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APPLICATION BULLETIN
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INPUT OVERLOAD PROTECTION FOR THE RCV420 4–20MA CURRENT-LOOP RECEIVER

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Because of its immunity to noise, voltage drops, and line resistance, the 4–20mA current loop has become the standard for analog signal transmission in the process control industry. The RCV420 is the first one-chip solution for converting a 4–20mA signal into a precision 0–5V output. Although the on-chip current sensing resistor is designed to tolerate moderate overloads, it can be damaged by large overloads which can result from short circuits in the current loop. Complete input protection from short circuits to voltages of 50V or more can be afforded with the addition of the relatively simple circuitry shown in this bulletin.

The complete protected 4–20mA current loop receiver circuit is shown in Figure 1. The RCV420 is connected for a 0–5V output with a 4–20mA current sink input. For a 4–20mA current source input, connect the input to pin 3 instead of pin 1. An on-board precision +10.0V buried zener voltage reference in the RCV420 is used to offset the span (for 0V out with 4mA in) via pin 12. It can also be used for powering external circuitry such as the voltage dividers used to set the underrange/overrange comparator thresholds.

An LM193 dual voltage comparator is used to detect underrange and overrange conditions at the output of the RCV420. The LM193 is designed to operate from a single power supply with an input common-mode range to ground. In this application the LM193 is operated from a single +15V power supply for input common-mode range compatibility with the RCV420 output. The open-collector LM193 comparator outputs are connected through 10kΩ pull-up resistors to a +5V supply for compatibility with TTL and similar logic families.

The RCV420 has a gain of 0.3125V/mA and a 4mA span offset (a 4mA–20mA input produces a 0V–5V output). Under input open circuit conditions (0mA input), the output of the RCV420 goes to –1.25V. To level-shift the output up, for a minimum of 0V at the comparator inputs, it is summed with the 10.0V voltage reference through the 10kΩ, 1.27kΩ resistor network. The table below shows selected operating points for the RCV420 input/output and the comparator input.

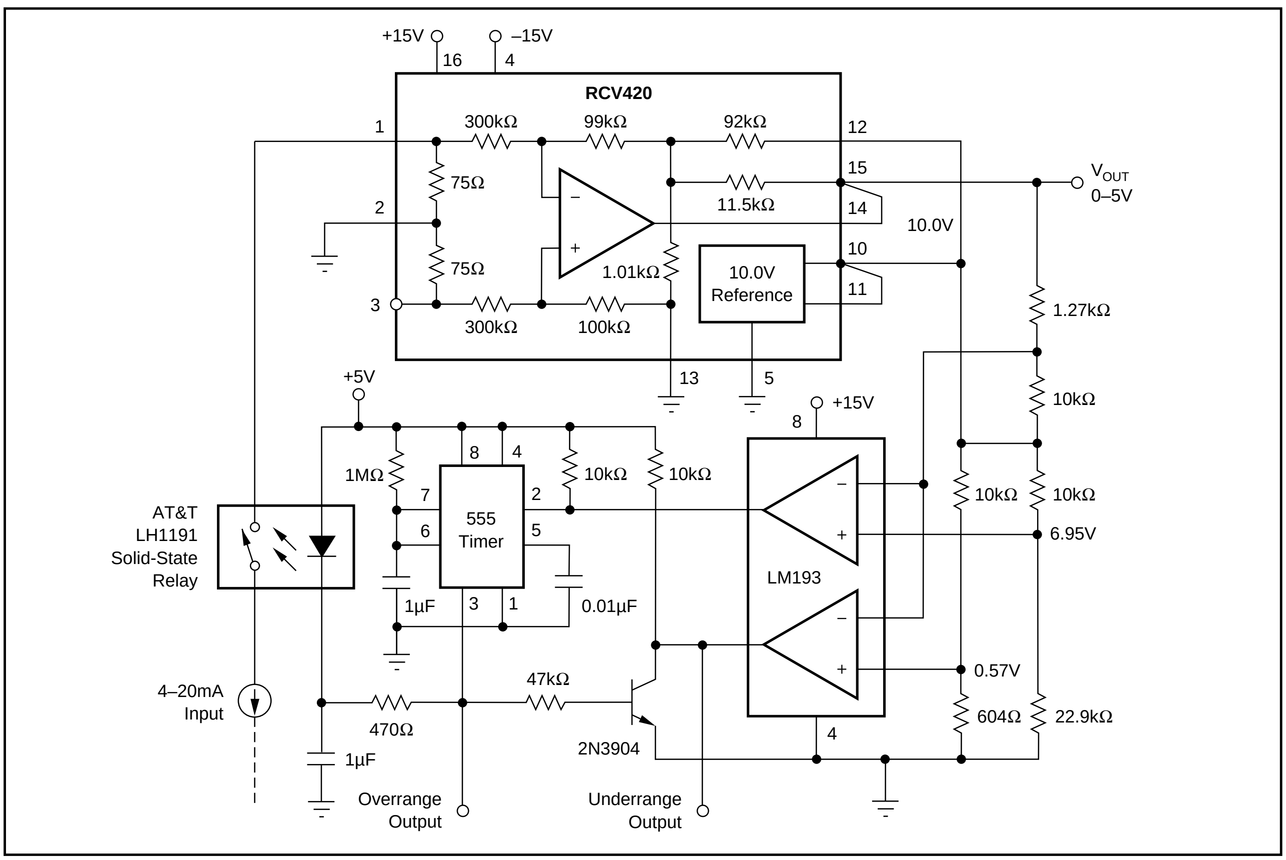

FIGURE 1. Input Protected RCV420.

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SELECTED OPERATING POINTS FOR RCV420 AND COMPARATORS

RCV420 INPUT (mA)	RCV420 OUTPUT (V)	COMPARATOR INPUT [1] (V)
0	–1.250	+0.017
2	–0.625	+0.572
4	0.000	1.269
20	5.000	5.563
25	6.563	6.950
36	10.000	10.000

NOTE: (1) From the 10kΩ, 1.27kΩ summing network.

The underrange comparator threshold is set at 0.57V by the 10kΩ, 604Ω resistor divider connected to the 10.0V reference. The comparator output goes high when the input to the current loop receiver goes below 2mA. The underrange output is TTL compatible.

The overrange comparator threshold is set at 6.95V by the 10kΩ, 22.9kΩ resistor divider connected to the 10.0V reference. The output of the overrange comparator goes low when the input to the current loop receiver exceeds 25mA.

With a 36mA current loop input, the overrange comparator input is 10V. For a 36mA overload set-point, the overrange resistor divider can be eliminated by connecting the overload comparator input directly to the 10.0V reference output of the RCV420.

The overrange comparator is connected so its output will go low on overrange to trigger the ensuing active overload protection circuitry. If the overload protection circuitry is not used, the inputs to the comparator can be reversed so its output will go high on overload.

The current sense resistors within the RCV420 are rated for overloads of up to 40mA continuous and for momentary overloads of up to 0.25A with 0.1s maximum duration and 1% maximum duty cycle. Overloads within these limits will not damage or degrade the rated performance of the receiver. If the 75Ω sense resistor were shorted to 48V (a common current loop supply voltage), the overload current would be 0.64A producing an $I^2 \bullet R$ power dissipation in the resistor of 30.7W. With a package thermal resistance (θ_{JA}) of 70°C/W, this would result in a theoretical junction temperature rise in excess of 2000°C. The input resistor would fuse, destroying the device, before the package temperature actually reached 2000°C. For input short circuits up to 3V, the current is limited to a safe 40mA by the 75Ω sense resistor within the RCV420. To prevent possible damage, external means are required to protect the RCV420 sense resistors from input short circuits to potentials greater than 3V.

The least expensive input short circuit protection is a resistor connected in series with the current loop at the receiver input. Select the resistor so that the input current under short-circuit conditions will be limited to 40mA by the series combination of the protection resistor and the 75Ω current sense resistor internal to the RCV420. Short circuit protection to 48V requires a 1125Ω resistor.

$$R_{PROTECTION} = (V_S/0.040) - 75\ (\Omega)$$

The problem with using a series resistor for input overload protection is the added voltage drop in the input current loop. A 1125Ω protection resistor in series with the 75Ω internal current sense resistor would result in a 24V drop at 20mA full scale input. In most applications the additional 24V burden can not be tolerated.

Another input protection scheme which can be used when only a small series voltage drop can be tolerated is to use a 0.032A fast-acting fuse (such as Littlefuse 217000 series, type F) in series with the current loop. This fuse adds negligible voltage drop to the current loop, and blows in less than 0.1s with an overload of 128mA or more. The problem with a fuse is that it must be replaced when it blows, and the cost of maintenance can be very high.

The active protection scheme shown in this application overcomes the disadvantages of resistor and fuse protection. It uses a solid-state relay for current loop interruption. After an interrupt time delay designed to provide a safe 1% maximum overload duty-cycle, the circuit resets automatically. The LH1191 solid-state relay used has a maximum on resistance of 33Ω which adds less than 0.1V of burden to the current loop at 20mA full scale input. Low receiver burden allows longer field wiring (with higher resistance) for remote sensors, and extra compliance for "intrinsically safe" barriers or other series connected receivers.

The solid-state relay is ideal for the resetable protection task. It is inexpensive as compared to a mechanical relay (less than $1.00), and because it is solid-state, it will not "wear out" if cycled continuously. The LH1191 is a single-pole, normally open switch rated for 280V, 100mA outputs. Relay overload currents are clamped to 210mA by current limiting circuitry internal to the relay. An extended clamp condition, which increases relay temperature, results in a reduction of the internal current limit to preserve the relay's integrity.

Protection circuitry interrupt timing is provided by a 555 timer connected as a monostable multivibrator (one shot). Under normal conditions, the output of the one shot is low holding the solid-state relay on by forcing approximately 8mA through the LED as set by the series-connected 470Ω resistor. When more than 25mA flows into the current loop receiver, the overload comparator triggers the one shot. With the values shown, the one shot output goes high, turning off the LED and the solid-state relay for about one second. At the end of one second the circuit automatically resets turning the relay back on. If an overload still exists, the cycle repeats. The overload current applied to the RCV420 is limited to about 210mA by the current limit of the solid-state relay and the 75Ω sense resistor internal to the RCV420. The one second cycle time of the overload circuitry assures safe 1% maximum overload current duty-cycle. The input to the circuit can be shorted to a 50V power supply continuously without damaging or degrading the accuracy of the RCV420. A short life-test was performed on a prototype circuit. After 168 hours with the receiver input shorted to 50V, there was no detectable change in receiver accuracy within the 0.005% resolution of the test system.

Since the overload protection circuitry interrupts the current loop, a logic gate is needed to prevent a false indication of open circuit. The 2N3904 transistor is wire-ORed to the underrange comparator output, assuring it will go high only during actual underload conditions. The 1µF capacitor connected to the 470Ω relay drive resistor delays relay turn-on to prevent possible logic race conditions which could produce a false underrange output logic “sliver”. The capacitor can be omitted if this is not a concern.