APPLICATION NOTE:
FUEL CELL SIMULATION

Elektro-Automatik

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1. Preamble

All models of the power supply series PSI 10000 and PSB 10000 feature an IU function which is based on an XY generator. It allows for the user to have the power supply set a DC current depending on the actual voltage on the DC terminal. The IU function is driven by a table of exactly 4096 values which are distributed over the voltage measuring range of 0...125% of the rated voltage. The table can either be loaded from an USB stick through the USB port of front panel or via remote control.

Definition of the IU function: I = f(U)

The automobile market regarding car models powered by (hydrogen) fuel cells is growing from year to year in the private, bus and transport sector. This application note is supposed to introduce and explain the fuel cell simulation feature of the above mentioned power supply series, helping to show possible applications and to start ideas.

2. Simulation of a fuel cell

In order to create a test environment, e. g. for the automotive sector, where fuel cells would be used but where cell fuel, temperature, pressure, supply and exhaust air cannot be monitored or where a test requires to be independent of resources or to reduce the preparation time in R&D phase, devices of the 10000 series and their functions are ideal. The "FC (Fuel Cell) function" is used for the simulation of the I-U curve of a fuel cell.

The characteristics curve of a fuel cell can be divided into three parts as shown below:

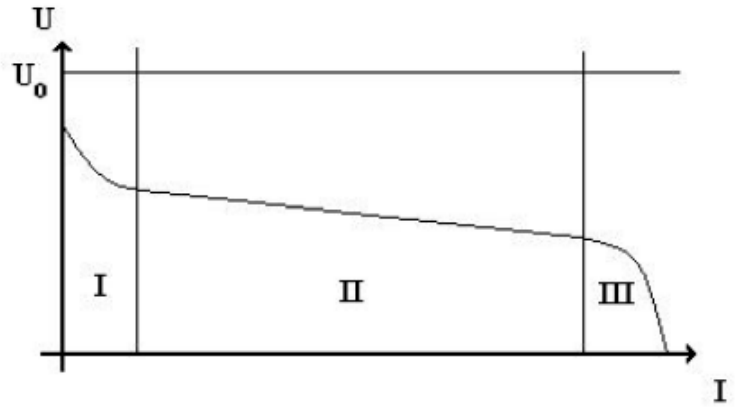

Figure 1: Typical curve

Part I: In this range electro-kinetic effects dominate the course of the curve.

Part II: In this section, the ohmic resistances of the fuel cell and the cables and contacts involved come into effect. It has a linear progression.

Part III: This exponential drop is related to the fact that, as the conversion rate increases, not enough hydrogen and oxygen are available at the anode and cathode, so energy is consumed quicker than supply diffuses to the electrodes.

The FC table function is used to simulate the characteristics of voltage and current of a fuel cell. This is achieved by setting up some parameters which define points on the typical fuel cell curve, which is then calculated as IU table and passed to the internal function generator. The user has to adjust values for four support points.

2.1 Input values

When setting up the curve points, following rules apply:

- U_{OC} > U-P2 > U-P3 > U-P4
- I_{SC} > I-P3 > I-P2 > I-P1
- Values of zero are not accepted

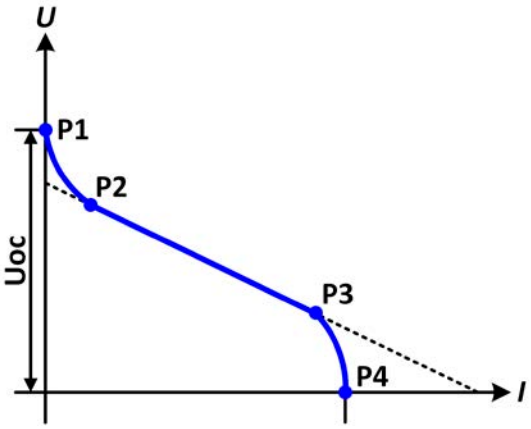

Figure 2: Depiction of the support points on the curve

For the selection of the proper device model it has to be considered, that for an optimal simulation of a fuel cell and utilization of the IU table function, the nominal voltage value of the device and the maximum voltage of the simulated fuel cell should match the rating of the power supply as closely as possible.

2.2 Calculation

For the calculation of the XY table the voltage set value also plays a role and thus should be identical to the value U_{OC}. When using, for example, this formula

$$U_{BZ} = U_{BZ}(0) - RI - \eta_D - \eta_d = U_{BZ}(0) - RI - b * log|I| + c * ln\left(1 - \frac{I}{I_{gr}}\right)$$

Figure 3: Fuel cell calculation

for the calculation of the static curve of a fuel cell and after rearranging the formula for I, in order to calculate the current data for the table, a curve like depicted below will result.

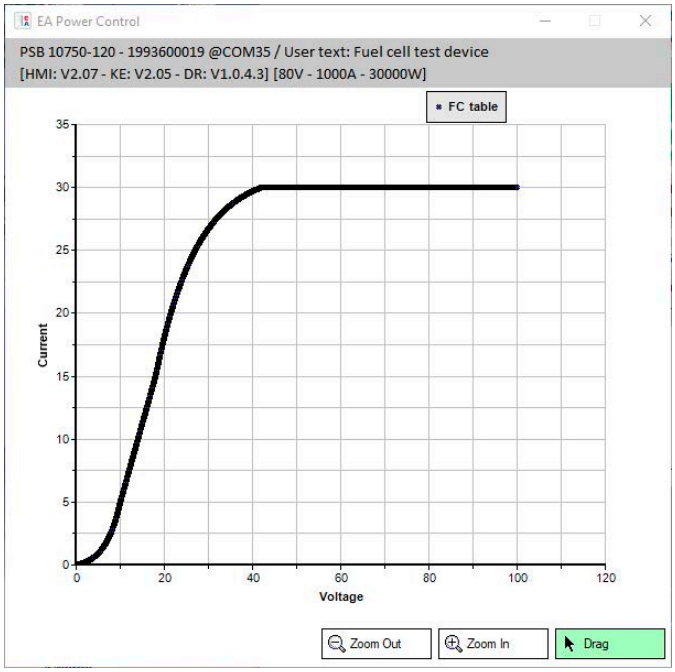

Figure 4: Exemplary result of a fuel cell curve calculation in the device

3. HMI control

The fuel cell simulation function can be accessed via the HMI in the menu page „Function Generator“, in tab „FC table (PS)“. The “(PS)” is used to indicate that this function only runs in source mode.

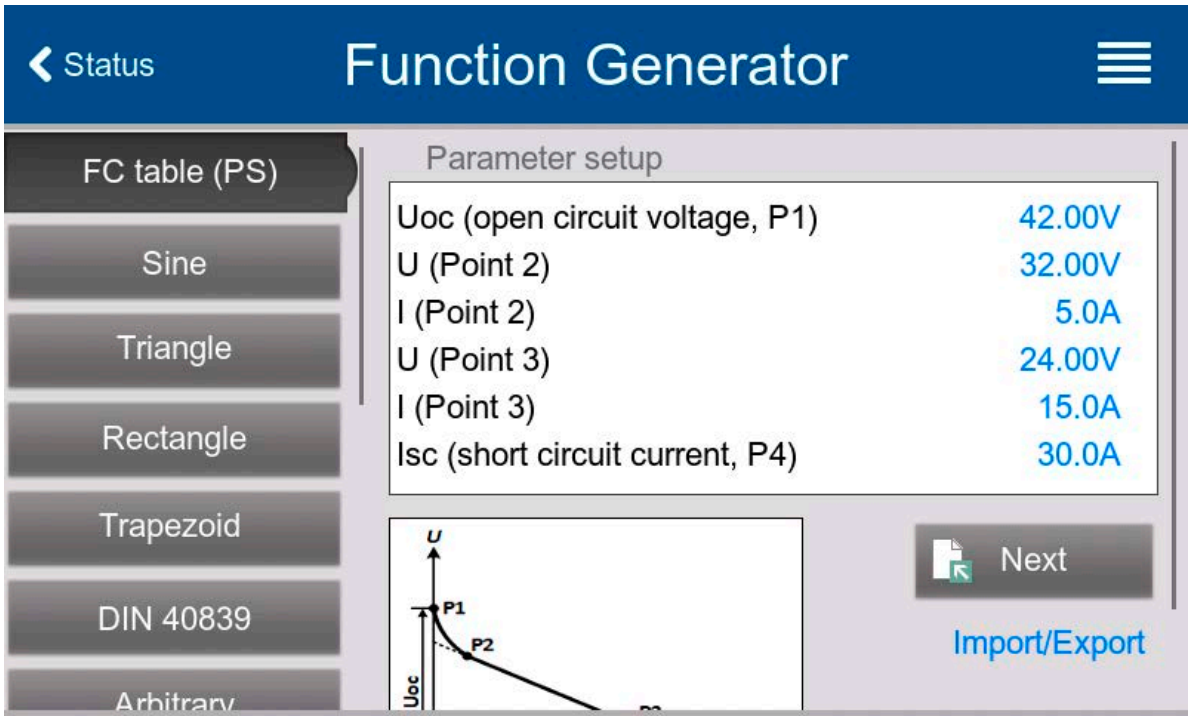

Figure 5: Depiction of FC table configuration on the HMI

The following parameters can be set for the FC table function:

Parameter	Range	Description
Uoc (Point 1)	0 V...U_{Nom}	Maximum voltage of the cell (open circuit voltage at no load)
Points 2+3: U	0 V...U_{Nom}	Voltage define the position of these two points in the XY coordinate system, which represents two supporting points on the curve to be calculated
Points 2+3: I	0 A...I_{Nom}	Current define the position of these two points in the XY coordinate system, which represents two supporting points on the curve to be calculated
Isc (Point 4)	0 A...I_{Nom}	Maximum output current of the fuel cell (short-circuit situation)

After setting up the four supporting points 1 thru 4, whereas Point 1 is defined by U_{OC} and 0 A and Point 4 is defined by ISC and 0 V, the device will calculate the function as IU table and load the XY generator. Depending on the load current, which can be between 0 A and I_{SC}, the device should set a variable output voltage between 0 V and UOC, resulting in a curve similar to the one depicted to the left.

The slope between Point 2 and Point 3 is depending on the values adjusted for Point 2 and Point 3 and can be freely modified as long as Point 3's voltage is lower than the one of Point 2 and Point 3's current is higher than the one of Point 2.

After calculating und uploading the table it's also possible to use the "Import/Export" feature to save the calculated table to an USB stick. It can be used to analyze the values or to visualize it in Excel or similar tools.

How to work with the FC table function

1. With an appropriate load connected, for example a DC-DC converter, start the function by switching the DC terminal on or tapping on the "Start" button.
2. The output voltage will be set depending on the load current, which is defined by the connected load, and will decrease with increasing current. Without any load, the voltage will rise to the adjusted UOC value.
3. Stop running the function anytime by the Stop button or by switching the DC terminal off.

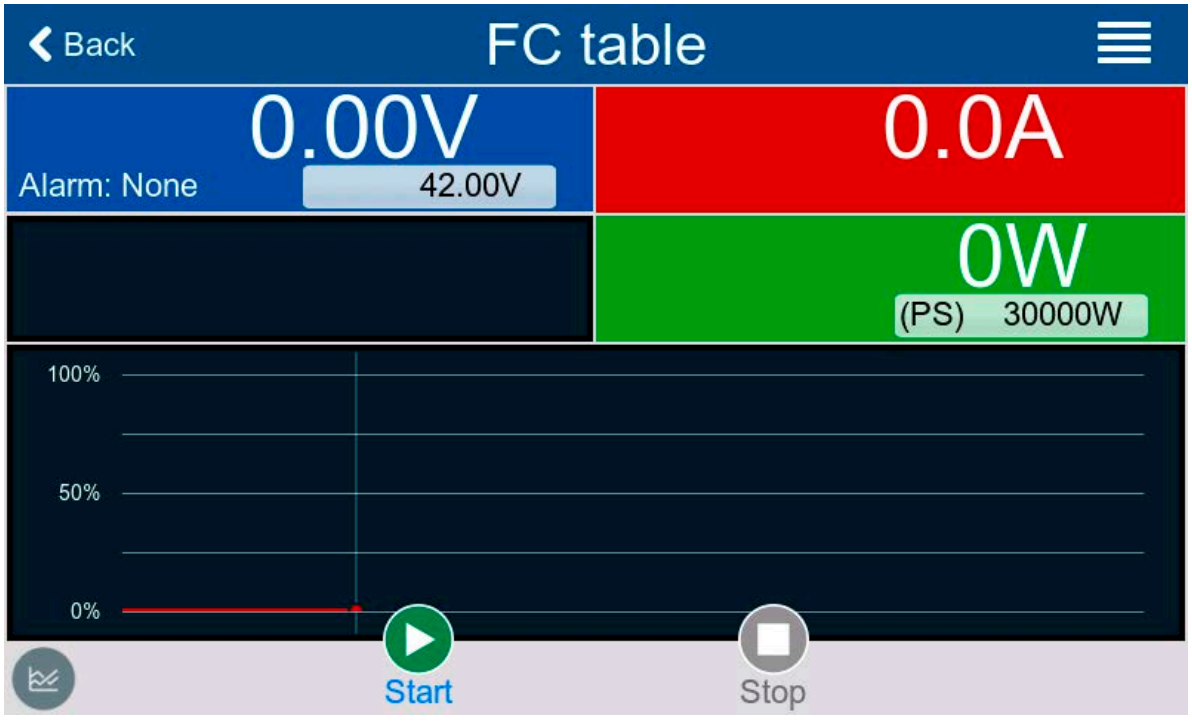

Figure 6: FC table (XY generator) screen

4. Control with EA Power Control in the Function Generator app

The unlockable app „Function Generator“ of the EA Power Control software offers a comfortable way to configure and control the fuel cell simulation from a PC. It can be found in the tab “FC table”.

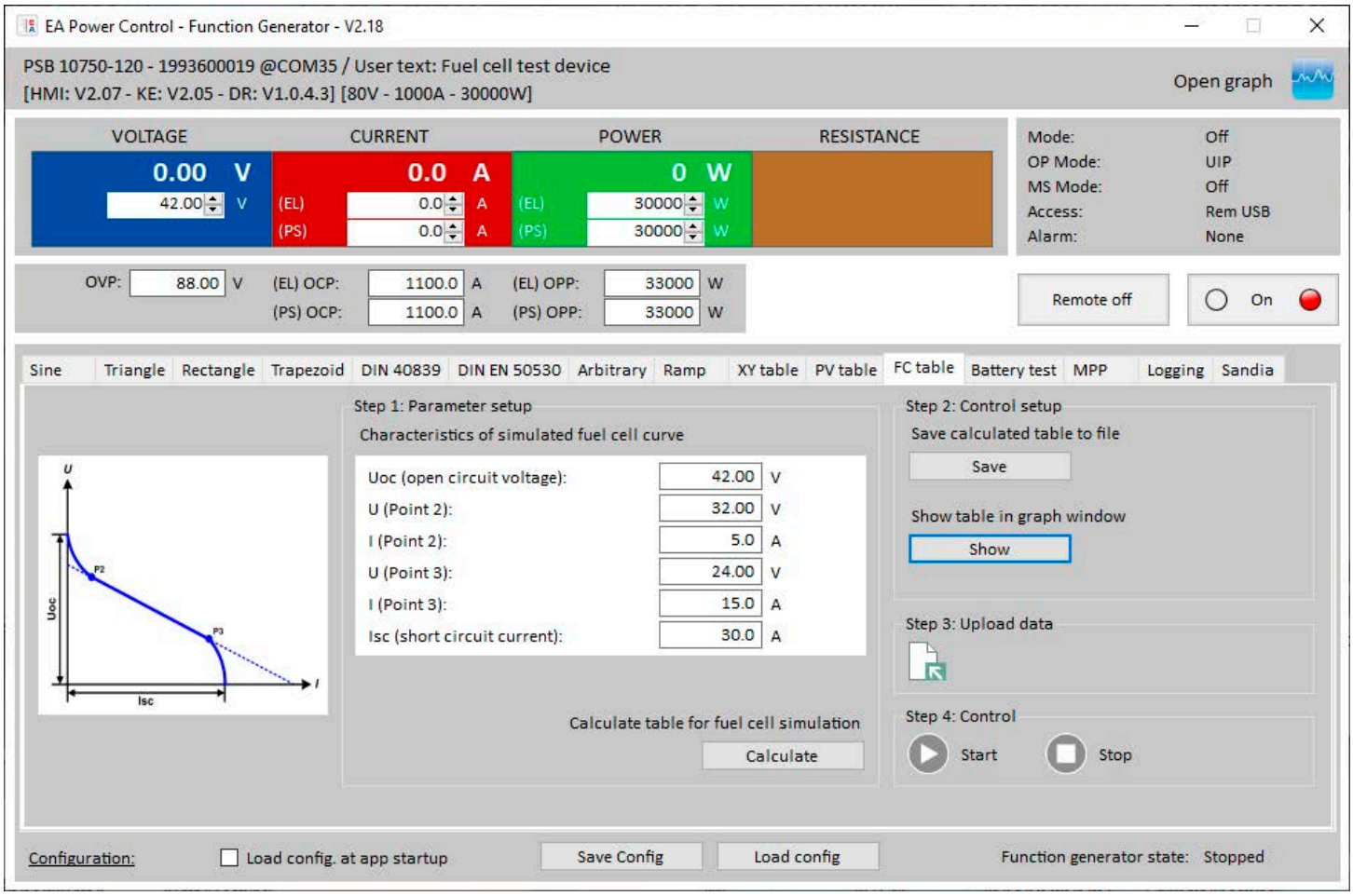

Figure 7: EA Power Control FC table

In step 1 the user can enter the parameters of the characteristics curve, just like via the HMI, and have the table calculated. In step 2 the calculated table can visulaized in an XY diagram to check for correct form before uploading it to the device. After uploading the table data, the function is conveniently controlled via the Start/Stop buttons. Visualization of data, similar to what the display of the device can do, is here also available via the “Graph”.

Table data can also be saved to a CSV file in Step 2, for use in other applications or loading it in the XY generator directly. The setup of Step 1 is saved or loaded with the “Save config” and “Load config” buttons.

5. Remote control from within a custom application

Furthermore, users have the option of creating a fuel cell characteristics curve using their own calculation basis and uploading them to the device. Several protocols like SCPI and ModBus, plus APIs like LabVIEW VIs and IVI drivers are available for this.

For all of them it's mandatory that before table data can actually be uploaded, remote control of the device must be activated first and after data upload the global set values of voltage and power must be set to suitable levels.

5.1 Curve data upload and simulation control via SCPI

Upload of a custom FC curve and control via SCPI shown by an example:

1. Choose the correct function mode
   [SOURce:]FUNCtion:GENerator:SELect FC (FC = fuel cell)
2. Set 4096 current table values via a program loop from 0-4095
   [SOURce:]FUNCtion:GENerator:XY:LEVel <NR1> (Choose a table position from 0…4095)
   [SOURce:]FUNCtion:GENerator:XY:DATa <NRf> (Current value in A for the table position)
3. Confirm table data
   [SOURce:]FUNCtion:GENerator:XY:SUBMit
4. Finally, run the simulation by switching the DC terminal on
   OUTPut ON

5.2 Curve data upload and simulation control via ModBus

Upload of a custom FC curve and control via ModBus shown by an example:

1. Choose the correct function mode (register 856):
   00 06 03 58 00 04 08 4F --> 0x0004 = Fuel cell curve in source mode
2. Set 4096 current table values in blocks of 16 values via a program loop in registers 2600-6680:
   a. Calculate the per cent values with: Hex value in % = Real current value * 0.8 / I_{Nom} * 32768
   b. Example for block 0:
   00 10 0A 28 00 10 20 00 01 00 02 00 03 00 04 00 05 00 06 00 07 00 08 00 09 00 0A 00 0B 00 0C 00 0D 00 0E 00 0F 00 10 91 5E
3. Finally, start the function by switching the DC terminal on:
   00 05 01 95 FF 00 9C 3B

5.3 Curve data upload and simulation control via IVI driver API

By using the EA Electro-Automatic IVI driver API (ElectroAutomatic.EA10000.Fx20 / EA10000.lib) for C++ and C#, the upload of a user-defined characteristic curve is illustrated in the following C# example:

```
using (var driver = new EA10000("ASRLXX::INSTR", false, false, "QueryInstrStatus=false"))
{
	driver.FunctionGenerator.TypePSB = FunctionGeneratorTypePsb.FC;
	for(int i=0; i<4096; i++)
	{
		driver.FunctionGenerator.XY.ConfigureTableEntry(i, (nominal_current/4096*i));
	}
	driver.FunctionGenerator.XY.Submit();
	//Include here: Wait 250ms
	driver.Output.Enabled = true;
}
```

5.4 Curve data upload and simulation control via LabVIEW VIs

All programmable power supplies, including the 10000 series, come with a LabVIEW VI package which contains ready-to-use VIs for the configuration and control of both function generators, along with a few code examples. The Ex_function_generator_ELR_PSI_PSB.vi can load XY table data directly from a CSV into the XY generator of the device, no matter what curve is represented by the data. The example also allows for configuration of other necessary parameters, such as the U/I/P limits (see block diagram below), and simulation control.

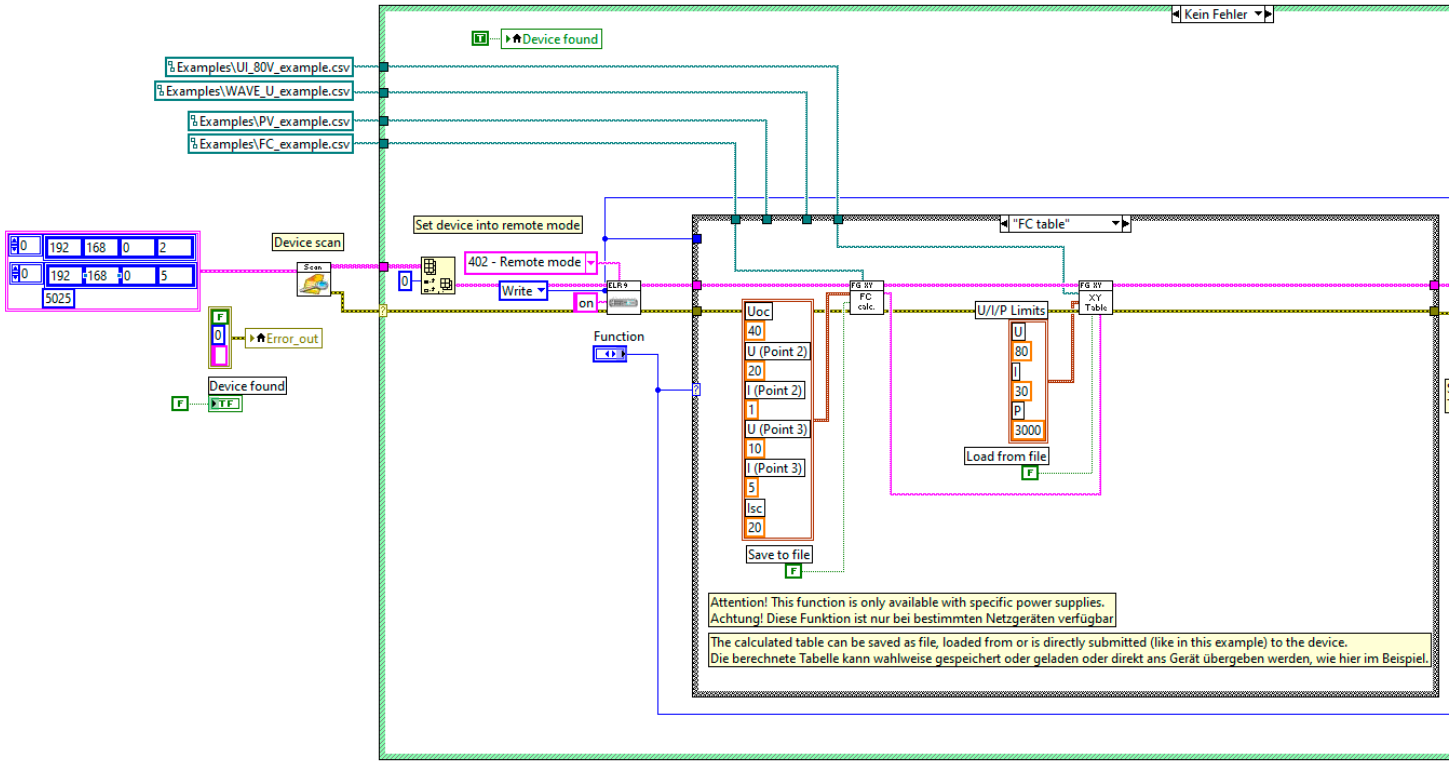

Figure 8: Excerpt of the block diagram of the example VI for function generator remote control

Elektro-Automatik

support@elektroautomatik.com www.elektroautomatik.com +49 (02162) 3785-0