Back in the days

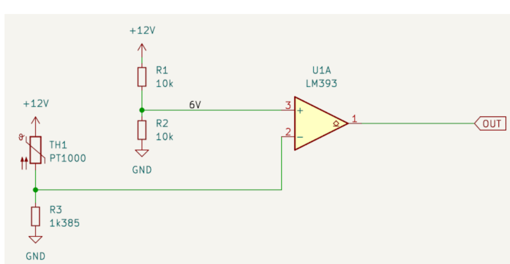
For a good start of our adventure, it would be good to familiarize with the history of these systems. I believe it all started in 1947, when John Bardeen and Walter Brattain developed a transistor prototype based on Germanium structure at Bell Labs[1]. The transition from bulky vacuum tubes to incomparably smaller transistors was, in fact, a major breakthrough that initiated rapid development electronics. You didn't have to wait long for another success: in 1967 Karl D. Swartzel developed the first operational amplifier - an electronic circuit consisting of a group of electronic components that allowed the implementation of mathematical functions (mathematical operation, thus its name): summing, differentiating, integrating, comparing, multiplying, generating functions. The operational amplifier became a solid base of the first analog computers, that began to be built, and this was the beginning of the SCADA era.

Learning by an example

What was the practical implementation? Let's say, that we need to monitor the temperature and alert if it exceeds a certain value - this is probably the simplest possible variant that we can imagine. So let's design a simple operational amplifier circuit that will perform this function. We start with a simple PTC sensor that has a specific resistance characteristics as a function of temperature. In the lookup table we find the characteristic value for the assumed temperature. Let's assume our temperature:

Temperature [Celsius]	PT1000 resistance
100	1385Ω

So our circuit, designed with operational amplifier, could look like this:



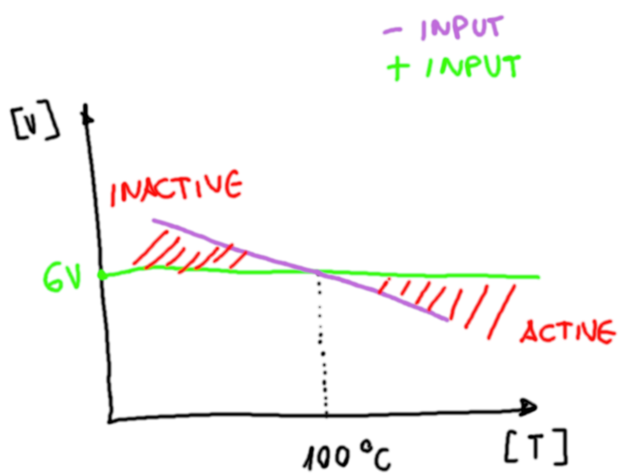
[1]In fact, it would be fair to say that many laboratories around the world have actively worked on the concept of the transistor, so it is a joint achievement of many scientists.

if U(+)>U(-)	then U(OUT)=12V
if U(+)<U(-)	then U(OUT)=0V

How does that work? Our operational amplifier is marked with the symbol U1A. Such an amplifier usually has two inputs: non-inverting, marked with the "+" symbol, and inverting, analogously marked with the "-" symbol. In this system, our operational amplifier plays the role of a comparator, i.e. it compares the voltage value at the both inputs.

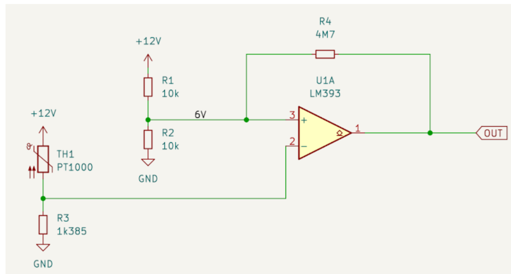
Two quantities are compared: a constant set value of U+, and a variable value as a function of temperature U-.

As you can easily see, U(+) is constant - since the ratio of resistance R1 to R2 is 1/1, they divide the 12V voltage in half, so the non-inverting input (marked with +) is fed with a permanent 6V signal.



Since our sensor is a PTC (positive temperature coeff.), so as the temperature increases, its resistance increases as well and the U(-) voltage decreases. If we assume the value for the TH1/R3 pair to present 1:1 voltage divider ratio at 100 degrees - and set the value of R3 to 1385Ω, then the U(OUT) signal switching point will be set exactly at a temperature of 100 centigrades, so the operational amplifier will output 12V within the range of 100 and over degrees of Celsius.

If you are observant, you may have noticed that the table above does not take into account the situation where U(+) is equal to U(-), i.e. at the switching threshold. Here, a situation may arise in which the switching threshold will be crossed multiple times. To avoid this phenomenon, a hysteresis loop is introduced - just insert another feedback resistor R4, connecting U(OUT) with U(+) with a value much greater than R1, R2 - for example several MΩ.



After U(OUT) is activated, it will additionally slightly raise the potential of the non-inverting input, increasing the difference in favor of U(+), and this in turn means that the U(-) voltage will have to be a little higher than 6V for the comparator to switch back, in the opposite direction. In this way, we obtain a certain dead zone that eliminates the phenomenon we may not want.

I would suggest you now to build such a circuit and check its operation in practice. You can - for example - investigate:

- how will such a system behave at the switching point without feedback loop resistor?
- how the introduction of hysteresis affects switching?
- how the value of the feedback resistor affects the width of the hysteresis window?

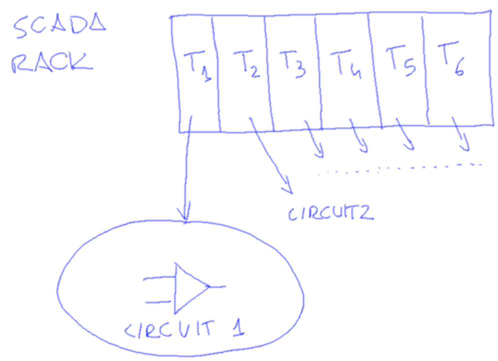
And if you are ambitious, I have a bonus task: before you disassemble the tested circuit and throw the electronic components into a drawer, rebuild this circuit according to a new concept: let the circuit signal a temperature drop below 30 degrees Celsius.

In our considerations, I have deliberately passed over further U(OUT) signal processing. The signal we receive can be used to signal an exceeded temperature alarm, to regulate it - for example by controlling the cooling system, etc.

First SCADA systems

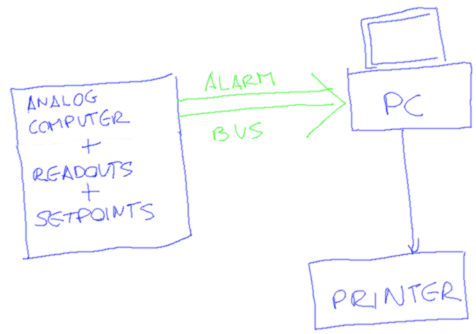
These are the basics of how the first SCADA systems were built. They had been a real gamechangers: it was much easier for several engineers to supervise the process parameters on a desktop collecting all this information in real time, rather than visiting each point of the system and making manual measurements, in a time pooling manner.

We managed to design our own temperature measurement system using analog data processing. It is obvious that if we wanted to monitor - for example - ten different temperatures - we would need to duplicate our measurement system ten times. If we planned to process other physical quantities as well, we would need to design further electronic circuits related for them. Can you imagine this tangle of wires for a system monitoring thirty different temperatures, fifteen pressures, ten control valves (reading their position and executing commands) and, for example, two electric motors?



However, these were the realities in which the engineers of the first SCADA solutions operated. The equivalent of a computer program were analog signal processing algorithms based on operational amplifiers. Changing the algorithm (e.g. temperature alarm setpoint) required changing the values of electronic components in the system, which was extremely burdensome and was one of the two biggest drawbacks of this solution. What was the second one? First of all, the scalability of such solutions and the ease of their expansion. But, for balance, it is worth mentioning that these systems also had their advantages: undoubtedly one of the greatest of them is the ability of fast processing signals: for example, the LM393 we used in our example circuit compares the values of U(+) with U(-) under one microsecond! And if we measure thirty physical quantities, all thirty are calculated simultaneously in less than a microsecond as well. This is really impressive! Achieving such performance in data processing was beyond the reach of the first programmable computers of a digital world. However, unlike their analog counterparts, they had memory in which they could record events. Therefore, their original role in SCADA solutions was to collect information about the occurrence of an alarm state for each one of the measurement inputs (binary "ALARM BUS" on the sketch below). This information was then processed into a corresponding message presented to the system operator, for example:

"P1 Tank temperature over 100 centigrades" and displayed on the monitor.



At the same time, the computer recorded the event along with the date of occurrence on the printer (sort of a paper syslog). Such solutions turned out to be incredibly helpful in situations where many alarms appeared simultaneously and it was difficult to determine which of them occurred as the primary cause. On the log printout, it was easy to determine what triggered the avalanche of alarms.