Humidity sensor HTU21P with a 4 – 20 mA current loop output via the AM462 U/I converter

The advance of automation technology means that humidity is becoming ever more important as a measurable variable. Thanks to the advent of high-tech sensors, which can be mass produced at little cost, humidity can now be quickly and accurately measured. The following application notes take the fact into account that the majority of the above are CMOS components and thus have digital output signals; however, analog, interference-proof signals are still required in the automation industry, for instance. A suitable analog two-wire current loop circuit in combination with a humidity sensor shall therefore be described herein.

Two-wire current loop

Heavy machinery often generates strong electromagnetic pulses when switched. Also the growing use of RF sources leads to noise being coupled into any unshielded signal lines. These electromagnetic signals add a noise level to any voltage signal deteriorating the resolution of any measurement – the longer the line the worse. If highly shielded wiring and housings are not an option, data has to be transferred via current signaling not voltage.
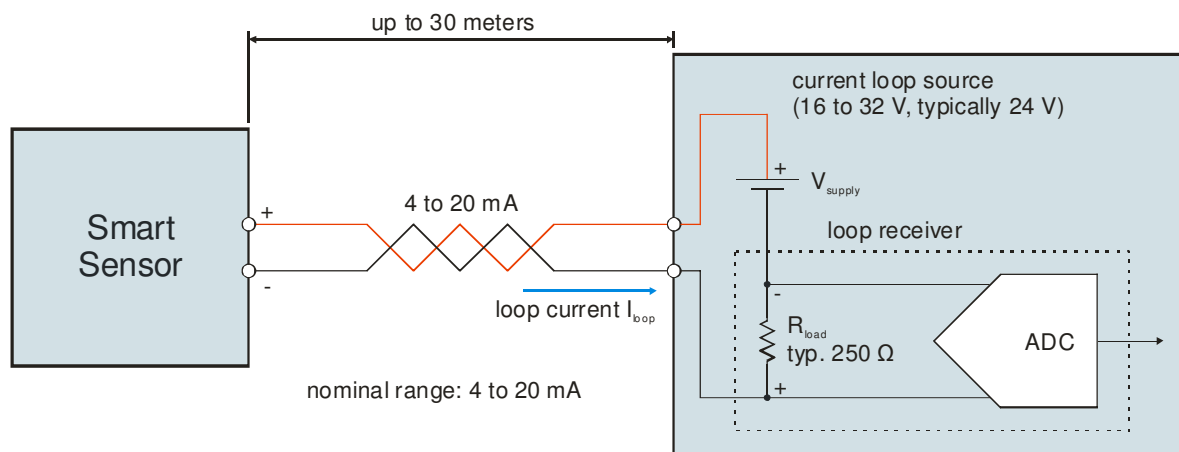

Figure 1: *sensor with a 4 – 20 mA current loop for interference-proof signal transmission to the programmable logic controller (PLC)*

AMSYS GmbH & Co. KG
An der Fahrt 4
55124 Mainz
Germany

Tel.: +49 6131 469 8750
Fax: +49 6131 469 87566
Email: info@amsys-sensor.com
Internet: www.amsys-sensor.com
As of: January 2019

Humidity sensor HTU21P with a 4 – 20 mA current loop output via the AM462 U/I converter

For many years normed current signals have been the medium of choice for transmission in an environment prone to interference or across large distances (see *figure 1*). Neither wire nor contact resistance affects the signal information thanks to the low impedance receiver (right side) and the sensor with current source and floating ground (left side).

In the schematic circuit diagram (*figure 1*) it is assumed that the transmitter generates the required signal current of $I_{loop} = 4 - 20$ mA depending on a measurement. Resistor R_{load} acts as a receiver in the programmable logic controller (PLC) which directly measures the voltage drop V_A that acts as an input signal for the PLC.

Humidity and temperature sensor HTU21P (smart sensor)

The OEM humidity sensor in the HTU21X series [1] is an integrated combination of a capacitive humidity sensing element and temperature sensor plus evaluation electronics.

The humidity sensor consists of a dielectric polymer film which is inserted between two electrodes. A fluctuating level of moisture results in changes of the capacitance of the sandwich. The temperature sensor is implemented by an integrated diode. Information on the temperature is required in order to electronically compensate for the temperature in the sensor, allowing users to profit from the added benefit of an independent temperature sensor. An integrated ASIC is used to measure the capacitance of the humidity sensor and calculate the relative humidity (%RH) with the help of the resistance of the temperature sensor.

Both measurement values, temperature and humidity, are individually calibrated during the production. Calibration and compensation are performed inside the sensor by the ASIC. The output is a calibrated linear signal of relative humidity and temperature, enabling an accuracy of ±2 %RH within a range of 20 to 85 %RH. An accuracy of ±5 %RH is given for measurements in the extended range from 5 to 90 %RH. However, the sensor can be applied across the entire range of 0 to 100 %RH.

The HTU21X series has been designed for an extended temperature range of -40 – 125 °C. For the most common range from 5 to 60 °C temperature accuracy is better than ±0.3 °C.
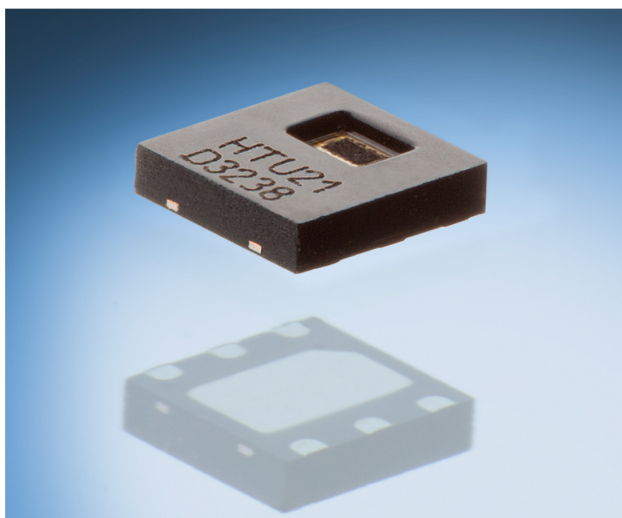

Figure 2: humidity and temperature sensor HTU21D, top and lower side

There are two different outputs available: The HTU21D has an I²C output for humidity and temperature and the HTU21P a PWM output which can be combined with a suitable circuit to produce an industrial analog signal for humidity.

The sensors in the HTU21X series are embedded in a reflow solderable Dual Flat No leads (DFN) package with a 3x3x0.9 mm³ footprint (see *figure 2*). The humidity sensors are available with or without a PTFE filter cover to prevent dust from deteriorating the performance.

Humidity sensor HTU21P with a 4 – 20 mA current loop output via the AM462 U/I converter

Industrial voltage-to-current converter IC AM462

The AM462 [2] (*figure 3*) is a voltage-to-current converter IC in the form of a multiple-stage amplifier with a number of additional and protective features, thus giving users great flexibility and a wide range of applications. All functions on the IC are consistently modular.

The various functional units can be individually accessed through the relevant pins and externally linked or operated separately.
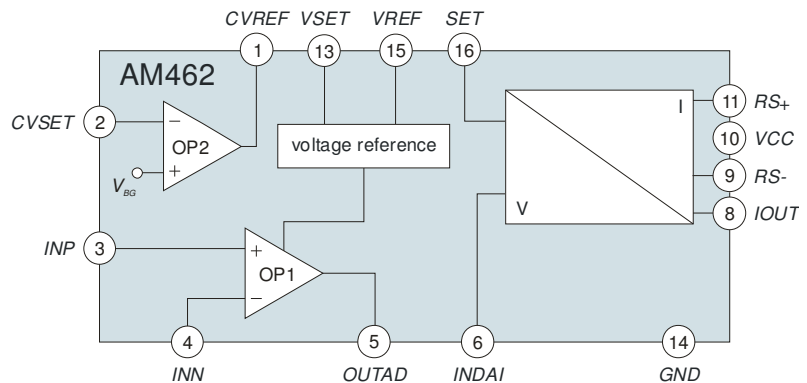

Figure 3: *block diagram of the AM462 voltage-to-current converter*

The individual functional units of the AM462 are as follows:

Operational amplifier stage: the amplifier stage (OP1) is suitable for input signals referenced to ground of 0 to VCC - 5 V. The gain can be set using two external resistors. The operational amplifier stage has been designed so that it can be set right down to zero if the load requires. The OP1 is voltage limited, therefore protecting the downstream stages even when overvoltage occurs at the front end of the device.

V/I converter stage: on the output side the *converter stage (V/I stage)* converts the input voltage into a freely selectable output current between 0 mA and 20 mA. Here, the converter's output stage triggers an external transistor (*Figure 4*) that ensures that the power dissipation is discharged outside the IC. The output current range can be set for the current offset and end value using two external voltage dividers.

Bandgap reference: the AM462 *reference voltage source* enables external components to be supplied with power (such as sensors and microprocessors, etc.). Reference voltage value V_{REF} can be set through pin *VSET* to V_{REF} = 5 V or 10 V. Intermediate values can also be set using two external resistors (between pin *VREF* and pin *VSET* and pin *VSET* and *GND*).

Operational amplifier: the additional *operational amplifier stage* (OP2) can be used as a source of current or voltage to supply external components. For this purpose the positive input of the OP2 is internally connected to voltage V_{BG}, enabling the output current or output voltage to be adjusted using one or two external resistors.
Besides the described modules the IC has internal overvoltage protection for the amplifier stage (OP1), integrated protection against reverse polarity as regards the output stage (V/I converter) across the full voltage range and an output current limit that protects the IC against destruction. A protected industrial output stage can thus be realized with a minimum of external circuitry.

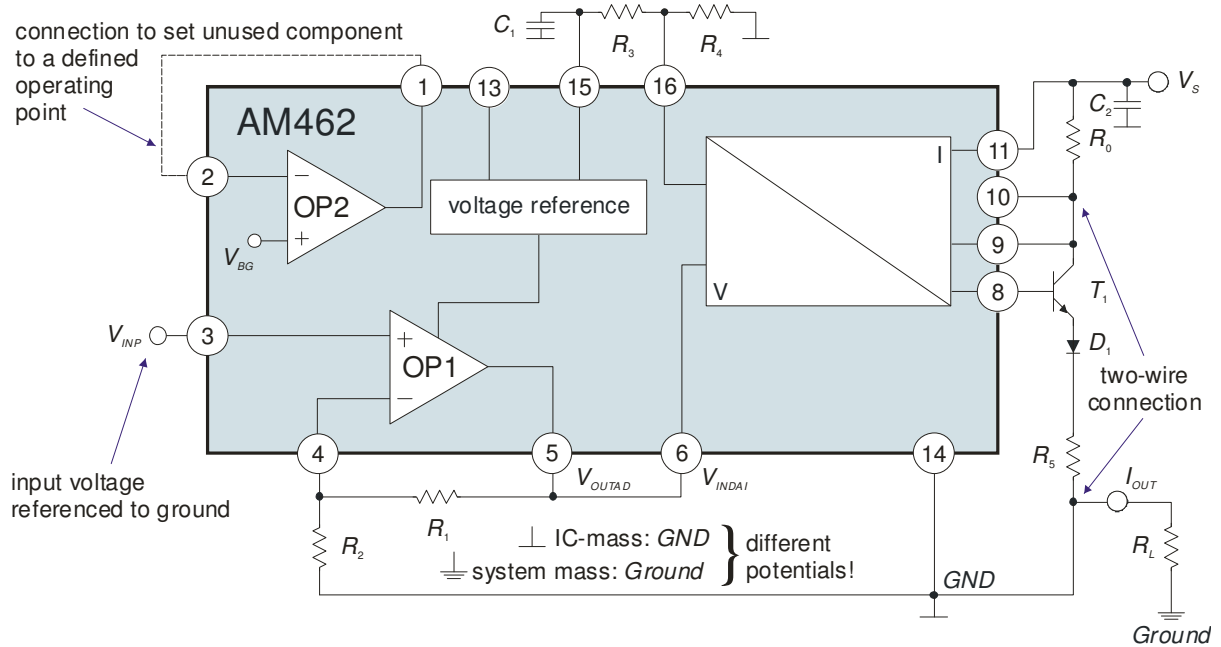# Humidity sensor HTU21P with a 4−20 mA current loop output via the AM462 U/I converter

Figure 4: *typical two-wire 4–20 mA application for input signals without an offset*

Circuit description/dimensions

Using the humidity sensor HTU21P (the variant with a PWM output) and the analog converter AM462 a circuit is to be devised which can generate a two-wire current signal of 4−20 mA proportional to the humidity. The external components should be dimensioned so that relative humidity *RH* can be determined from an output current value of I_{out} by applying the following equation:

$$RH = \left(\frac{I_{out} - 4mA}{16mA} \right) * 100\% \qquad (1)$$

The circuit concept has been devised so that the sensor's pulse width output signal can be converted into a DC signal using a low-pass filter. This is to be converted into a suitable current signal in the subsequent AM462.

Humidity sensor HTU21P with a 4 – 20 mA current loop output via the AM462 U/I converter

Converting the PWM signal using a low-pass filter

In order to keep the ripple down to a minimum, a low-pass filter of the second order has been selected to average the PWM signal (*Figure 5*).

$R = 100\,k\Omega$
$C = 0.33\,\mu F$

With these values, according to simulated calculation the ripple for voltage V_{TP} at the end of the low-pass filter is less than 0.5 %.
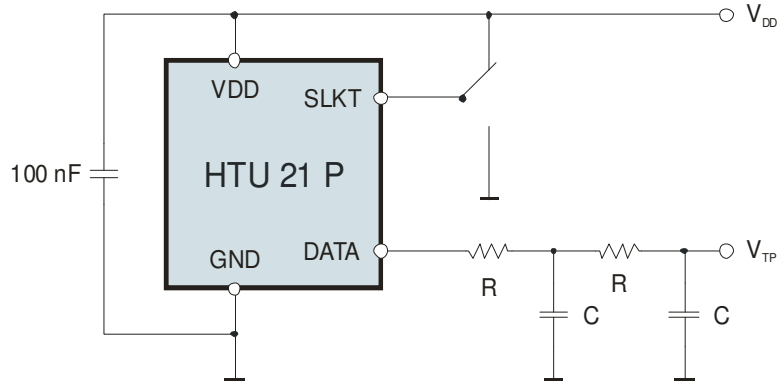

Figure 5: *HTU21P and a low-pass filter*

Depending on pulse width T_{PW} the relative humidity is calculated in percent according to the sensor's manufacturer specifications and using the following equation:

$$RH = -6 + 125\frac{T_{PW}}{T_F} \qquad (2)$$

with T_F the period stipulated by sensor HTU21P:

$$T_F = \text{typ. } 1/120\,Hz = 8.33\,ms$$

At a relative humidity of 0 %RH the pulse width of the sensor is $T_{min} = 0.359\,ms$, with $T_{max} = 6.343\,ms$ at 100 %RH.

Signal voltage V_{TP} beyond the low-pass filter is:

$$V_{TP} = \frac{T_{PW}}{T_F}V_{DD} \qquad (3)$$

At a supply voltage of $V_{DD} = 3\,V$ the two signal voltages $U_{min} = 0.144\,V$ and $V_{max} = 2.544\,V$ are accrued at minimum and maximum humidity for V_{TP}.

Voltage supply for sensor HTU21P

The supply voltage for the sensors is to be set to approx. 3 V using the internal OP2 operational amplifier on AM462 and resistors R_6 und R_7. $R_7 = 10\,k\Omega$ is specified (see Equation 10 on the AM462 datasheet [2]).

With
$$R_6 = \frac{3V - 1{,}27V}{1{,}27V}R_7 \qquad (4)$$

the following is accrued: $R_6 = 13.6\,k\Omega$. The next value in the E24 series is selected: $R_6 = 14\,k\Omega$. This results in a V_{DD} supply voltage for HTU21P of 3.05 V.

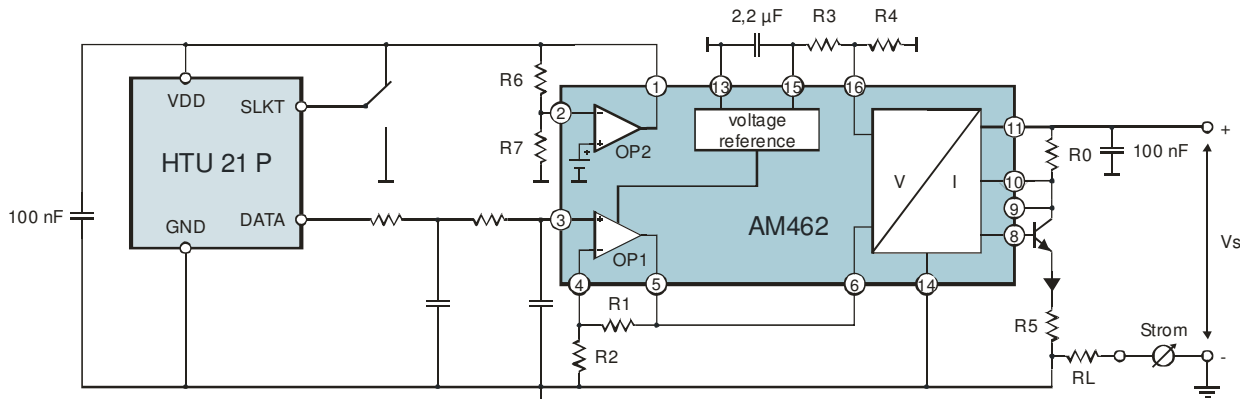## Dimensioning the voltage-to-current converter

Figure 6: HTU21P circuit (PWM) with an AM462 for 4–20 mA operation

The reference voltage is set to 10 V using pin 13 connected to ground. Load resistance R_0 should lie between 17 Ω and 38 Ω and is selected so that $R_0 = 30$ Ω.

For the two maximum ratings of 0 %RH and 100 %RH relative humidity both output currents of $I_{min} = 4$ mA and $I_{max} = 20$ mA should be achieved. Required gain G for operational amplifier OP1 can be determined according to Equation 6 on the AM462 datasheet:

$$G = 8R_0 \frac{I_{max} - I_{min}}{U_{max} - U_{min}} = 1{,}575 \qquad (5)$$

The gain is set using R_1 and R_2, where 20 kΩ < $R_1 + R_2$ < 200 kΩ. R_1 is set to 22 kΩ and R_2 determined by (see Equation 6 on the AM462 datasheet):

$$R_2 = \frac{R_1}{G - 1} = 38{,}2 k\Omega \qquad (6)$$

The next value in the E24 series is selected: $R_2 = 39$ kΩ.

Input voltages V for the voltage-to-current converter thus amount to $V_{min} = G\ U_{min} = 0.229$ V and $V_{max} = G\ U_{max} = 4.043$ V.

The converter's output current I_{out} is (see Equation 2 on the AM462 datasheet):

$$I = \frac{V}{8R_0} + I_{set} \qquad (7)$$

At a relative humidity of 0 %RH, the following should be true:

$$I_{set} = 4mA - \frac{V_{min}}{8R_0} = 3{,}05 mA$$

.

Humidity sensor HTU21P with a 4 – 20 mA current loop output via the AM462 U/I converter

This allows resistors R_3 and R_4 to be determined within the limits of $20\,k\Omega < R_3 + R_4 < 200\,k\Omega$. R_4 is selected as $R_4 = 2.2\,k\Omega$ (see Equation 5 on the AM462 datasheet [2]), which leads to

$$R_3 = R_4 \left(\frac{V_{ref}}{2 I_{set} R_0} - 1 \right) = 120 k\Omega \qquad (8)$$

.

Load resistor R_L is stipulated as being $R_L = 300\,\Omega$ and stabilizing resistor R_5 as $R_5 = 39\,\Omega$. 1N4148 was chosen as the diode and MPS A43 as the transistor.

This results in the following list of external components for the circuit:

AM462: $R_0 = 30\,\Omega$ $R_1 = 22\,k\Omega$ $R_2 = 39\,k\Omega$ $R_3 = 120\,k\Omega$
                      $R_4 = 2.2\,k\Omega$ $R_5 = 39\,\Omega$ $R_6 = 14\,k\Omega$ $R_L = 300\,\Omega$

Low-pass filter: *2x R* = 100 kΩ, 2x *C* = 0.33 µF

Diode: 1N4148

Transistor: MPS A43

As there will probably be minor discrepancies between the measured and the computed values, gain *G* should be able to be corrected using resistors switched in parallel to either R_1 or R_2, for example.

Measurement results

Example humidity measurements were taken using a test setup. The respective humidity sensor was placed in a thermally insulated container with different defined humidity levels. The measurements were taken at room temperature.
The current was measured depending on the relative humidity (*Figure 7*) and the humidity determined by the pulse width for comparison (*Figure 8*).
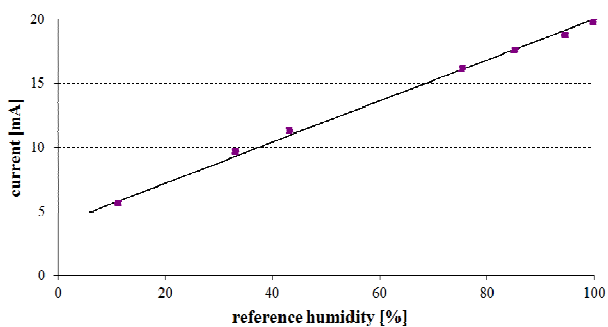

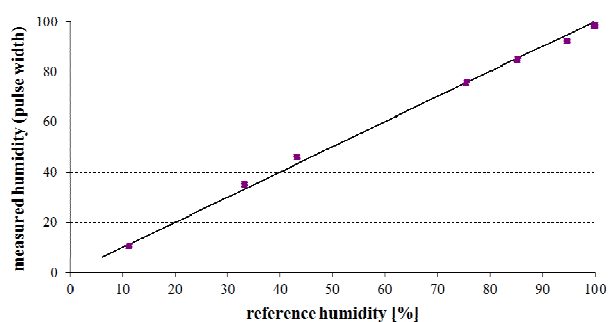**Figure 7:** *output current depending on the relative humidity*

Figure 8: *pulse width depending on the relative humidity*

Measurements taken on six combinations of humidity sensor HTU21P and ASIC AM462 showed that at a respective saturation time of five minutes the degree of error amounts to around 3.0 %FS in a range of 20–80 %RH and at a temperature of 10–60 °C.

Humidity sensor HTU21P with a 4−20 mA current loop output via the AM462 U/I converter

Summary

The areas of application for humidity and temperature sensors are not limited to individual fields of application. These sensors can be used in all instances where knowledge of the level of humidity in conjunction with temperature is important, enabling appropriate action to be taken.

In an industrial environment, where strong electromagnetic interference must be reckoned with and where long wires and cables may have to be used, a two-wire current measurement system provides a suitable solution. This application note illustrates what a circuit for an OEM humidity sensor based on a MEMS could look like.

The principle of the aforementioned circuit applies to all sensors with a PWM output; its details must be adapted to the specific PWM signals, however.

Further information

[1] HTU21P product page and datasheet:
http://www.amsys.de/produkte/feuchtigkeitssensoren/htu21p-feuchte-temperatursensor-mit-analogem-ausgang/

[2] AM462 voltage-to-current converter IC product page:
https://www.analog-micro.com/en/products/ics/uiconverter/am462/

Contact

AMSYS GmbH & Co. KG
An der Fahrt 4
55124 Mainz
Germany

Phone: +49 6131 469 8750
Fax: +49 6131 469 87566
Email: info@amsys-sensor.com
Internet: http://www.amsys-sensor.com