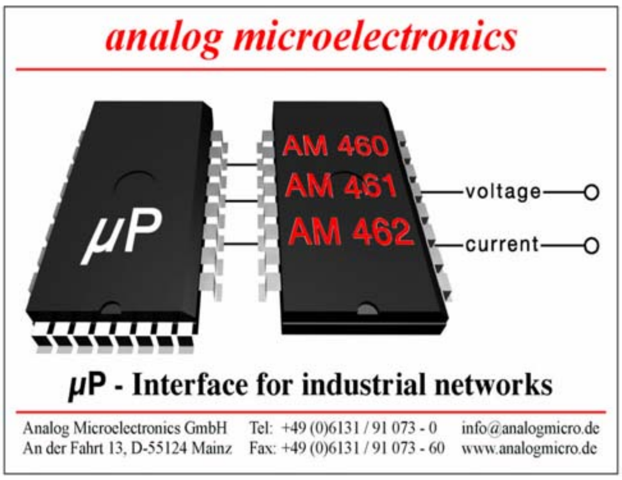
AM462: voltage-to-current converter IC for 2-wire current loop applications (4…20mA)

The analog network using currents of 4...20mA is still the most common medium for the transfer of information in the industrial environment. The following article explores the use of an analog 2-wire current interface circuit (current loop) for an output current of 4...20mA (standard value). Using an AM462 IC (voltage-to-current converter IC) as an example it will describe how a 2-wire interface circuit suitable for industrial use can be designed for a PLC (programmable logic control). The characteristics of a current loop circuit such as this are explained for practical application. The article will also specifically illustrate how a current loop with various control instruments can be dimensioned.

Please note:
The information contained herein can be applied to all voltage-to-current converter ICs produced by Analog Microelectronics (AM400, AM402, AM422, AM442 and AM460). [1]

Industrial analog interfaces



In practical industrial use voltage and current signals of 0…5(10)V or 0(4)…20mA are the most common method of transferring analog information in conjunction with a PLC. This transmission technique is introduced many years ago and exists still beside the new digital bus systems because the evident advantages.
The differences between the transmission of voltage and current and when these come into play will be described by way of introduction.

Transmission of voltage, e.g. 0…5(10)V

If analog voltages are transmitted to a receiver via a long cable, these may be easily falsified. This is due to the sum of the voltage drops which may occur across the transmitter output resistor, the inner cable resistor and the contact resistors. The resulting transmission error is the sum of the aforementioned resistors multiplied by the input bias current of the receiver. If this is low enough, which is equivalent to the receiver input resistor being high impedance, these resistances can be treated as negligible.

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In order that the transmitter is not excessively charged and that the mentioned resistors can be disregarded a high impedance input at the receiver end of the setup is thus required. If OPs are used at this end as input amplifiers, for example, one can expect to be working with input resistances of <1MΩ.

With a high impedance setup such as this and particularly at the receiver input one would theoretically expect an increased sensitivity to electromagnetic interference which in turn can lead to considerable error. In the transmission of voltage a compromise must thus be found between the transmission error on the one hand and the effect of interference with regard to electromagnetic radiation on the other.

Summary for voltage transmission**:** Where electromagnetic interference is not an issue and/or where short cable lengths are sufficient, with a suitably dimensioned receiver signals can be transmitted without any further reservations using voltage signals of 0...5(10)V.

Transmission of current of 0(4)...20mA

When transmitting in an environment prone to interference or across large distances standard current signals have long been favored.

If a current source acts as a transmitter, this always supplies the required current regardless of any inner cable or contact resistors. This means that the current signal is not influenced by the configuration of the hardware. Unlike the transmission of voltage electromagnetic interference has no major effect on the transmitted current signals due to the low impedance receiver input on the one hand and the current source acting as a floating mass on the other (parallel switching of the real current source output resistor and the receiver input resistor).

Summary for current transmission**:** Where electromagnetic interference poses a problem (e.g. in welding apparatus or external hf-transmitters, etc.) or if long cable lengths are necessary, current signal transmission is the more suitable method of transferring analog information.

In industrial use a difference is made between 2- and 3-wire applications. Due to its greater significance in this field the following shall focus on the 2-wire version, also known as a current loop.

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Characteristics of the current loop setup

- ***Simple handling:*** If the power consumption of both the transmitter and the connected consumers is constant, both the load circuit and signal current can be transmitted via the same line, as will be shown here. All that is needed is a load resistor as a working resistance; the supply voltage must also be large enough to intercept all voltage drops which may occur within the electric circuit. The voltage drop across this resistor or the current through this resistor act as a useful signal.

- ***Low system costs:*** In place of an expensive A/D converter, a processor and a suitable driver for the digital signals, all that is required in the simplest current loop setup are a cable, resistor and measuring instrument. The costs of the digital version become particularly obvious when high demands are made of the resolution capacity of the A/D converter.

- ***Error detection:*** The advantage of 4…20mA signal transmission lies not only in the high degree of noise immunity but also in the fact that a powerful error detection system is automatically included. In compensated systems (the smallest signal I = 4mA at the output) signals of between >0 and <4mA indicate that there is an error in the system. The signal (I = 0mA) denotes a cable break or a complete function failure of the signal conditioning unit. Signals of over 20 mA suggest that there is excessive voltage at the input end or an error in the signal conditioning.

- ***Large transmission distances:*** The transmission distance depends solely on the driving capability of the transmission stage, the line resistors and the measuring resistor (working resistance) at the receiver end of the setup. If measuring instruments are to be built into the line the working resistance must be observed in conjunction with the input resistors of the measuring and register apparatus. These are often inserted into the current loop as cheap, self-sufficient devices, from whence they and the IC are supplied with 4 mA, and must thus be taken into account when the current loop is being dimensioned.

2-Wire signal transmission

In the simplest of current loop setups the transmitter is an adjustable current source and the receiver a terminator from whence the signal can be received (see *Figure 1*).

In the schematic circuit diagram (*Figure 1)* it is assumed that the transmitter generates the required signal current of I_{OUT} = 4…20mA, dependent on a certain measurement value. Resistor R_L acts as the receiver via which the voltage drop V_A or, directly in series, current I_{OUT} can be measured.

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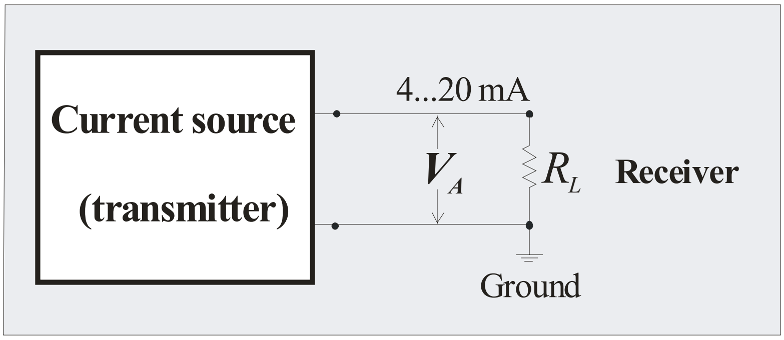

Figure 1: Schematic diagram of 4…20mA current loop operation

In practice a transmitter is naturally made up of several components. In sensor technology, for example, it is referred to as a transducer and comprises a sensing element (transducer), a supply unit for the sensing element and a current source (*Figure 2*). In other current loop applications the transducer may be replaced by the PWM output of a buffer amplifier [2], for example, or in a very general system by a signal source with a voltage output.

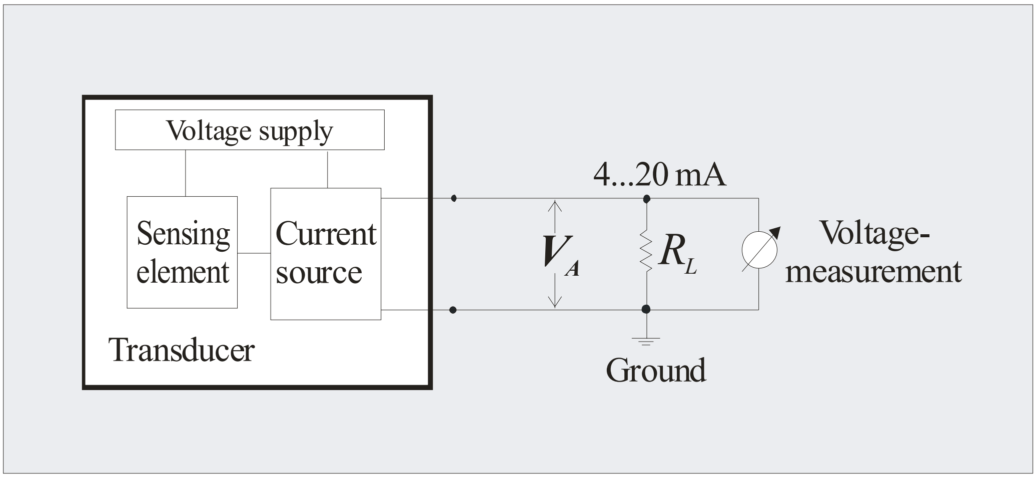

Figure 2: Current loop circuit with a complete transducer

As most sensing elements and also PWM circuitry generate a voltage of between zero and an end point value (FS) a voltage-controlled current source must be integrated in the transducer which is capable of producing a minimum current of 4mA at a required span of 16mA, for example (the offset is equivalent to the zero signal of the transducer).

In industrial control units it is often the case that the control unit (maintenance section) is a long way from the transducer. It is thus both practical and economic to use the supply line for

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the transducer as a signal line so that just two lines are sufficient. Circuitry such as this is known as a 2-wire application and is the subject of the following description.

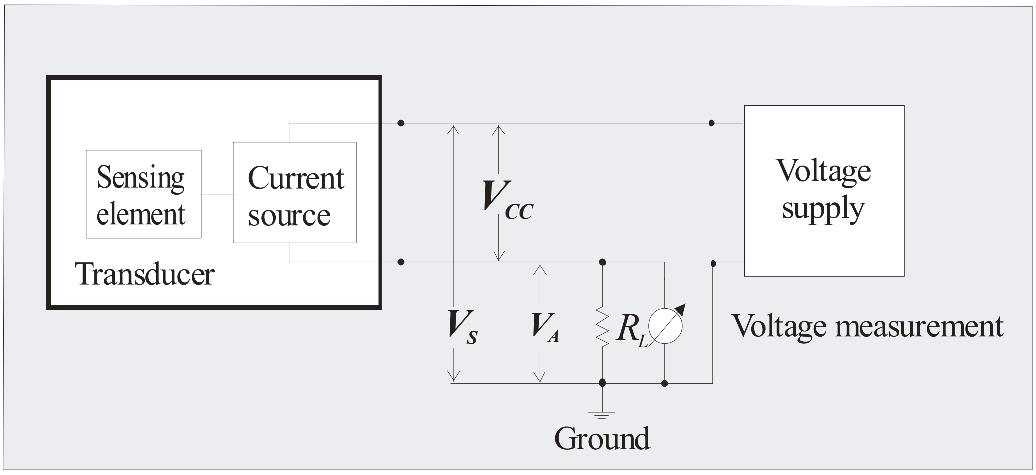

Figure 3: Practical application of a current loop circuit

As shown in *Figure 3* central voltage supply units are used which are installed in the control unit and to which a number of transducers can be connected, for example.

AM462 IC for 2-wire current loop operation

The following description involves the use of an AM462 device by Analog Microelectronics as a voltage-controlled current source. This IC can be supplied with voltage by the external voltage supply (of up to 35V) and converts the transducer signal into an adequate current of 4…20mA (*Figure 3*).

In order to understand the application of AM462 in a current loop and recognize the full advantage of the additional functions the IC will first be introduced in the following.

The nucleus of the current loop circuitry is AM462 (see *Figure 4*), a multistage amplifier IC (for transducers with single-ended outputs) with a number of additional and protective functions which can be used optionally. AM462 has been conceived as a voltage-to-current converter and consists of several modular function blocks (OPs, V/I converter and reference) which can either be connected up externally or operated separately (see *Figures 5* and *6*).

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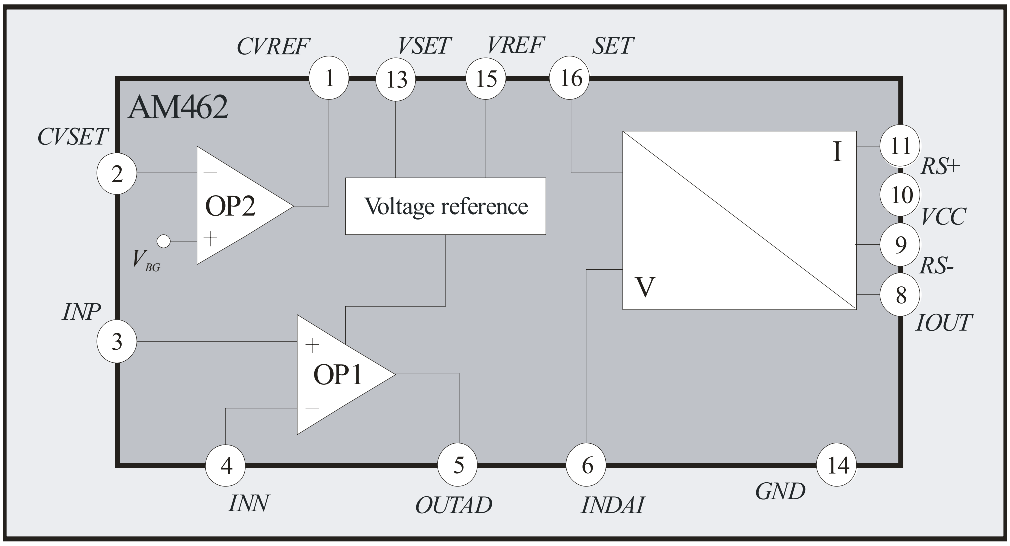

Figure 4: AM462 as a voltage-to-current converter IC for 2-and 3-wires applications

The functional units are as follows:

1. *Operational amplifier stage* OP1 enables a positive voltage signal to be amplified. OP1 gain can be set via the external resistors.
2. The internal *voltage-to-current converter* (V/I converter) provides a voltage-controlled current signal at the IC output which can activate an external transistor; this in turn supplies the actual output current. To reduce power dissipation the transistor is an external component and protected against reverse polarity by an additional diode.
3. The *reference voltage source* included in AM462 enables external components, such as sensors and microprocessors etc., to be supplied with voltage and simplifies 2-wire operation. The reference voltage can be set to values of between 5 and 10V.
4. A second *operational amplifier* (OP2) can be used as a current or voltage source to power external components. OP2's positive input is connected internally to voltage V_{BG}, enabling the output current or voltage to be set within a wide range using one or two external resistors.

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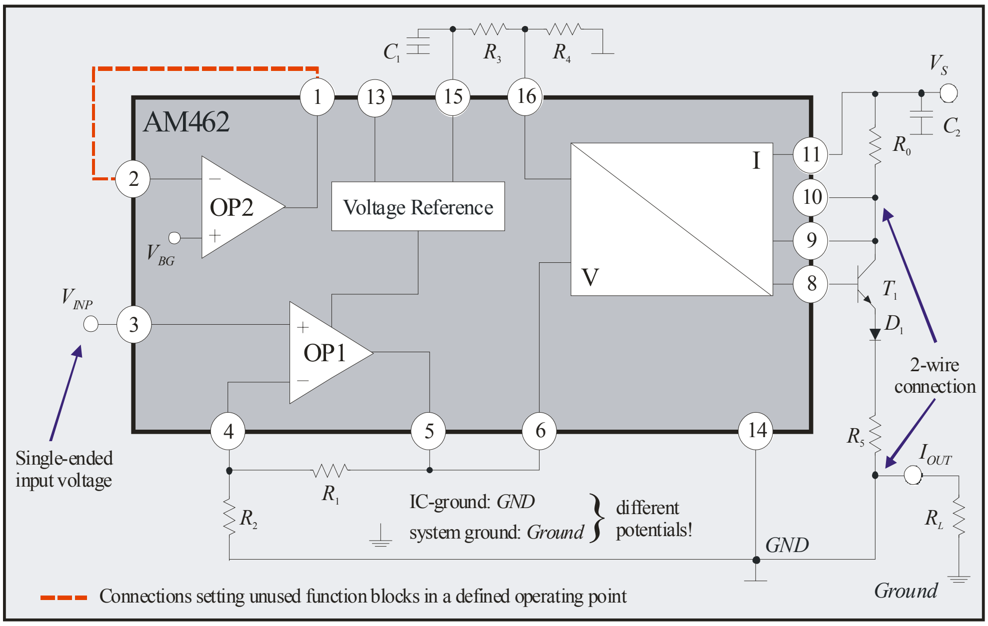

Figure 5: Application of AM462 as 4..20mA, 2-wire voltage-to-current converter

Details of the dimensioning of AM462 and example applications (also for 3-wire operation) are given in the AM462 data sheet [1].

The IC also includes internal circuitry protecting the input amplifier OP1 against overvoltage, integrated protection against reverse polarity with regard to the output stage (V/I converter) across the entire voltage range and an output current limiter which protects the transistor from destruction.

It should be noted that in 2-wire operation any additional current load (such as the use of OP2 in AM462 as a current/voltage source, for example; see *Figure 6*) is curbed by the domestic power consumption of the IC and in general by the limitation to 4mA. The power consumption of the entire system (AM462 plus all external components) must thus not exceed the sum of $I_{OUT\text{min}}$ = 4mA. This must be taken into consideration in particular with regard to operating parameters which bring about an increase in the power consumption (e.g. operating temperature).

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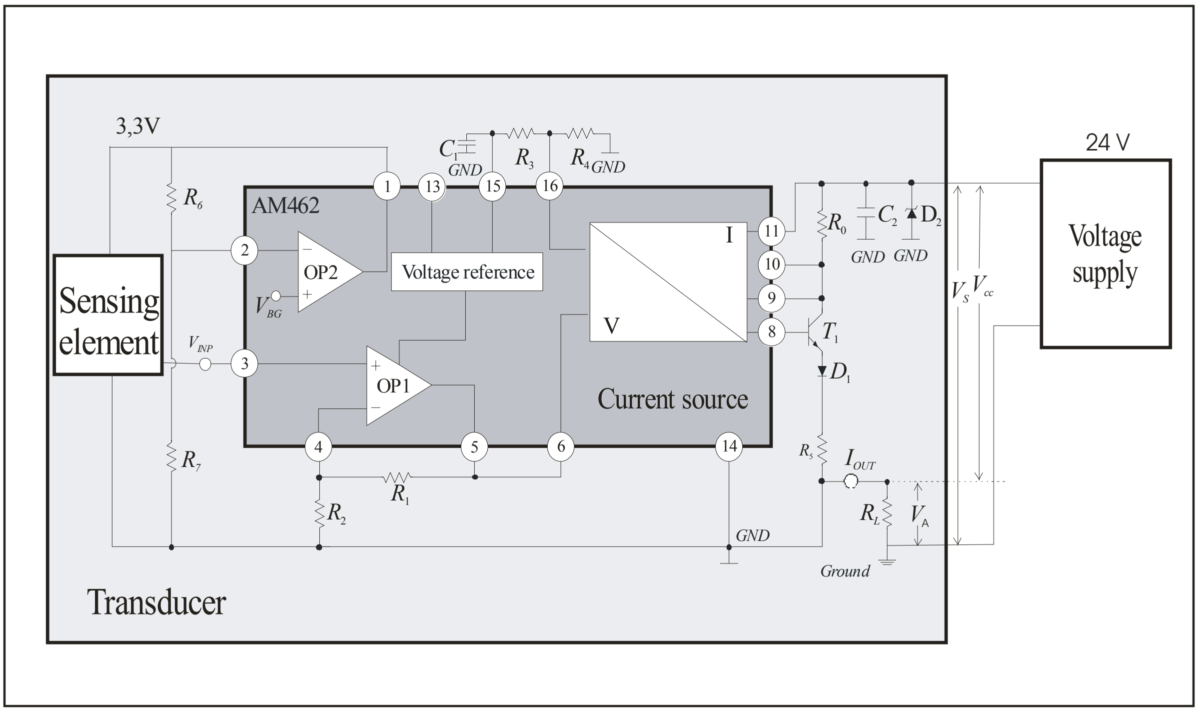

Figure 6: AM462 circuitry in a current loop with a 3.3V sensing element supply

Current loop IC AM462 in practical use

Figure 6 demonstrates how AM462 can be used in a practically relevant application. It is assumed here that the sensing element is operated by 3.3V which are drawn from the IC.

GND is the virtual reference point for all components which are upstream of the voltage-powered current source and for the current source itself. The capacitor and Zener diode, which serve as protection against overvoltage, are also referenced to GND.

GND is connected up via resistor R_L to the system ground (Ground) and is thus not at the same potential as Ground.

$$GND \neq Ground$$

V_{CC} is the IC's supply voltage where the following must apply to the external voltage supply with reference to Ground: $V_S = V_A + V_{CC\,min}$.

The following applies to AM462: $V_{CC\min} = V_{Ref} + 1V$ and $V_S = 6/11\ldots35V$

The number of devices which can be installed on the 2-wire current loop and the maximum length of the transmission line can be determined using the following formulae (see *Figure 7*). The following applies:

$$V_A = I_{\max} \cdot R_L + I_{\max} \cdot \sum_i R_{li} + \sum_k V_{Mk}$$

where R_l is the line resistance, R_L the load resistance and V_M the voltage drop at the measuring instruments. According to *Figure 6* the following applies:

$$V_S \geq V_{CC\min} + VA \text{ or } V_{A\max} = V_S - V_{CC\min}$$

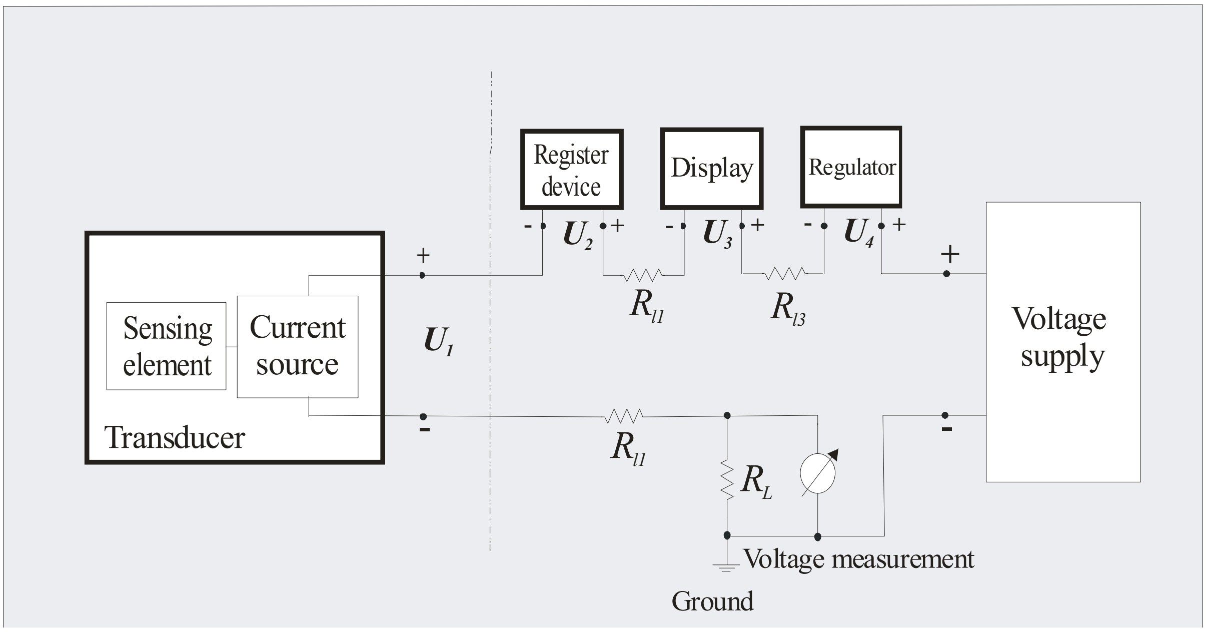

***Figure** 7*: Using current loop technology in a control system

If the values of R_L, V_M and V_S are either known or given, using $R_{li} = \frac{\rho \cdot l}{A}$ (ρ = the specific resistance of copper, ρ = 0.016 Ωm²/m, l = line length in m and A = line cross section in mm²) the maximum line length and/or permissible number of measuring instruments can be determined.

With reference to the value of resistor R_L it should be mentioned here that this should be of low impedance for reasons of EMC sensitivity; its lower value is limited by the resolution capability of the measuring instrument (measurement of the voltage drop across R_L at minimum current).

Figure 7 gives the circuitry of a sensor which makes use of the 2-wire current measurement technique. Suitable devices as used in a PLC, for example, have been inserted into the electric circuit.

Conclusion

Despite the general increase in digitization processes, transmitting analog measurement values without interference using a 4...20mA interface is still the most popular method of transferring information in the industrial environment.

The application described herein illustrates which factors must be taken into consideration when transmitting current signals in a 2-wire configuration. Taking AM462 as an example, it has also been shown how simple it is to assemble a real and practicable circuit, how this must be dimensioned and which advantages the current loop application entails.

Further reading

www.analogmicro.de/german/index/html

[1] Data sheets AM400, AM402, AM422, AM442 and AM460

[2] Application note AN1014

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