LELO_GR01_SKY130A

Skywater 130nm Temperature sensor

Who

Nicolas, Nikolai and Walter, aka. Group 1

DISCLAIMER

The LVS is not passing due to a NetGen bug. When LVS is bypassed in simulation, it simulates fine with LPE included. Regular "make cdl lvs" also works, it is just when doing "make lpe" that it crashes at the LVS stage.

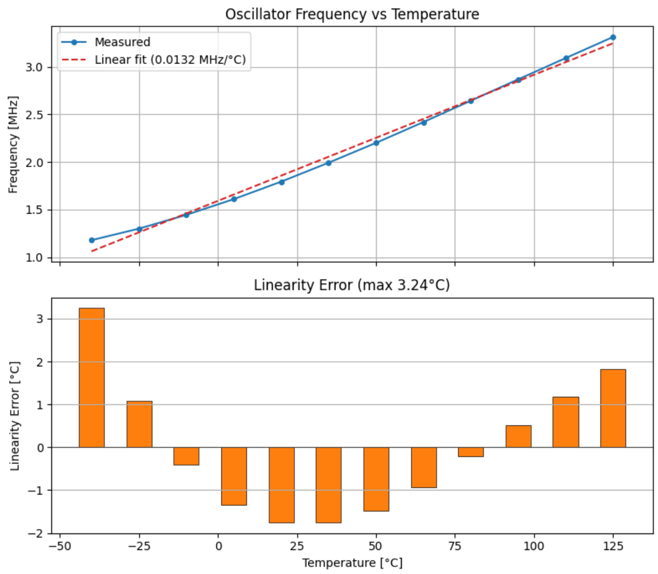


Figure 0.1: The linearity error with parasitics (Typical).

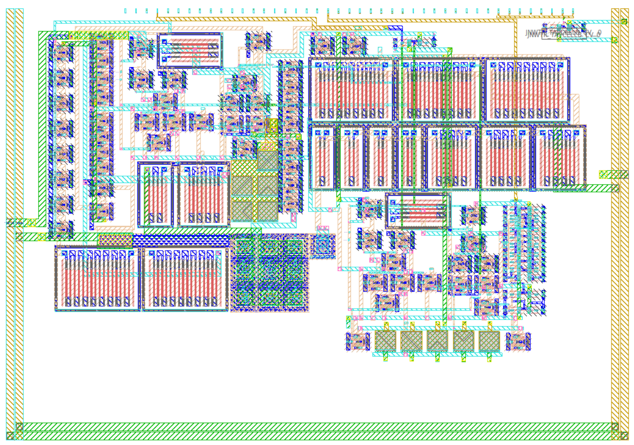


Figure 0.2: Picture of full analog layout with fanout to Tiny Tapeout 1x1.

Why

Bandgap module: In order to measure temperature with an electrical circuit, we need to make some kind of electrical phenomenon which depends on temperature. Here we chose to generate a current.

Oscillator module: To avoid having to make an ADC, the current that scales linearly with temperature can be converted into a frequency. If we can do this, then it will be less accurate than with a good ADC, but also way less complex, because frequency can be read without an ADC.

Digital module (counter): In order to convert the frequency from the oscillator into a digital value we need to quantify it somehow. There are several ways to do this, measuring the period, the time between rise and fall or the number of pulses in a time frame are some options.

How

Bandgap module: The bandgap works since the voltage across our "diodes" (two diode-connected PNP transistors) will vary based on a factor of kT/q where T is the temperature in kelvin (and the size). So, both our diodes have a known voltage drop VD1 and VD2 which depends on the temperature. In order to use this voltage drop to create a varying output current we set a resistor above one of the diodes. Then we force the voltage above the resistor VR1 (12 * 7.535kΩ = 90.42kΩ) to be the same as the voltage above the other diode Q2 using an OTA. The voltage drop across the resistor (and thus the current) will then be VR1 - VD1, or VD2 - VD1. By setting the diodes at different sizes, we will then get a temperature dependent current through the loop.

We then use current mirrors to mirror this to two different branches. One is a constant voltage (VREF), and one varies with temperature (IPTAT). VREF is constant because it is set by resistors (70.667 * 7.535kΩ = 532.473kΩ). IPTAT is not locked by resistors, and therefore varies with temperature. Afterwards, these go into the oscillator to be compared.

Oscillator module: The oscillator works by using these two signals as inputs. The IPTAT current charges a capacitor, and also goes into the negative input of an OTA. The VREF goes into the positive input of the same OTA. When IPTAT has charged the capacitor, the voltage on this node will eventually rise above the positive input. When this happens, there will be an output after a certain delay, caused by the inverters. This output then turns on a transistor in parallel with the charging capacitor, which will empty it. This process generates one period of an oscillating output signal, which will increase in frequency with the current charging the capacitor, and therefore temperature. This means we have successfully generated a frequency that scales relatively linearly with temperature. The slight non-linearity of this will be the temperature inaccuracy, which needs to be minimized. This will also be affected by variations in the die of the final tapeout.

Waveforms are shown below.

Counter module: In order to get a digital value for the temperature, we used a counter that counts the number of pulses from the oscillator during a period of a reference clock at 32768Hz. This counter has been designed in System Verilog according to this FSM:

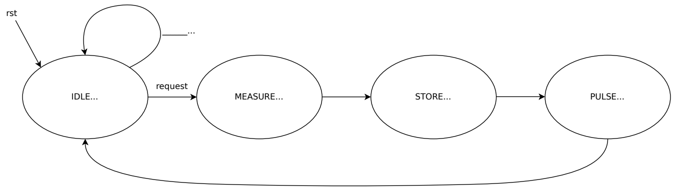


Figure 1: Finite state machine used for the counter

This FSM takes as input the reference clock at 32768Hz, a reset, a request wire to start a measurement and the squared signal generated by the oscillator. It outputs the number of pulses detected, the wire pwr which is used to powerup the analog circuits and a done signal which pulses when the measurement ends.

With a 2MHz oscillator signal, we get the following waveforms:

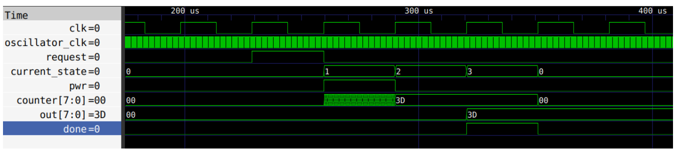


Figure 2: Example of a waveform from the FSM

When the request signal is received, the FSM start to power up the analog part and count the number of pulses generated by oscillator in the internal variable counter. Next, it powers down the analog, puts the value of the counter variable in the out variable and generate a pulse through the done wire to indicate the end of the measurement. In this example we get 0x3D pulses (in hexadecimal, or 61 in decimal) during one period of the reference clock.

We can plot the output of the counter in function of the oscillator frequency, as shown in the next figure:

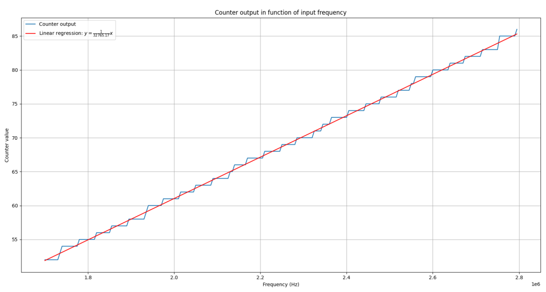


Figure 3: Output of the counter in function of the oscillator frequency

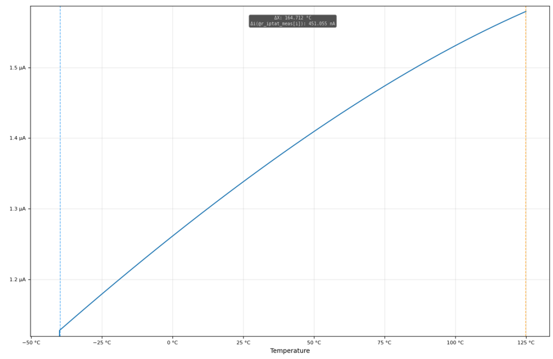
As expected, the linear regression tells us that the number of pulses is equal to the oscillator frequency divided by the reference clock frequency. To reduce the quantization noise it is possible to reduce the reference clock frequency so the FSM can count more pulses in one period.

For testing the digital module, we made an oscillator simulator, which reads from .csv files we got out from our simulator runs for the analog. This oscillator simulator then chooses a frequency from the chosen csv based on a temperature it gets in as a parameter. This means that we can pretty accurately get simulation results for the entire system without having to simulate them together.

Key parameters

Parameter	Min	Typ	Max	Unit
Technology		Skywater 130 nm		
AVDD	1.7	1.8	1.9	V
Oscillation frequency	1.7	2.3	3.1	MHz
Temperature	-40	27	125	C

Simulation Graphs



Bandgap:

Figure 1: IPTAT simulated with a sweeping temperature between -40 and 125 degrees C. A 1k resistor has been placed between IPTAT node and ground to measure this.

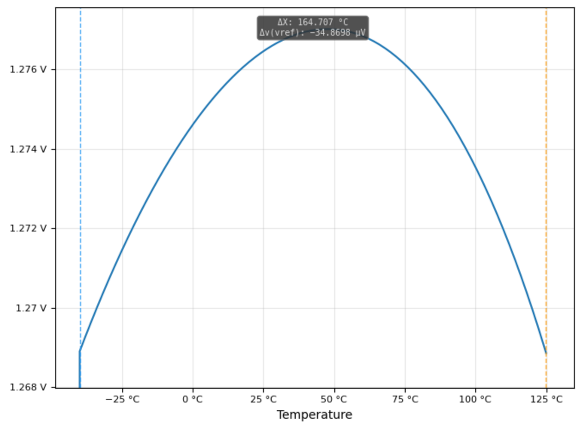


Figure 2: VREF simulated with a sweeping temperature between -40 and 125 degrees C. It is quite constant, with a tiny delta between the startpoint and endpoint, and nearly centered peak.

Oscillator: typical: Image: remote

Figure 3: tran simulation of the oscillator for a temperature of 40°C.

Image: remote

Figure 4: Plot of the oscillator frequency for various temperature between -20°C and 120°C.

Image: remote

Figure 5: Plot of the linearity error of the oscillator translated in temperature measurement error.
Oscillator: Montecarlo simulations: Image: remote

Figure 6: Results of Montecarlo simulations of the bandgap and osciallator setup at different temperatures.

Image: remote

Figure 7: Estimated error in the temperature measurements with two points calibration for extreme test conditions Montecarlo simulations. The results are well within spec, as the plot shows around +-3 C error peak within the 0-70 C range. Though it must be noted that these measurements are BEFORE being fed through the digital part, so quantization is not visible here.

Full system: Typical runs:

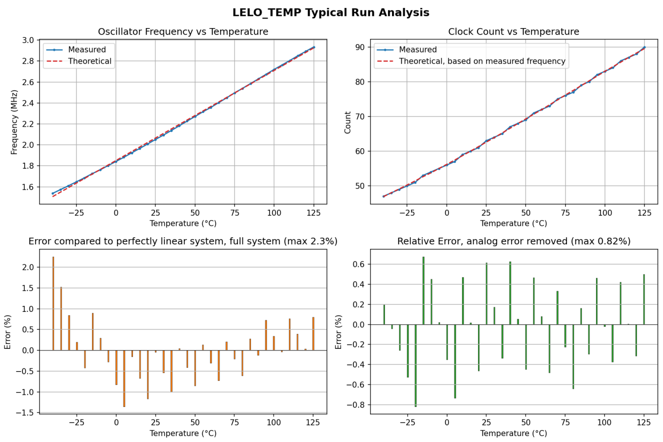


Figure 8: Several plots showing different aspects of the full system. Top left: The oscillator frequency compared to a linear approximation. Top Right: our "count" compared to a perfect theoretical float count. Bottom left: Total error of all parts (digital and analog) per measurement in percent compared to a theoretical perfectly linear system. Bottom right: The digital error, analog error removed

Full system: Montecarlo simulations:

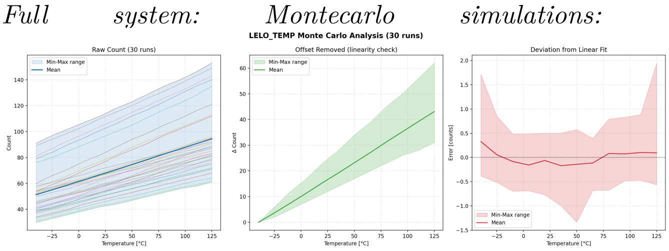


Figure 9: Results of Montecarlo simulations fed through the digital system.

What

What	Cell/Name
Schematic Top level	design/LELO_GR01_SKY130A/LELO_GR01.sch
Schematic Oscillator	design/LELO_GR01_SKY130A/oscillator.sch
Schematic Bandgap	design/LELO_GR01_SKY130A/bandgap.sch
Schematic Diff Amp	design/LELO_GR01_SKY130A/diffamp_1.sch
Schematic GM Cell	design/LELO_GR01_SKY130A/GM_cell.sch
RTL digital module	rtl/LELO_TEMP.sv

Signal interface

Top level:

Signal	Direction	Domain	Description
VDD_1V8	Input	VDD_1V8	1.8V Main supply
VSS	Input	Ground	
PWRUP_-1V8	Input	VDD_1V8	Power up the circuit
OSC_-TEMP_1V8	Output	VDD_1V8	Temperature dependent frequency
:—	:—:	:—:	:—
CLK	Input	VDD_1V8	32.768kHz clock for digital
Request	Input	VDD_1V8	Input signal to request measurement
Done	Output	VDD_1V8	Signal to indicate that value is ready
Out	Output	VDD_1V8	Output value in counts (8 bits)

Bandgap:

Signal	Direction	Domain	Description
VDD_1V8	Input	VDD_1V8	1.8V Main supply
VSS	Input	Ground	
PWRUP_-1V8	Input	VDD_1V8	Power up the circuit, not currently used
VREF	Output	VDD_1V8	1.27V reference voltage generated
IPTAT	Output	VDD_1V8	PTAT current which increases with temperature

Oscillator:

Signal	Direction	Domain	Description
VDD_1V8	Input	VDD_1V8	1.8V Main supply
VSS	Input	Ground	
VREF_BG	Input	VDD_1V8	1.27V reference voltage generated
IBP_B	Input	VDD_1V8	PTAT current to drive the oscillations
OSC_-TEMP_1V8	Output	VDD_1V8	Temperature dependent frequency

Diffamp:

Signal	Direction	Domain	Description
VDD_1V8	Input	VDD_1V8	1.8V Main supply
VSS	Input	Ground	
VIP	Input	VDD_1V8	Positive input voltage
VIN	Input	VDD_1V8	Negative input voltage
VOUT	Output	VDD_1V8	Output voltage

GM Cell:

Signal	Direction	Domain	Description
VDD_1V8	Input	VDD_1V8	1.8V Main supply
VSS	Input	Ground	
IBP	Output	VDD_1V8	Output current, approx 10uA at 27C

Digital Counter:

Signal	Direction	Domain	Description
clk	Input	VDD_1V8	32.768kHz reference clock
rst	Input	VDD_1V8	Active high reset
request	Input	VDD_1V8	Start a temperature measurement
oscillator_clk	Input	VDD_1V8	Oscillator signal to count
pwr	Output	VDD_1V8	Powers up the analog circuits
done	Output	VDD_1V8	Pulses when measurement is complete
out	Output	VDD_1V8	8-bit pulse count result

Install

Clone LELO_GR01_SKY130A

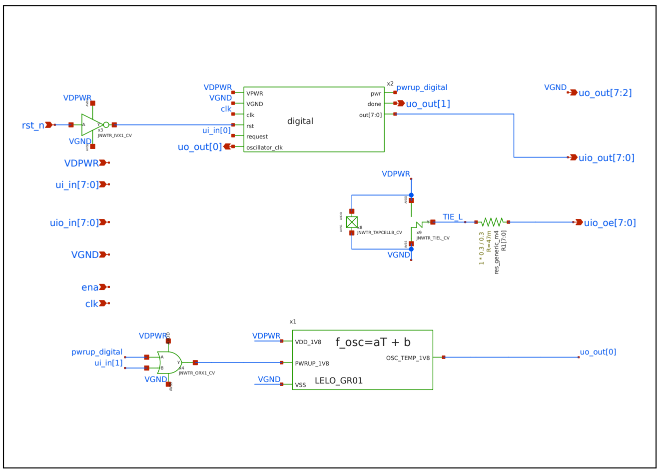
To install, do the following

```
python3 -m pip install cicconf
git clone --recursive https://github.com/analogicus/
cicconf --rundir ./ --config lelo_gr01_sky130a/conf
```

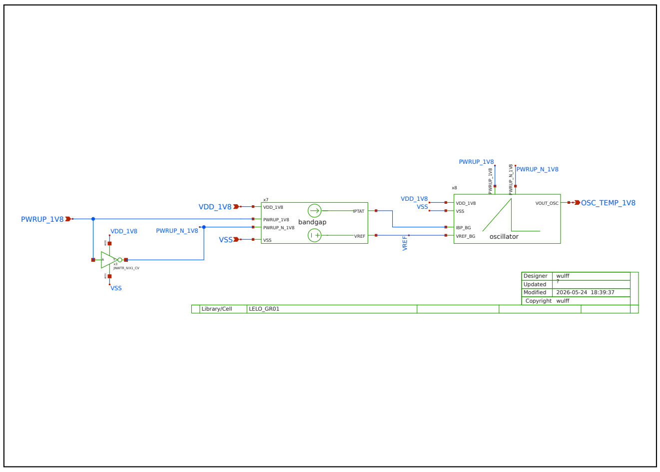
Schematics

LELO_GR01_SKY130A

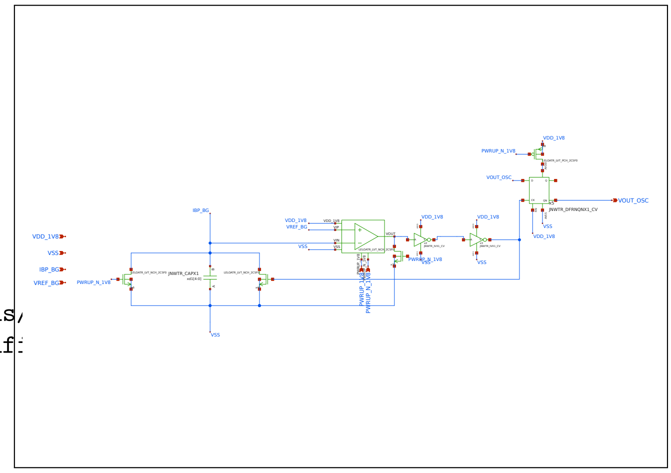
tt_um_lelo_gr01_analogicus:



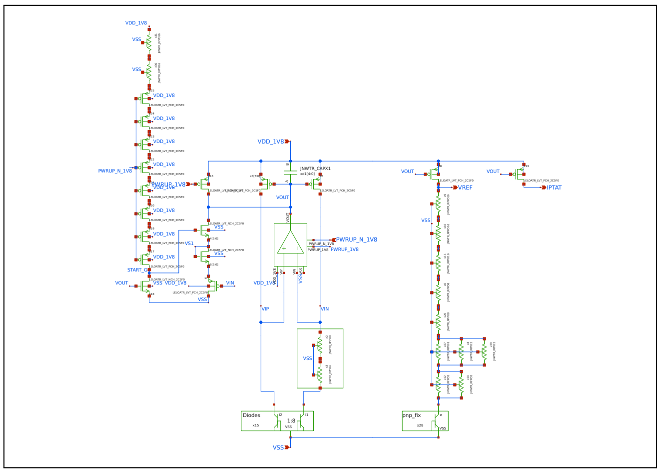
LELO_GR01:



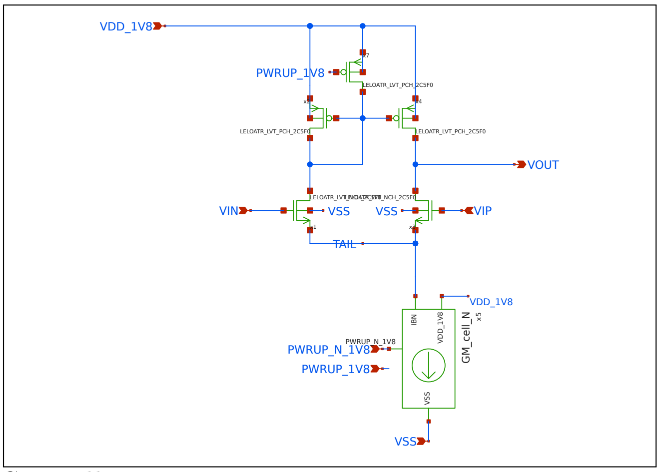
oscillator:



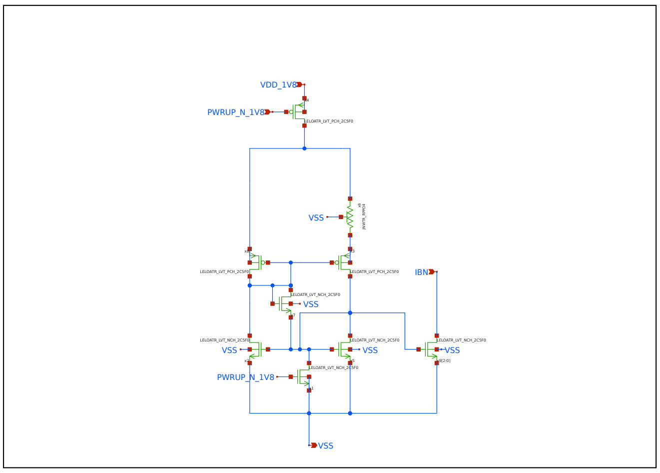
bandgap:



diffamp_2:


VDD_1V8
PWRUP_1V8
VOUT
VIN
VSS
VIP
TAIL
VDD_1V8
GM_cell_N
PWRUP_N_1V8
PWRUP_1V8
VSS

GM_cell_N:


VDD_1V8
PWRUP_N_1V8
VSS
IBN
VSS
PWRUP_N_1V8
VSS

Simulations

LELO_GR01_SKY130A

tt_um_lelo_gr01_analogicus:
LELO_GR01:
oscillator:
bandgap: README.md: “dbd086a Fri May 1 15:18:43 2026 +0200”

TB_NCM
Transient analysis (tran): Check transient operation

Name	Parameter	Description	Min	Typ	Max	Unit
Bandgap Reference Voltage	**vref_avg**	**Spec**		**1.227**		**V**
		Sch_typ		1.227		
		Sch_etc	1.222	1.231	1.239	
		Sch_3std	0.893	1.222	1.552	
PTAT Mirror Current	**iptat_typ**	**Spec**		**0.00**		**uA**
		Sch_typ		1.10		
		Sch_etc	0.97	1.10	1.27	
		Sch_3std	0.47	1.09	1.71	
Amp Tail Voltage	**v_tail_typ**	**Spec**		**0.141**		**V**
		Sch_typ		0.141		
		Sch_etc	0.113	0.143	0.175	
		Sch_3std	0.118	0.140	0.162	

diffamp_2:
GM_cell_N: