

# LibreSilicon's 1st Test Wafer (珠江芯片一号)

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## Abstract

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For further clarification consult the complete documentation of the process.

## Document Revision History

VERSION	DATE	DESCRIPTION	TRACKING NOTES
Draft 0.0	2018-05-25	START with empty document, ADD Ring Oscillator	-

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# 1 Considerations

PearlRiver is the first Testwafer for the LibreSilicon 1  $\mu m$  Technology.

This Testwafer should contain almost all test structures to evaluate and qualify the technology-dependent parameters. So on Wafer we placed structures to measure the sheet-resistance of all Poly- and Metallayer, as well capacitors, NMOS and PMOS transistors, bipolar junction transistors, diodes and flash cells. There are even gate cells like NAND3, NOR3 and some others used for ring oscillators.

The parameters, measured from all test structures are used for the Spice3f and other models.

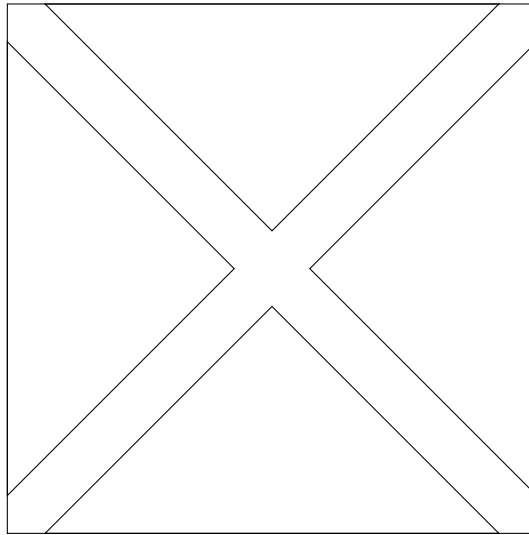
## 1.1 Orientation

There are two different systems to give orientation while talking about locations on the die. One system uses words like top (= upper side), right, bottom (= lower side) and left. The other system uses cardinal directions like north, east, south and west to name the same. Both systems are very common, but here we use the cardinal directions, just as convention.

Wafers smaller than 8 inches, or 200 mm, have a flat side to give orientation and encode the crystal structure. Well, we like to call the side South with the notch or the flats.

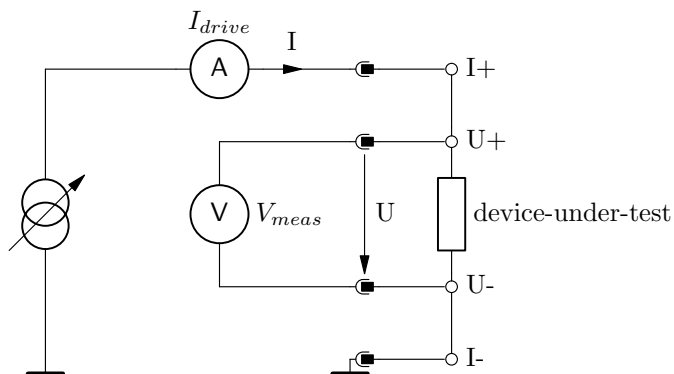
All machines in the process flow have effects while dealing with the structures on the wafer. For instance etching is slightly more aggressive on the eastern side of a structure than on the western side. To understand and measure this effect, all structures on the die are placed in a dedicated way. Structures are grouped together in a triangle. This triangle we call quarter, while placed four times on the same die, each rotated 90 degrees.

One Die with all Quarters



## 1.2 Four-terminal Sensing

Schematic (Four-terminal Sensing)

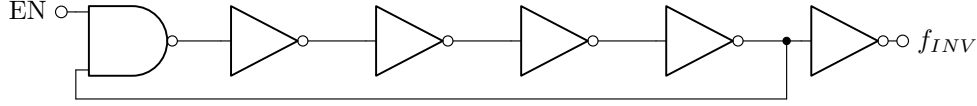


## 2 Ring Oscillators

Ring Oscillators are the hidden Champions in case of qualifying a process.

Here is a example of a Ring Oscillator with 5 inverting stages (build with inverters).

Schematic (Ring Oscillator with INV-Gates)



If  $EN = 0$  the Ring Oscillator does nothing. But when  $EN$  becomes 1, the output of the most left NAND2 Gate depends on the other input. With both inputs for the NAND2 Gate are 1, the output goes to 0, otherwise the output is 1.

Hence we can describe  $EN$  as a high-active Enable signal.

Assuming now  $EN = 1$ , the Ring Oscillator is enabled, the NAND3 Gate delivers the inverted input value from the long feedback line on his output. Assuming there was a level change, this edge propagates through every gate (which takes time  $t_D$  for every INV Gate). At  $n \cdot t_D$  this edge comes back over the feedback line with inverted polarity, while using odd numbers only of inverting Gates.

While edges propagates once through the long line of inverting gates and arrives on the enabling gate again inverted, after 2 runs, this forms a waveform on  $f_{INV}$  which is similar to a clock with a 50-50 duty cycle. The last buffer, between the feedback line and the output pin, is just a buffer to keep the driven capacity on the output line low. Now we can say, that the frequency of the output signal depends just on the delay  $t_D$  over the inverting gates. The Equation for odd numbers of  $n$  is

$$f_{INV} = \frac{1}{2n \cdot t_D} \quad (1)$$

Usually, Ring Oscillators are build from 100..150 Gates in one row. The reason for that is the lowpass characteristic of PAD Cells - the output frequency on PAD cells should be below their cut-off frequency.

With a reasonable guessed value of  $t_D$  and equation 1 we can now adjust  $f_{INV}$  below the cut-off frequency.

At this point we should think about  $t_D$  which depends of course from different parameters, at least

1. the Supply Voltage for the inverting Gates,
2. the current Temperature,
3. and the Quality of the processed technology for every Gate.

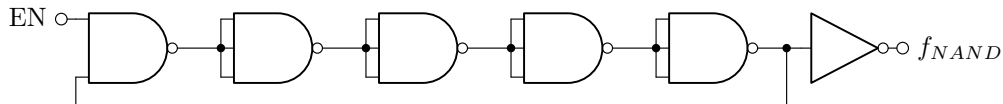
All three items matter for Process Evaluation and Process Calibration, just by indirect measurement of  $t_D$  under different test conditions. BTW,  $t_D$  follows equation 1 as

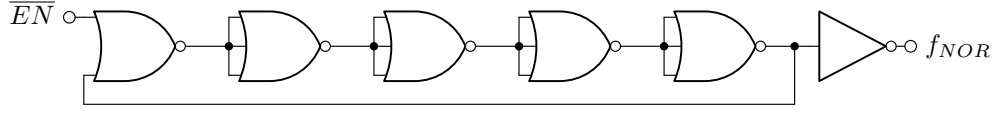
$$t_D = \frac{1}{2n \cdot f_{INV}} \quad (2)$$

If you are already familiar with cell design, you might be knowing that the delay  $t_D$  over the gate differs for both edges. We assume here, that the transistor sizes for PMOS and NMOS transistors are well balanced with a relationship of  $\gamma = 2$  and therefore  $t_D$  has the same value for both edges.

With knowledge of the Ring Oscillator build by simple Inverting Gates, we might think about more advanced cells with different transistor sizes. The schematic with NAND3-Gates looks quite similar.

Schematic (Ring Oscillator with NAND3-Gates)





While using 3-input NAND Gates, all inputs on every gate are wired together. Using just 2-input NAND Gates would be possible also but not recommended as 3-input NAND Gates having one more stacked transistor and are heavier to process accurately. Hence getting the oscillating output frequency on  $f_{NAND}$  means much more. Adapting the same scheme on NOR3-Gates we get this third Ring Oscillator schematic.

Schematic (Ring Oscillator with NOR3-Gates)

Now please, make yourself familiar with the method of "Logical Effort" for calculating the transistor sizes to get well balanced cells. We still assume that  $\gamma = 2$ , where the PMOS transistors are 2 times bigger than the NMOS transistors.

As the logical effort differs for every type of Gate (and therefore there delay), we can calculate the relationship between all output frequencies  $f_{INV}$ ,  $f_{NAND}$  and  $f_{NOR}$ .

The highest output frequency should have the INV Gate based Ring Oscillator ( $f_{INV}$ ) with the lowest logical effort  $g = \frac{3}{3}$ , followed by the NAND3 Gate based Ring Oscillator ( $f_{NAND}$ ) with logical effort  $g = \frac{5}{3}$ . The lowest frequency should have the NOR3 Gate based Ring Oscillator ( $f_{NOR}$ ) with logical effort of  $g = \frac{7}{3}$ .

According to the calculation of getting the delay from the logical effort, the relations can be expressed as

$$f_{INV} \approx f_{max} \quad (3)$$

$$f_{NAND} \approx \frac{9}{11} \cdot f_{INV} \quad (4)$$

$$f_{NOR} \approx \frac{9}{13} \cdot f_{INV} \quad (5)$$