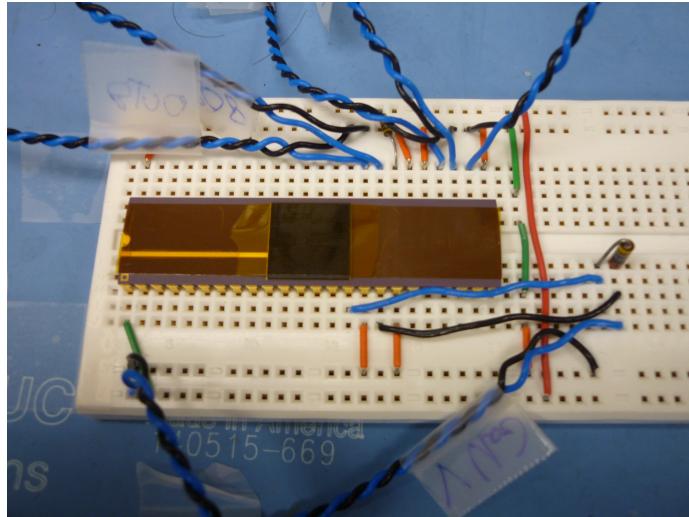


Figure 4: close-up

## 2 Characterization for high impedance voltage source

This section aims to characterize the behavior of the ROIC while exposed to a voltage source with a high resistance in the order of several  $M\Omega$ . A focus is put onto the performance in reset state, the relationship between input current and output voltage, and the current limiting properties of the input transistor.

### 2.1 Reset

This measurement addresses the behavior of the circuit in reset mode. Figure 5 shows the measured values during reset mode. Note that the input voltage is  $2.4 V$ , which is important when calculating the input current.

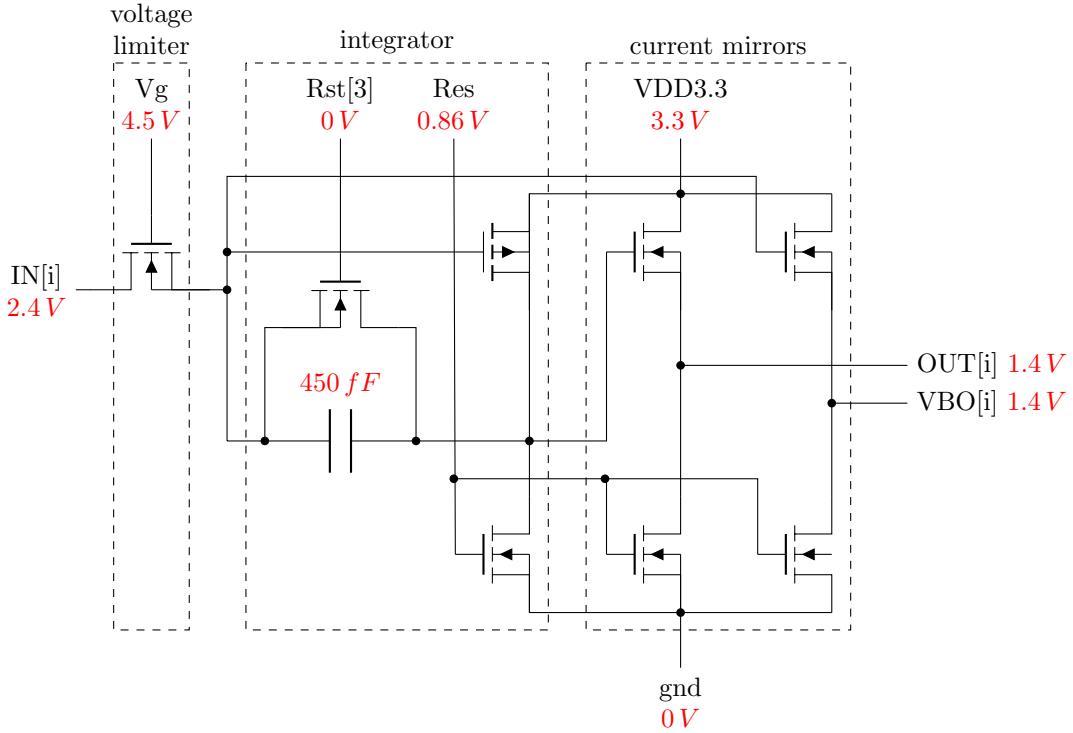


Figure 5: Schematic of ROIC channel template

## 2.2 Source follower

There are two identical source followers per lane. We can use the  $VBO$  source follower to characterise both. This because the input can be directly controlled, and the output directly read. Figure 6 shows both the measured data and a fitted line with the formula  $vbo = 0.827v_{in} - 0.624$ . It will be assumed that this line characterises the performance of both source followers for  $1 < v_{in} < 4$ .

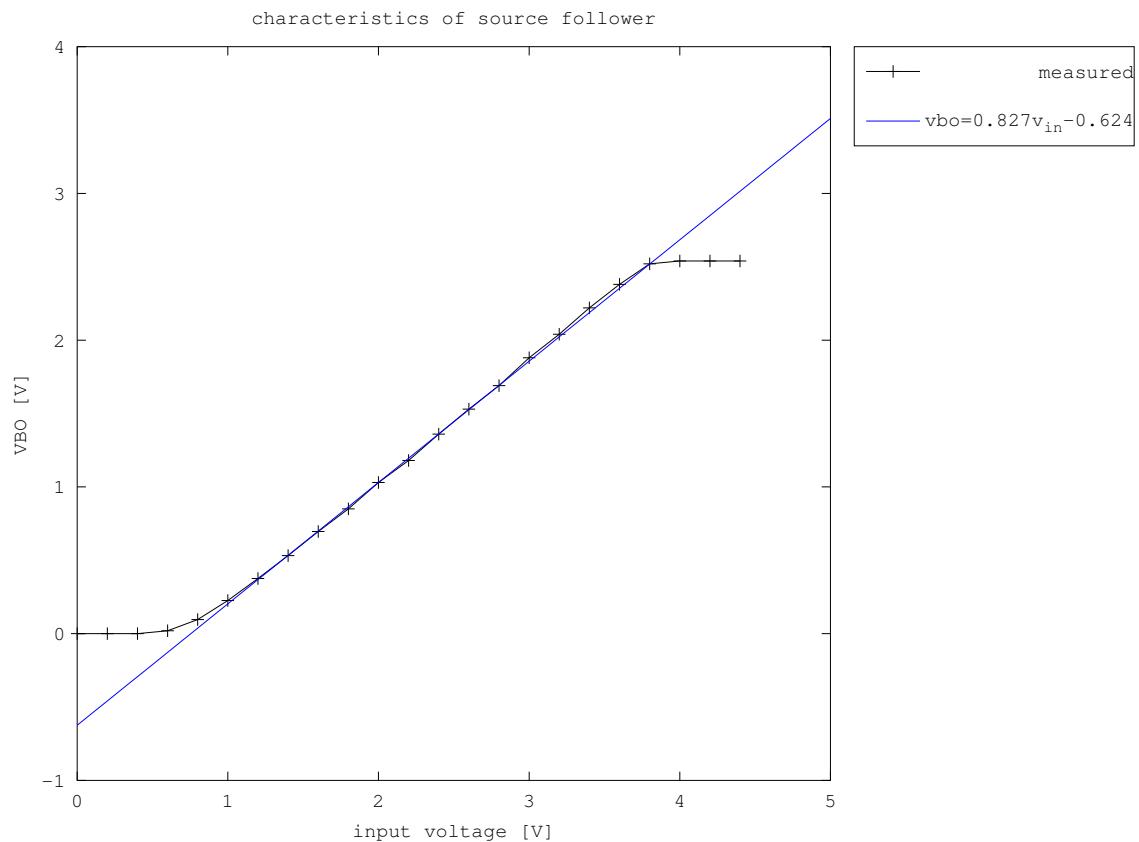


Figure 6: plot of the input voltage against VBO. This plot shows the characteristics of the voltage follower

### 2.3 Standard performance

This test aims to address the basic relationship between input current and output voltage. Figure 7 shows the setup used for this test. Channel 8 was used, so the end of the  $20 M\Omega$  resistor is connected to IN[8], and probes are connected to OUT[8] and VBO[8].

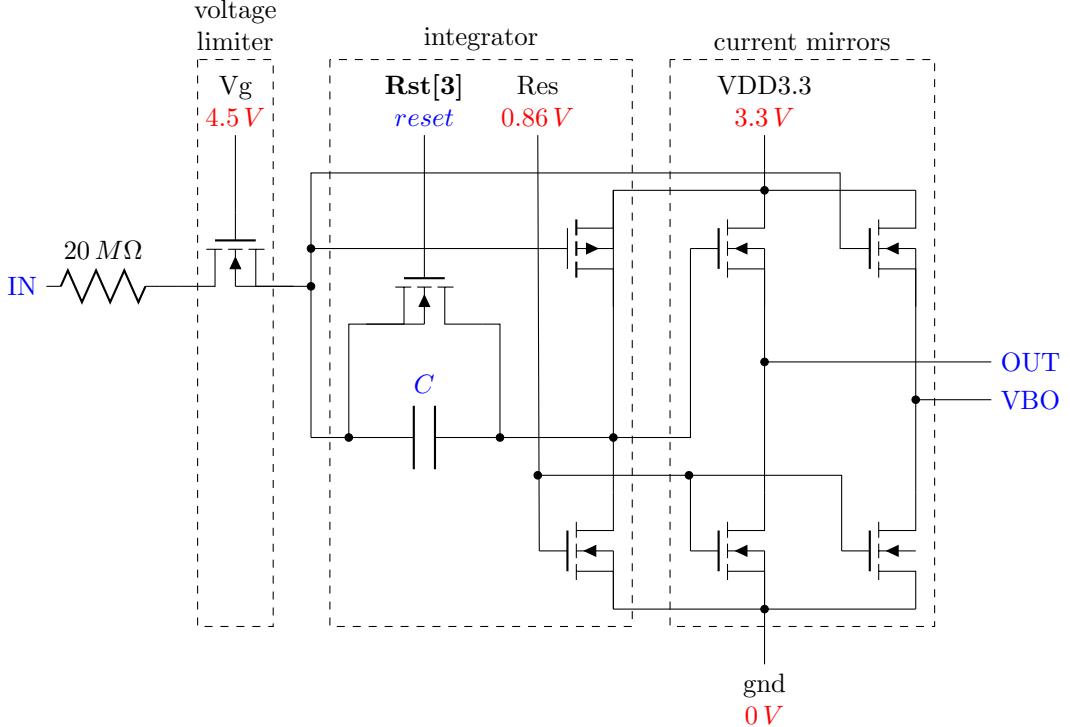


Figure 7: Schematic of ROIC channel template

Figure 8 shows the time versus voltage plot of both the VBO and OUT for a constant input voltage. The rising and falling slopes are the VBO and OUT respectively. The timescale of this plot does not allow for much inside in VBO, but it does show some interesting results for the behavior of OUT. When the reset switches, the input node immediately loses some charge. Note that the oscilloscope matches the rising edge of the rset signal to time is 0 s, so this drop is at 0 s. It is interesting to observe that the slope is constant for all input voltages. The slopes is much slower than the time necessary for the reset transistor to switch, so the observed slope is not limited by the reset transistor, but by the source follower that tries to keep up. This observed slope is therefore the maximum rate at which the output node can be pulled down in the current set-up. Iso note that the slope gets steeper when the integrator capacitance decreases. This is to be expected. However also note that the maximum slopes across the different capacitances are all identical.

Figure 9 shows the same plot as fig. 8, but now the x axis is scaled with input current. This shows for fig. 8a and 8b that the relationship between output voltage and charge is equal across different input voltages. For fig. 8c and 8d however, one can see that the higher voltages lose this

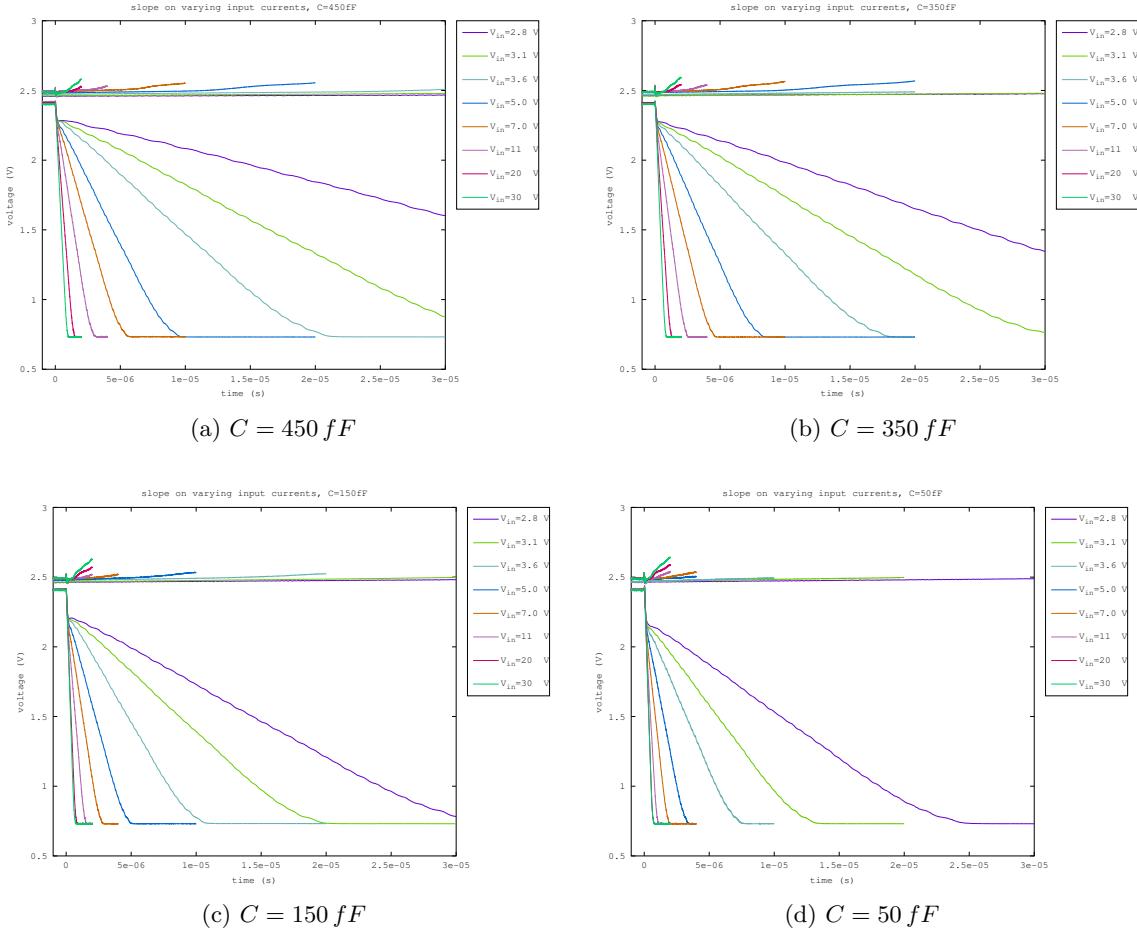


Figure 8: Expected versus measured charge up times for different input voltages. The input voltage is connected to the input through a resistor of  $20 \text{ M}\Omega$

property. Another interesting observation is that when one looks closely at the plot, one can observe a small oscillation with a period that is constant with charge. Also the period is constant across different voltages. A hypothesis explaining this behavior has yet to be found.

Figure 10 shows the  $\delta Q/\delta V$  against charge plots. Note that  $\delta Q/\delta V$  is the capacitance. One can observe that while the capacitance is charging, the full value of the capacitance can be observed, and when the capacitance is completely discharged, it behaves as if it is not there. One can use these plots to estimate the integration capacitance. The capacitance for fig. 9a, 9b, 9c and 9d are approximately  $450 \text{ fF}$ ,  $350 \text{ fF}$ ,  $220 \text{ fF}$  and  $180 \text{ fF}$  respectively.

Figure 11 shows  $\delta V/\delta t$  against input voltage for all capacitances. One can observe that all four have different slopes at first, but there appears to be a trend that they all converge to a value of  $\delta V/\delta t \approx 3.2 \cdot 10^6$ .

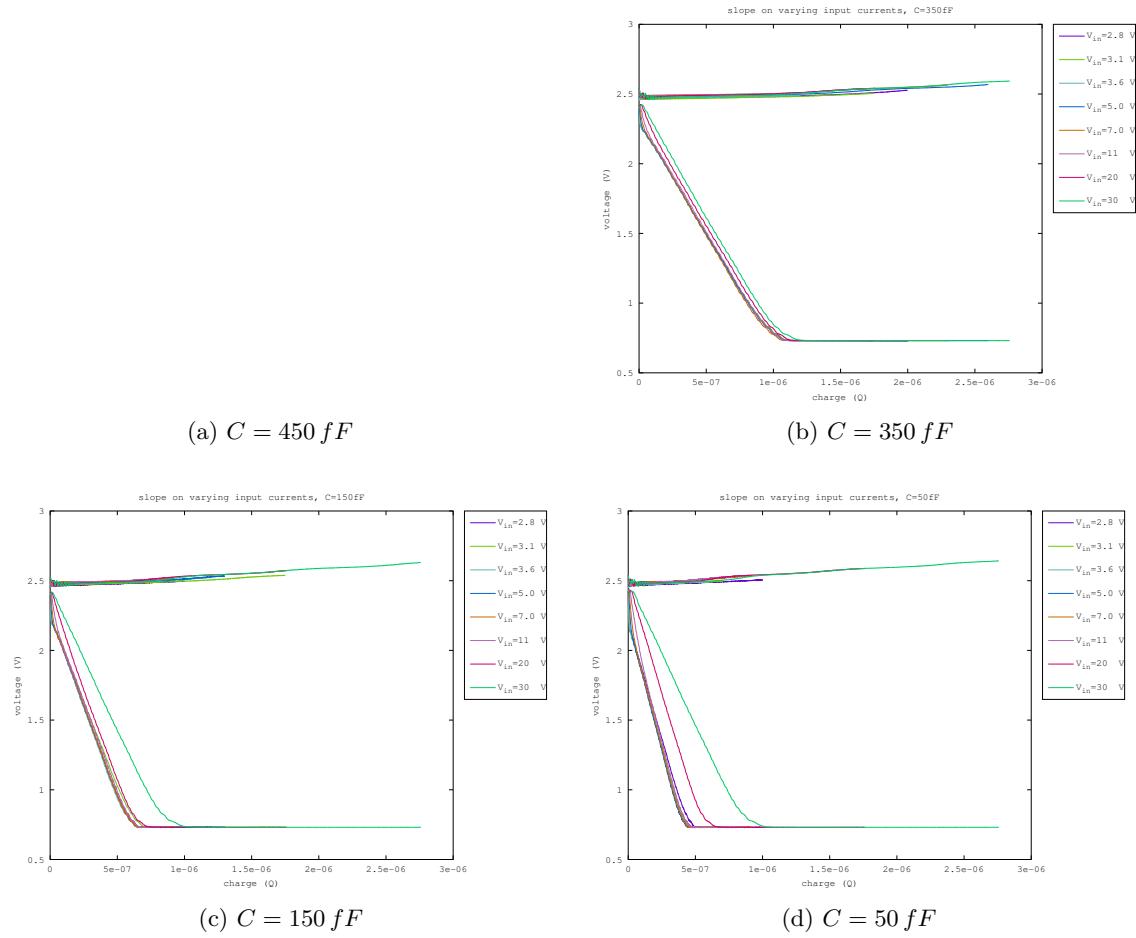


Figure 9: This plot is showing charge versus voltage

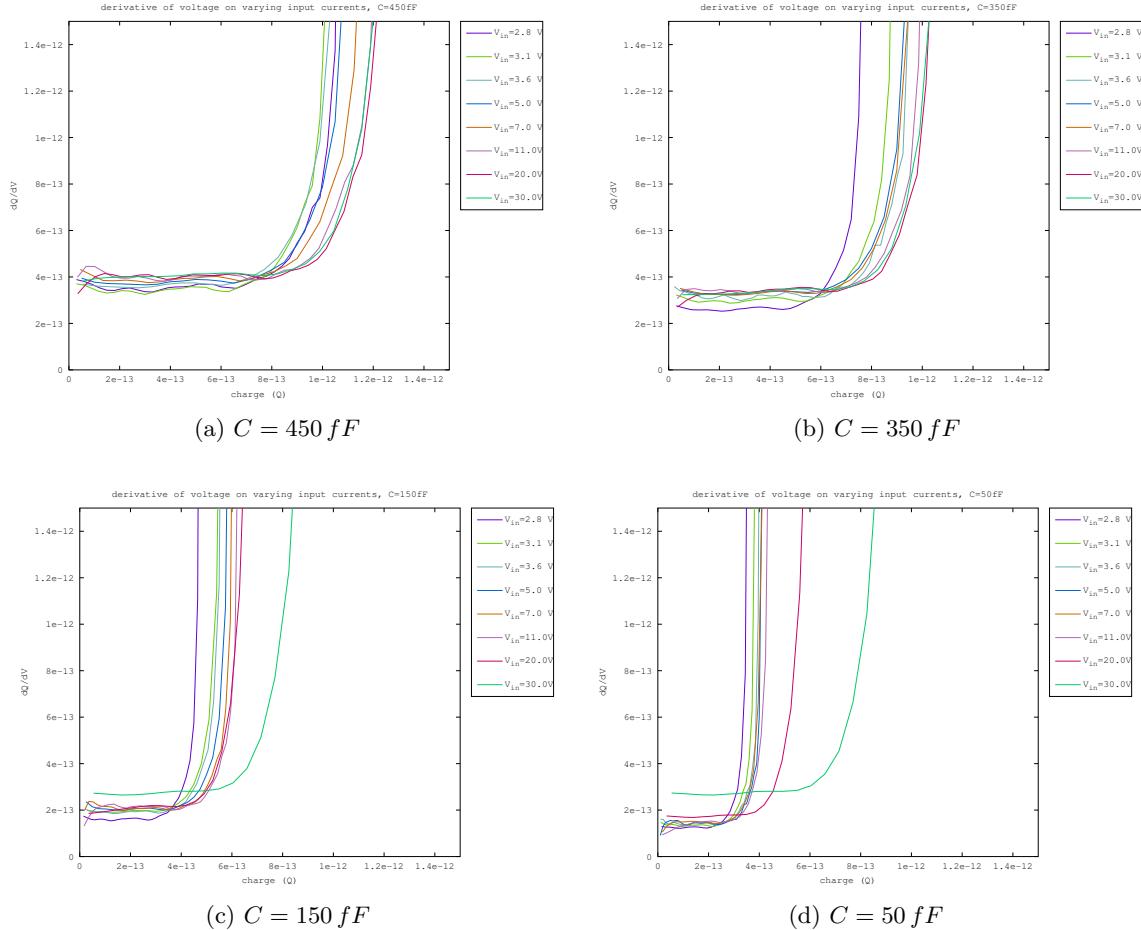


Figure 10: The plot shows  $dv/dt$  against time. The plot is in log scale, which allows for an easy read on the maximum slope and the time needed to discharge the integrator capacitance.

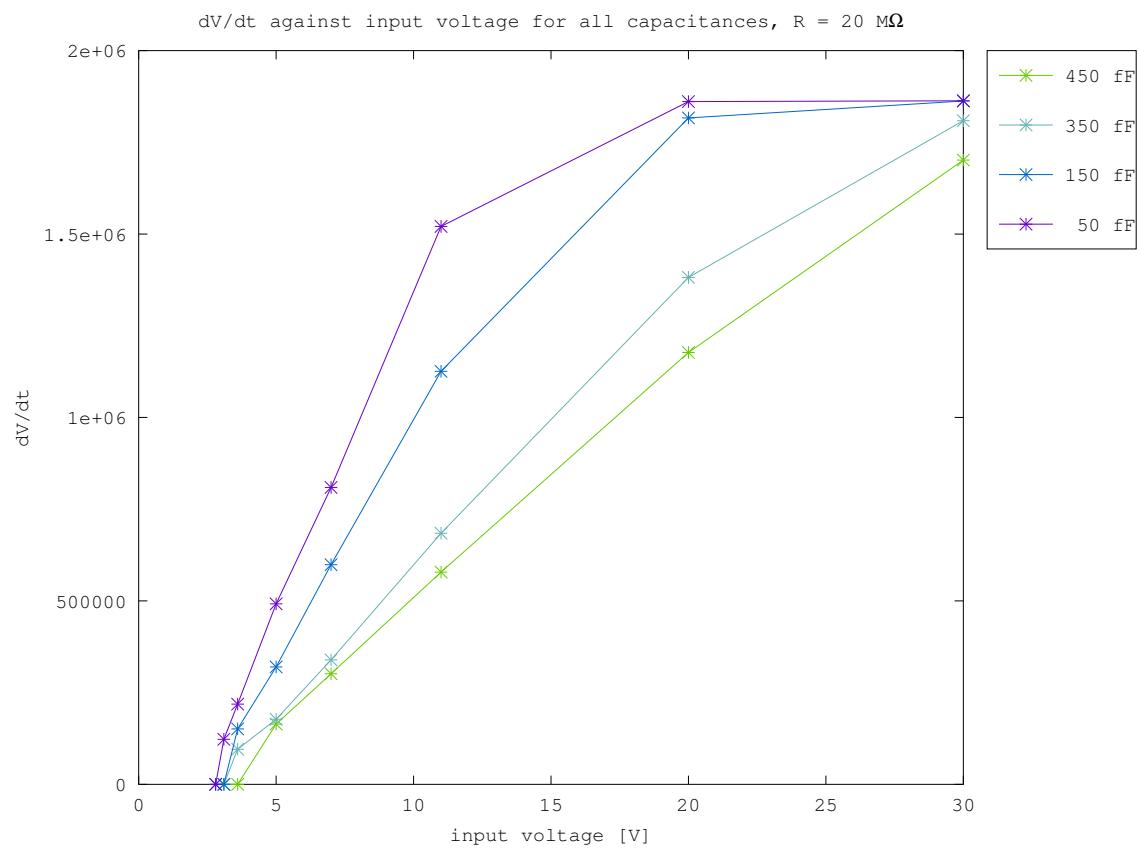


Figure 11: dV/dt against input voltage for all four capacitances. The x indicate the measurements.

## 2.4 large current performance

In this section the  $20 M\Omega$  input resistor is replaced with a  $4 M\Omega$  resistor. The main goal is to observe the ROIC for very large currents.

Figure 12 shows the same plot as fig. 8, but this time with larger currents. Where a minimum slope could be observed at fig. 8, it is more prevalent here. This also shows more information about the behavior of VBO. For small voltages the VBO does not increase, but as the voltages get larger, one can observe that the voltages of VBO start rising when the OUT is done with discharging. It is also interesting to note that VBO seems to be not affected by the minimum slope at OUT. This gives rise to the hypothesis that the OUT is limited by the source follower.

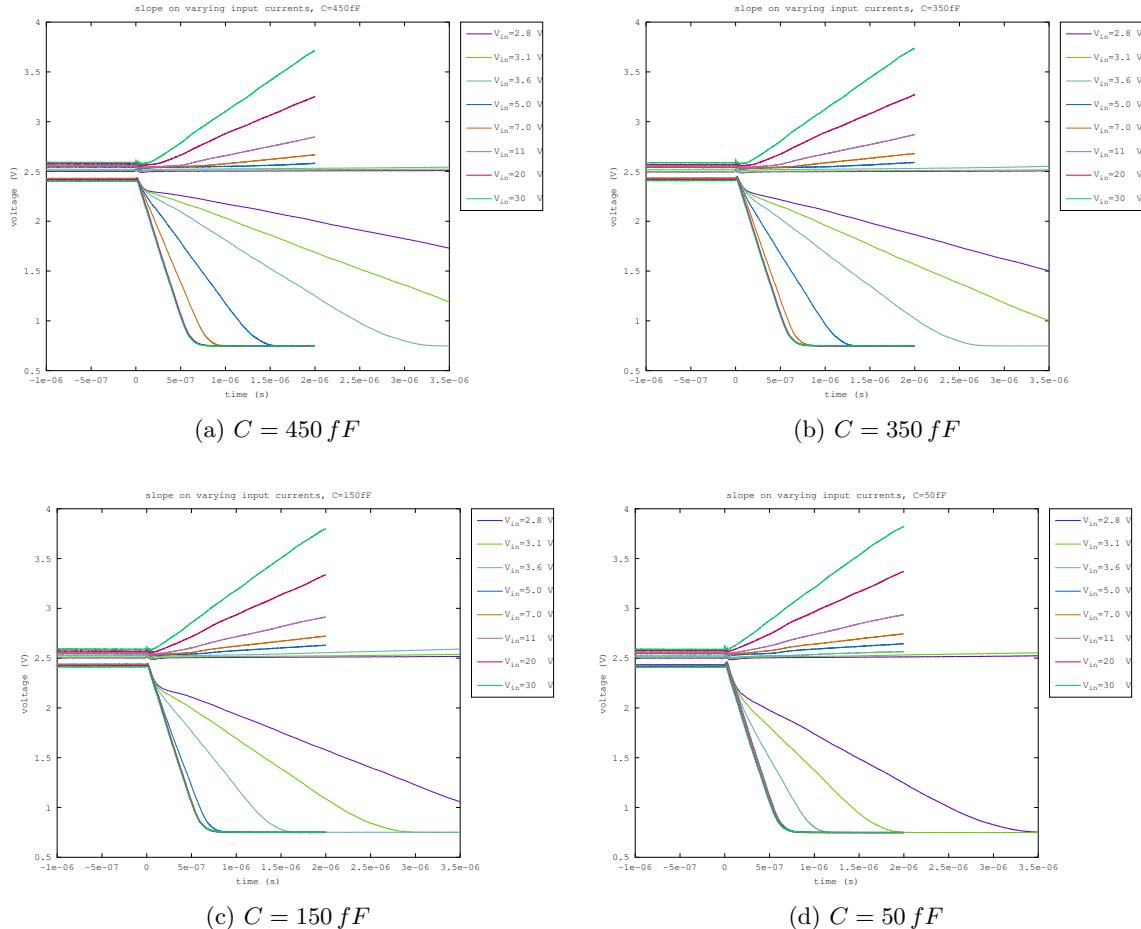


Figure 12: Expected versus measured charge up times for different input voltages. The input voltage is connected to the input through a resistor of  $4 M\Omega$

Figure 13 shows a similar plot as in fig. 9 but with higher currents. In fig. 9 one could observe that all currents fitted to the same line, but deviated at higher currents. This effect is also observed here, but in a stronger form. Which is to be expected.

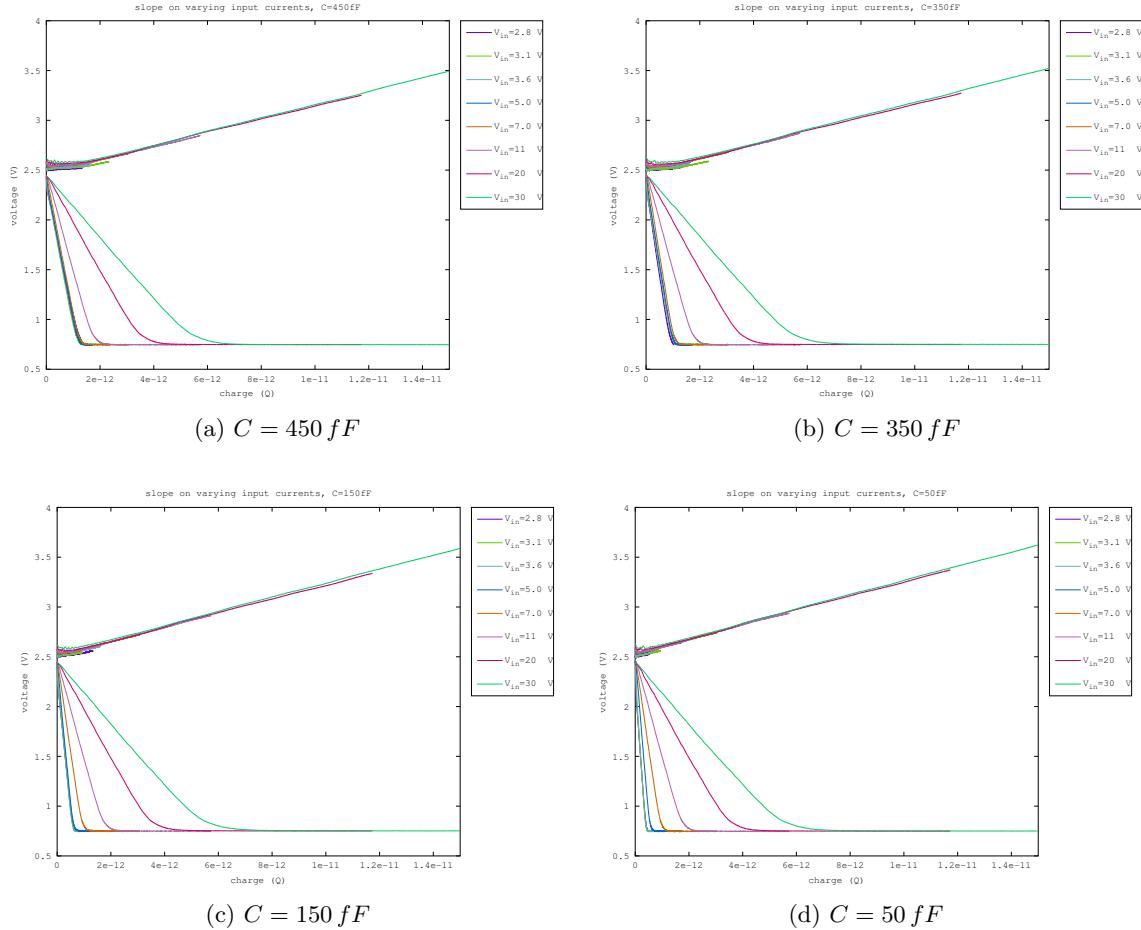


Figure 13: This plot is showing charge versus voltage

Figure 14 shows a plot of  $\delta V/\delta Q$  against charge. Note that the behavior for the low voltages differ across the different capacitances, but that the high voltages are not affected by a change in capacitance. This observation agrees with the hypothesis that the output is not limited by the input current, but by the speed of the source follower at the output.

Figure 15 shows the same plot as fig. 11, but with higher current. This plot clearly shows that all four capacitance configurations saturate at a  $\delta V\delta t \approx 3.1 \text{ V}$ . This cannot be a limit applied to the input, because the capacitances are different. Therefore the output is limiting this, conform previous observations.

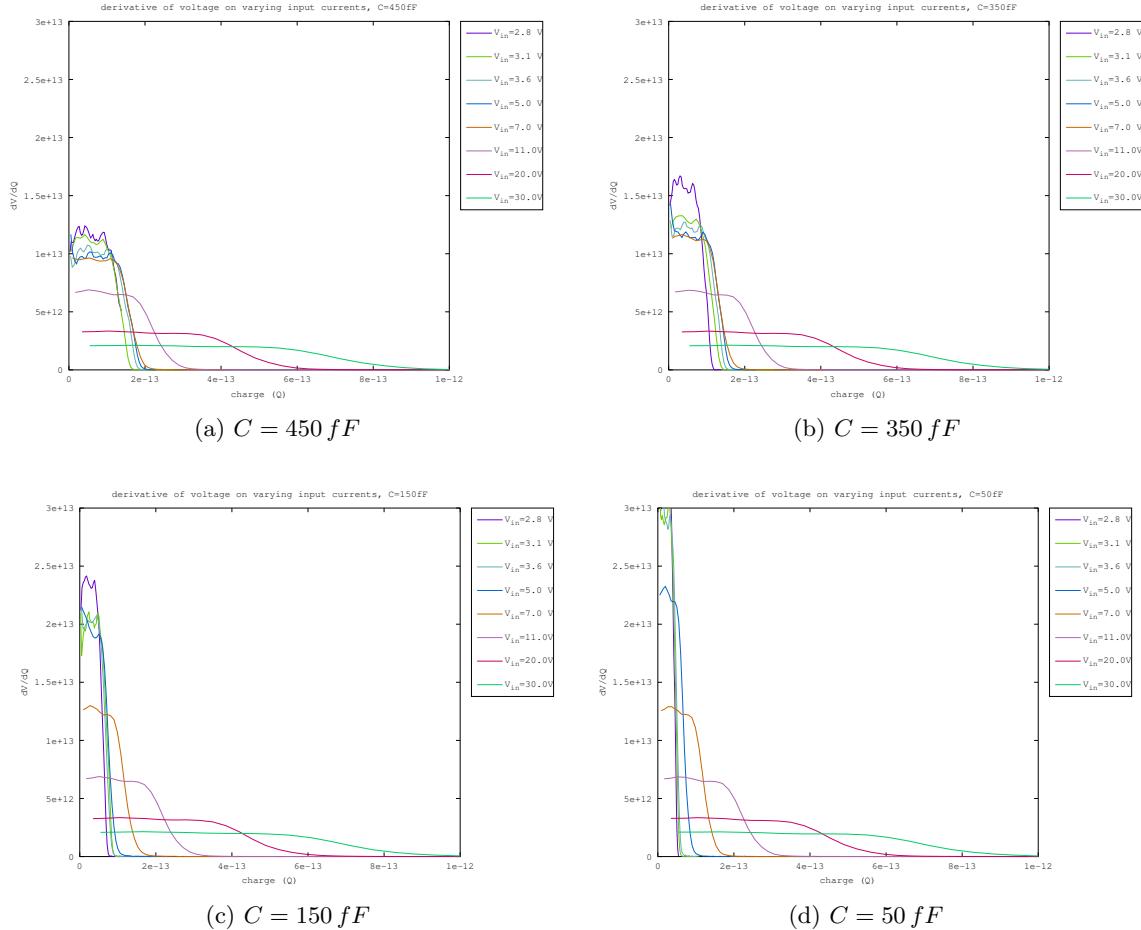


Figure 14: The plot shows  $dv/dt$  against time. The plot is in log scale, which allows for an easy read on the maximum slope and the time needed to discharge the integrator capacitance.

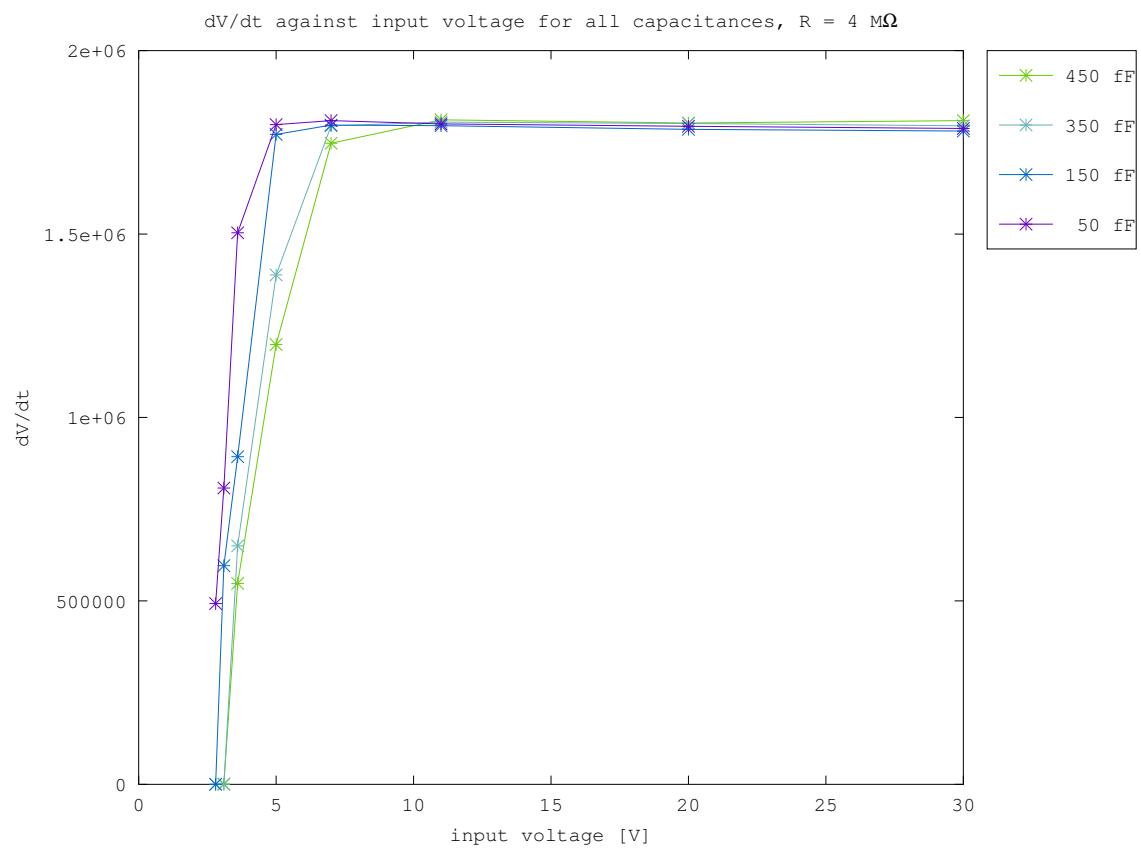


Figure 15:  $dV/dt$  against input voltage for all four capacitances. The x indicate the measurements.

## 2.5 Voltage limiter

This section focusses on the output of the source follower that is directly connected to the output of the high voltage transistor connected to the input of the ROIC. The setup is identical to section 2.3, but the time scale is different to observe the slower behavior of VBO.

Figure 16 shows the time against voltage plot. This are a couple of important observations that can be made from these plots. First and foremost: the behavior of the VBO is almost not affected by the capacitance. The behavior is fairly similar. There is a difference however, in that the VBO starts rising as the OUT reaches zero. This means that the VBO for  $450\text{ fF}$  is slightly delayed when compared to  $50\text{ fF}$  for example. It is also interesting to observe that VBO never increases above  $2.6\text{ V}$ . This behavior is most likely due to the high voltage input transistor doing its job as a current limiter. Finally one can observe that for very low currents, VBO does not reach  $2.6\text{ V}$ . The reason for this is that the input reaches the voltage level of the power supply before the current limiter kicks in.

Figure 17 shows the plots of voltage against charge. One can observe that increasing the current causes the behavior to converge to a line with a linear slope that is constant with  $Q$ , and a saturation at  $2.6\text{ V}$ .

Figure 18 shows  $\delta V/\delta Q$  for the VBO. The main observation one can make from these plots is that the behavior of VBO is almost entirely unaffected by the integration capacitance.

Figure 19 shows the  $\delta V/\delta t$  against input voltage for VBO across all capacitances. For large voltages seem to behave in a normal linear fashion. The startup shows a scene that looks as if the  $450\text{ fF}$  and  $350\text{ fF}$  setup behave identical, and that the  $150\text{ fF}$  and  $50\text{ fF}$  setup behave identical. This might be due to the lack of measurement points, but is worth investigating further.

Figure 20 shows the relationship between  $V_g$  and the voltage limit posed by the high voltage transistor at the input.

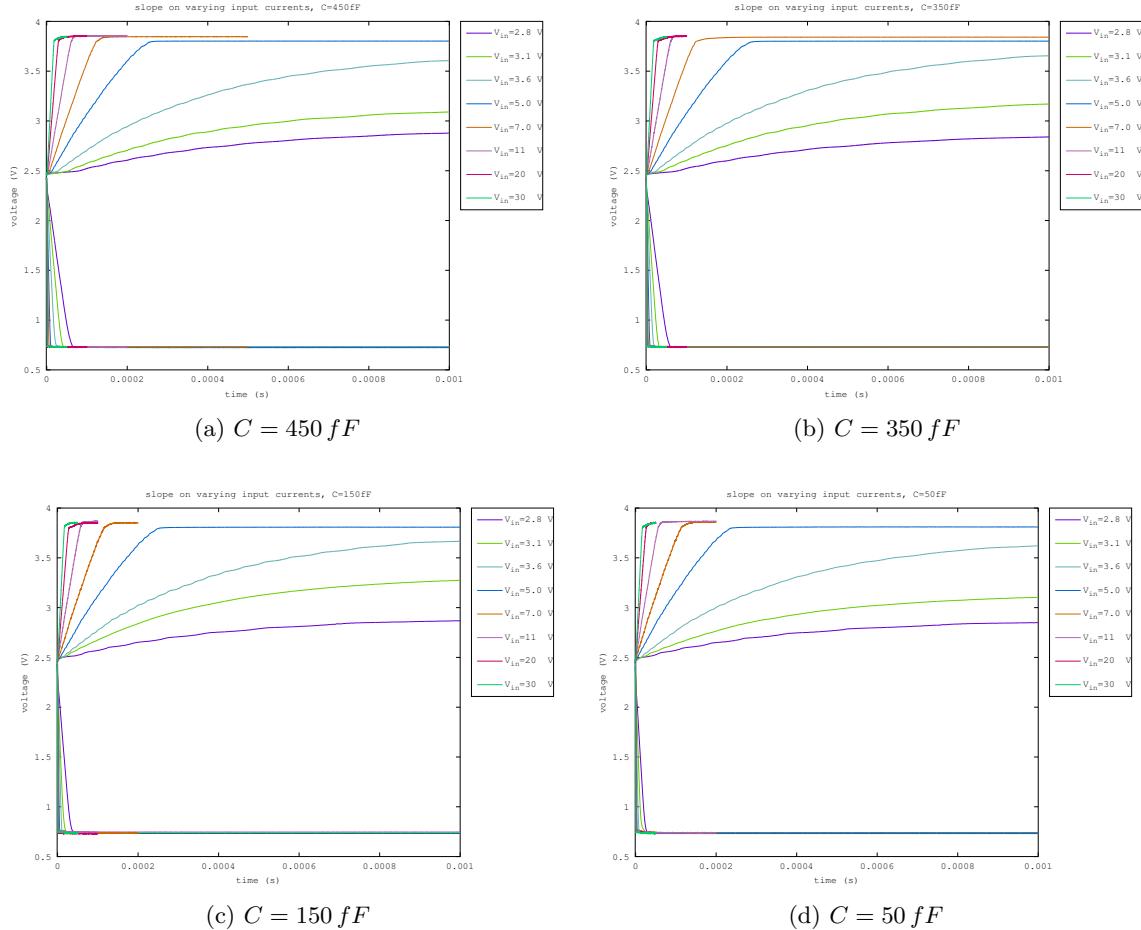


Figure 16: Expected versus measured charge up times for different input voltages. The input voltage is connected to the input through a resistor of  $20 \text{ M}\Omega$

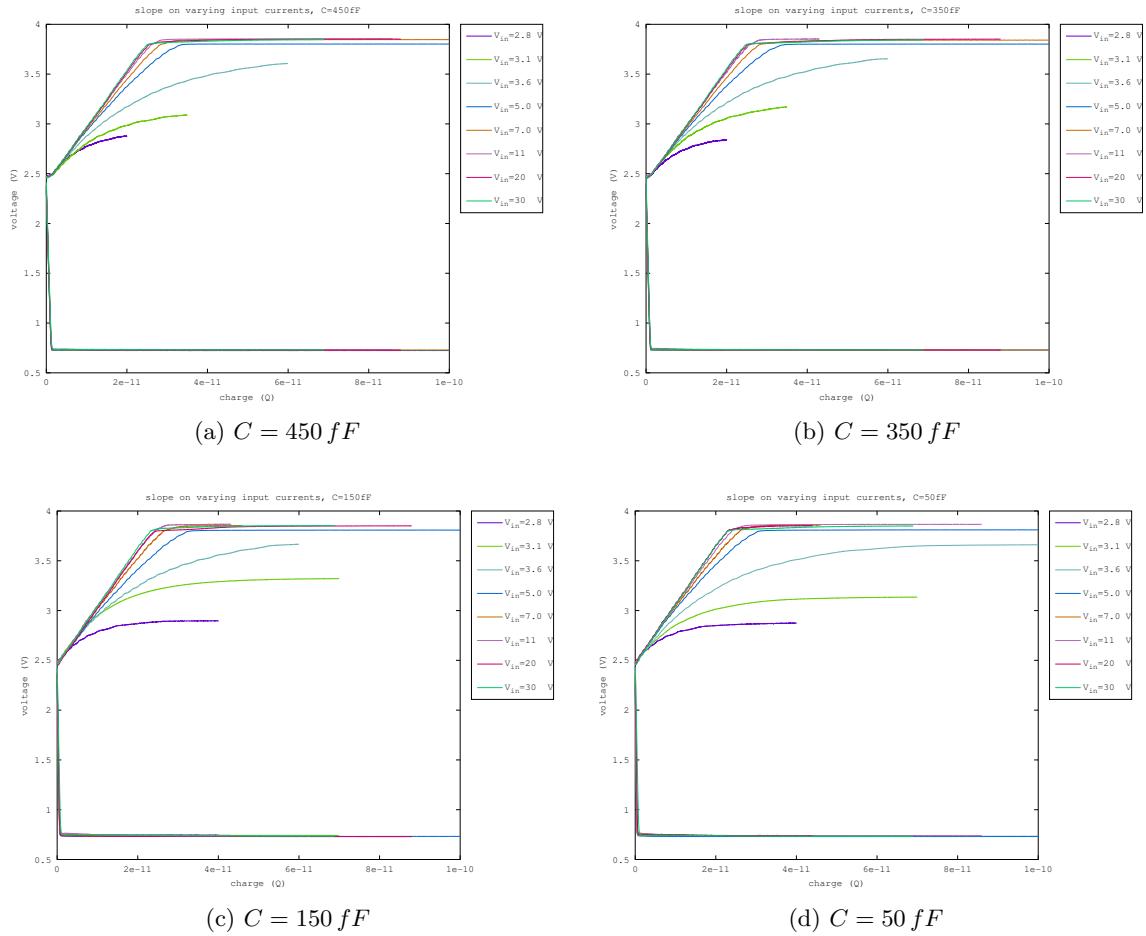


Figure 17: This plot is showing charge versus voltage

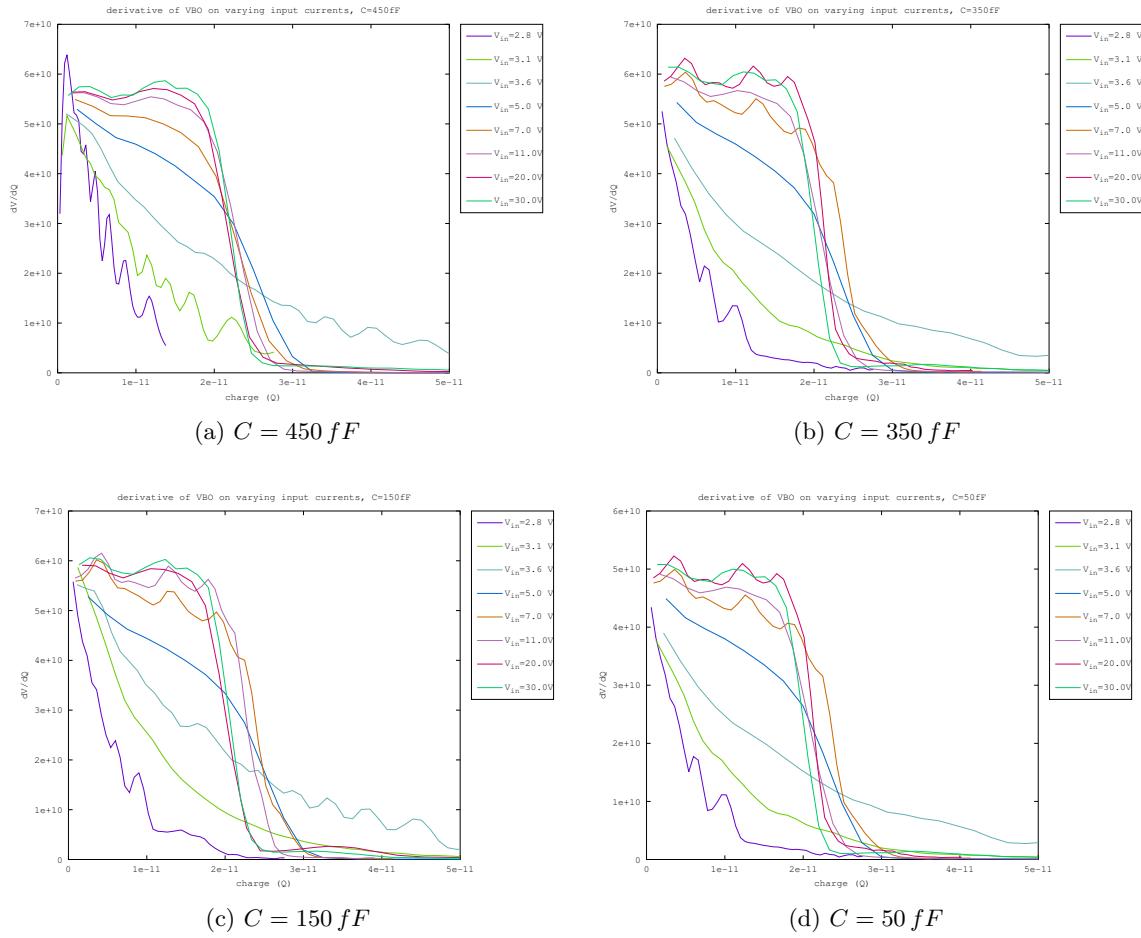


Figure 18: The plot shows  $dv/dt$  against time of the vbo.

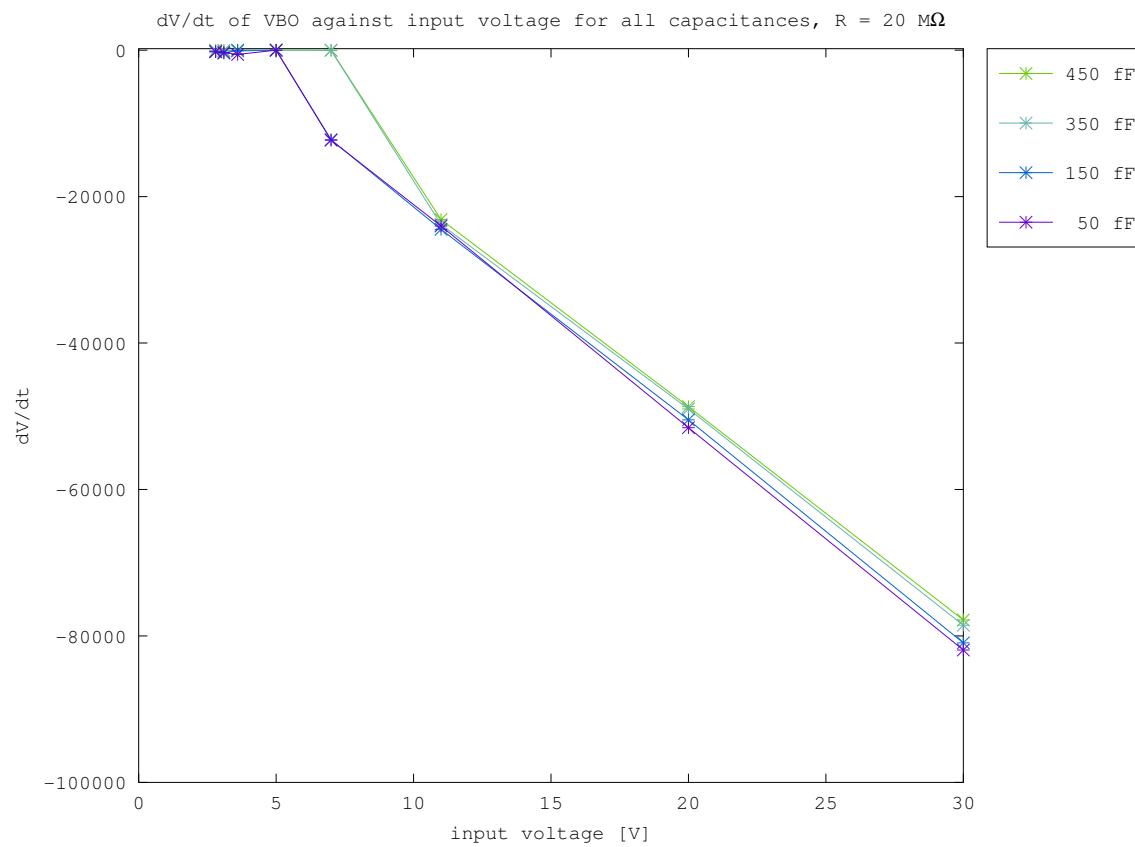


Figure 19:  $dV/dt$  of VBO against input voltage for all four capacitances. The x indicate the measurements.

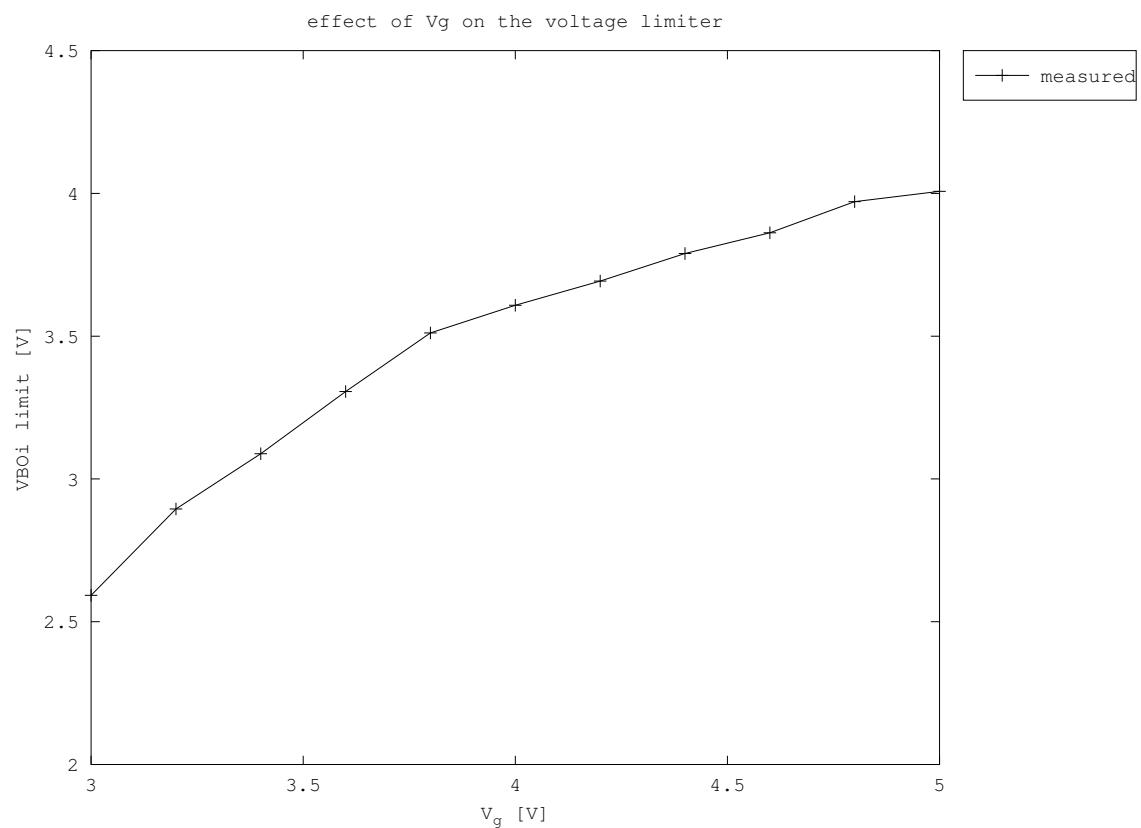


Figure 20: voltage limit as a function of  $V_g$

### 3 Characterization of GaN sensors

After the ROIC is characterized, it can be put to use by measuring the GaN sensors it is designed for. However, before starting on the GaN sensors, the device first gets an upgrade. This time, labVIEW is used to control and readout the oscilloscope in real time. This time the reset signal is not generated by the oscilloscope, but by a separate function generator. This leaves room for the function generator on the oscilloscope to drive the input voltage. Using the oscilloscope and a voltage amplifier, a range of 0 to 25 V can be achieved. The main advantage is that this range can be controlled in labVIEW, which enables an automatic programmed voltage sweep.

This measurement method is used to measure the performance of the different sensors in forward bias. The result of this is shown in fig. 21. The VBO channel is used for the measurements because of the large currents. There are several observations that can be made using this plot. First of all, there are several pins that appear to be unaffected by the input voltage. This is not due to the GaN sensors, but because the ROIC channel broke after a certain point. This is most likely because the input was accidentally connected to a ground pin, which puts the high voltage directly to the input of the ROIC. A second observation is that the reset value of the VBO cannot be contained for large input voltages. This most likely means that the amount of current that is put into the ROIC is larger than the opamp in the ROIC can keep up with. Using an external current meter, the maximum amount of current the opamp can compete with is approximately  $15 \mu\text{A}$ . Finally it is interesting to observe that there is a substantial variance across the different devices. In order to test whether this variance is due to noise or due to variance across devices, a second set of measurements are made, but this time on a single device. The results are shown in fig. 22. These measurements show that the variance over different measurements is relatively low, and that the observed variance in fig. 21 is actually caused by variance across different devices.

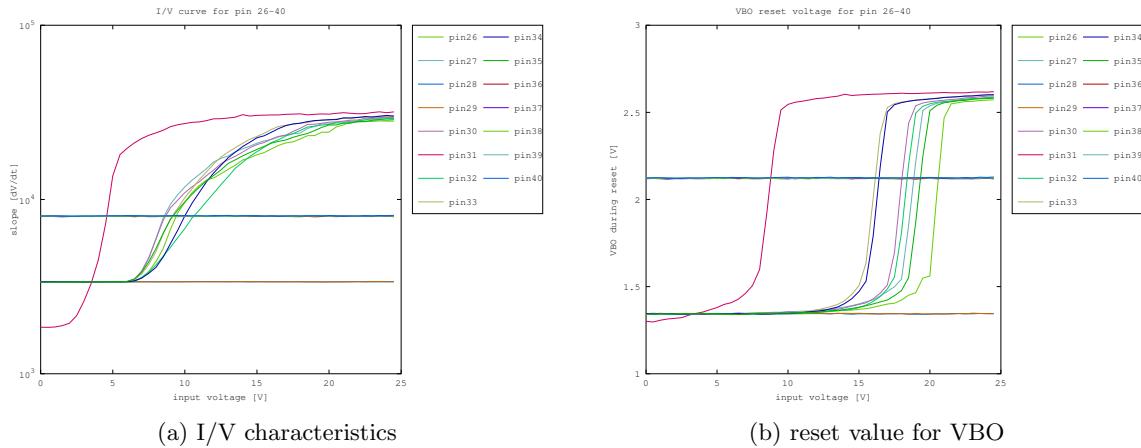


Figure 21: The slope and reset values for the VBO of pin26-40

The next step is to investigate reverse bias, and to achieve that the ground and pin input of the GaN sensor are switched around. The I/V characteristics for several pins are shown in fig. 23. The jumps to negative current between 0 and 2.4 V is due to the ROIC being 2.4 V. Therefore for lower voltages, the current flows into the opposite direction. The numbers are not representative for the actual current though, because the ROIC and measurement method are not designed for that

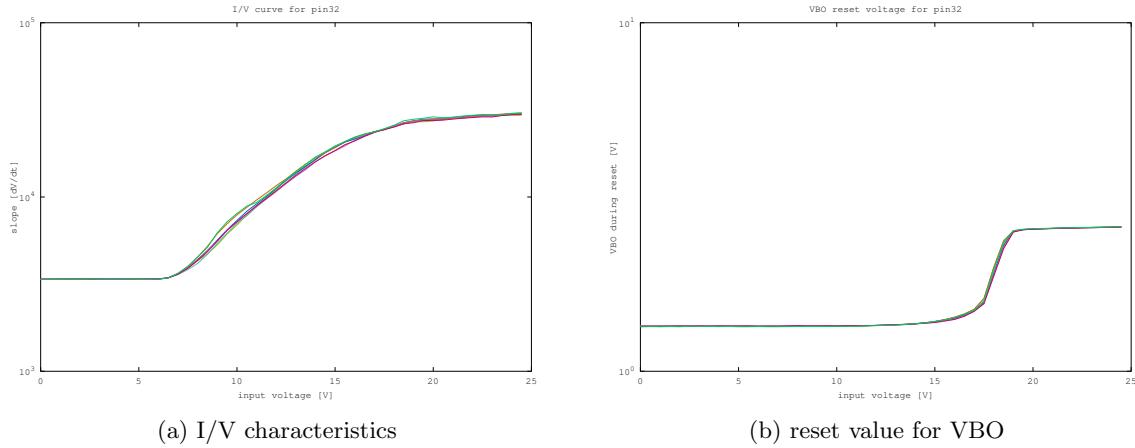


Figure 22: The slope and reset values for the VBO of pin32 repeated multiple times to test variance across measurements

direction of current. The main observation that can be made is that the voltage range available in the current setup is insufficient to observe the most interesting part of the I/V characteristics.

### 3.1 High voltage range I/V characteristics

In order to get a higher voltage range, the setup is changed again. The amplifier used for the input voltage caused a lot of noise and did not amplify enough. The new setup uses a manually controlled voltage source as input voltage. The input voltage is also measured by the oscilloscope. labVIEW continuously takes measurements where it extracts both the current voltage and current. By manually sweeping the input voltage one can accumulate data points to construct the I/V characteristics. The I/V characteristics for pin 21 on the chip are shown in fig. 24. Note that the pin number indicates the GaN sensor on a chip that is connected. The results in this plot match with the expected behavior of GaN sensors based on previous measurements. There is a small exponential increase in current for low bias voltages. At a high bias voltage the device goes into breakdown with a steep exponential increase.

### 3.2 High input currents

When the bias voltage

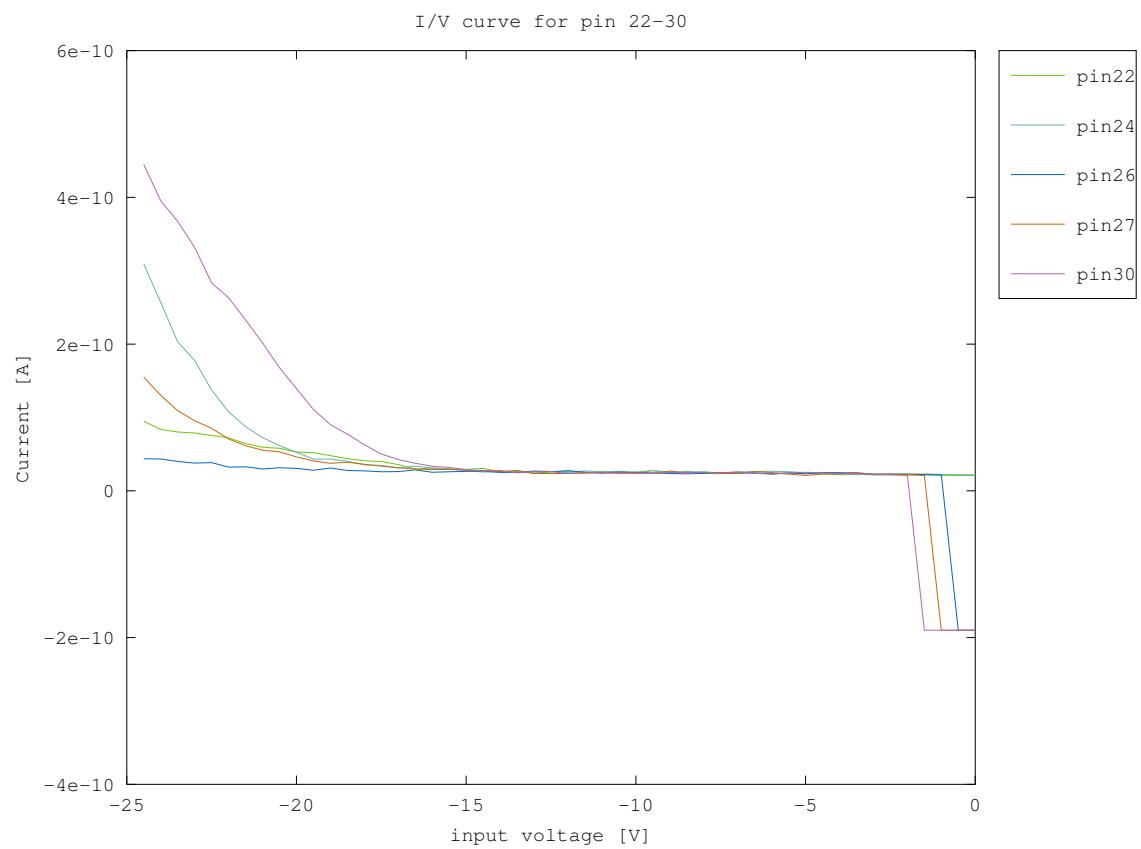


Figure 23: Voltage to current characteristics for several GaN sensors

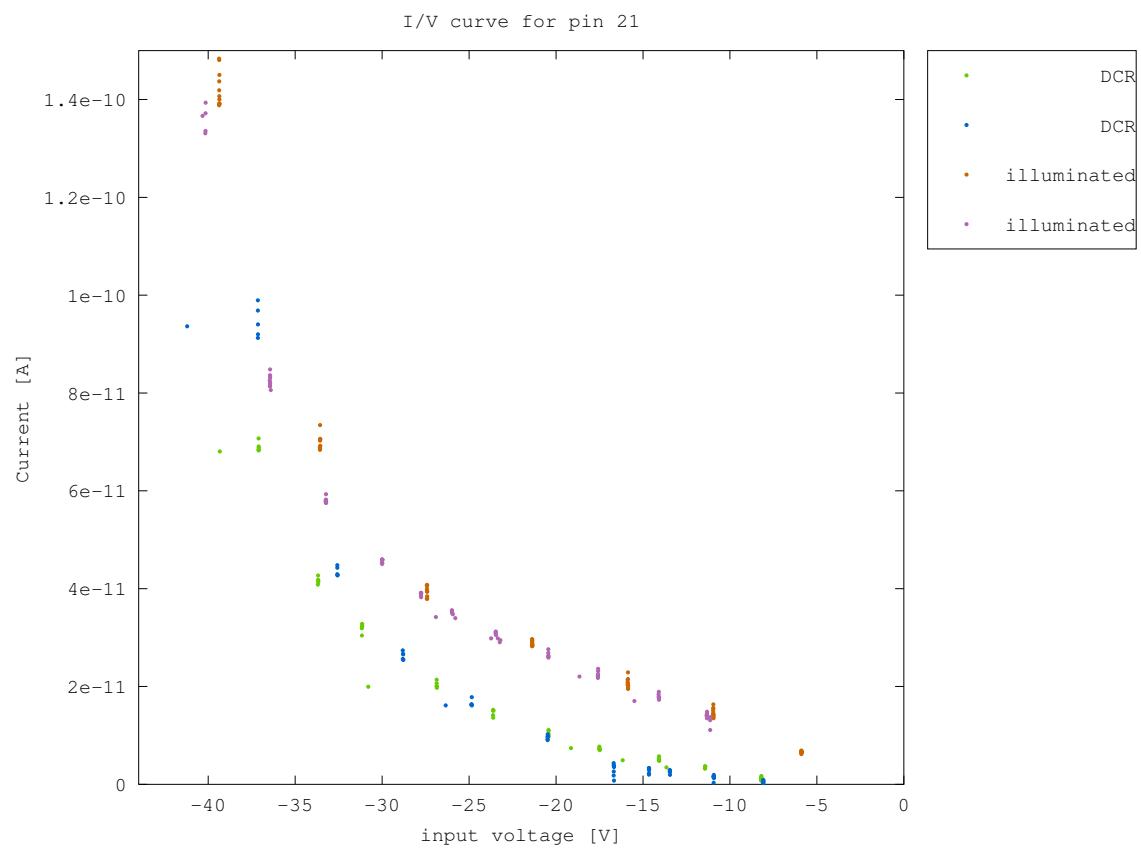


Figure 24: Voltage to current characteristics for several GaN sensors