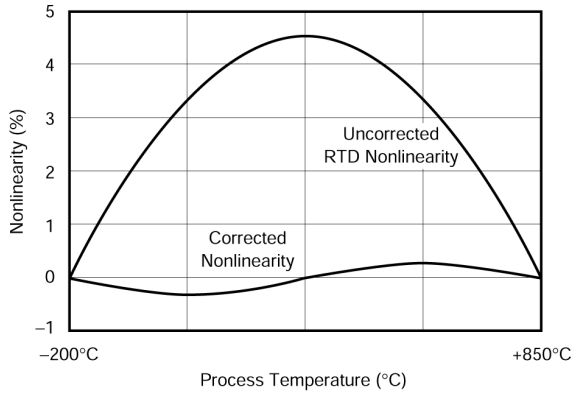
XTR105 具有传感器激励和线性化的 4mA 至 20mA 电流变送器

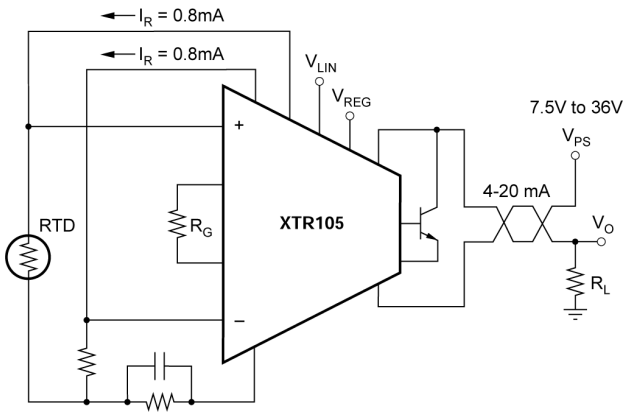
1 特性

- 低未调整误差
- 两个精准电流源：每个 800μA
- 线性化
- 2 线制或者 3 线制 RTD 操作
- 低温漂：0.4μV/°C
- 低输出电流噪声：30nA$_{PP}$
- 高 PSR：110dB（最小值）
- 高 CMR：86dB（最小值）
- 宽电源电压范围：7.5V 至 36V
- 封装：DIP-14 和 SO-14

2 应用

- 现场变送器和传感器
- 工厂自动化
- 与 HART 调制解调器兼容
- 温度和压力传感器
- 工业过程控制
- SCADA 远程数据采集
- 2 线 4mA 至 20mA 电流环
- 电压转电流放大器





使用 XTR105 进行 Pt100 非线性校正

3 说明

XTR105 是一款带有两个精准电流源的单片 4mA 至 20mA、2 线制电流发送器。该器件在一个单集成电路上提供针对铂 RTD 温度传感器和桥、仪表放大器以及电流输出电路的完整电流激励。

多用途线性化电流提供一个对 RTD 的第二阶修正，通常可以实现一个 40:1 的线性改进。

仪器放大器增益可针对宽范围的温度或者压力测量进行配置。整个电流发送器的总体未调整误差足够低以允许在未经调整的情况下用于很多应用。这包括零输出电流漂移，和非线性。XTR105 在低至 7.5V 的环路电源电压上运行。

XTR105 采用 DIP-14 和 SO-14 表面贴装型封装，工业温度范围为 –40°C 至 +85°C。

封装信息

器件型号	封装(1)	封装尺寸(2)
XTR105	D（SOIC，14）	8.65mm × 6mm
	N（PDIP，14）	19.3mm × 9.4mm

(1) 有关更多信息，请参阅节 10。
(2) 封装尺寸（长 × 宽）为标称值，并包括引脚（如适用）

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4 Pin Configuration and Functions

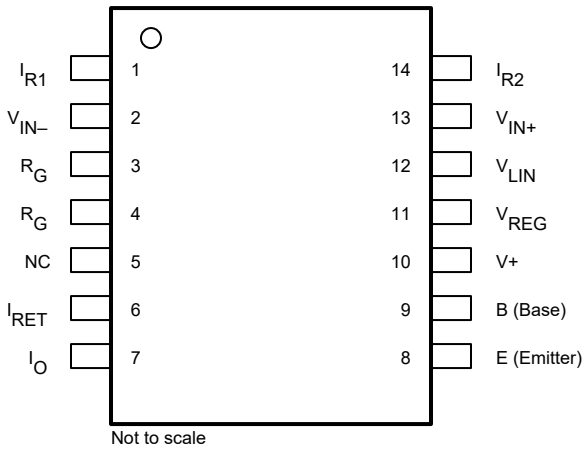


图 4-1. D Package, 14-Pin SOIC, and N Package, 14-Pin PDIP (Top View)

表 4-1. Pin Functions

PIN		TYPE	DESCRIPTION
NAME	NO.		
B (Base)	9	Output	Base connection for external transistor
E (Emitter)	8	Input	Emitter connection for external transistor
I_O	7	Output	Regulated 4mA to 20mA current loop output
I_{R1}	1	Output	800µA reference current output, channel 1
I_{R2}	14	Output	800µA reference current output, channel 2
I_{RET}	6	Input	*Local ground* return pin for V_{REG}, V_{LIN}, I_{R1}, and I_{R2}
NC	5	—	Not internally connected
R_G	3, 4	—	Input stage gain setting pins. The resistance R_G between pins 3 and 4 sets the gain of the voltage-to-current transfer function
V+	10	Power	Loop power supply
$V_{IN–}$	2	Input	Negative (inverting) differential voltage input
V_{IN+}	13	Input	Positive (noninverting) differential voltage input
V_{LIN}	12	Output	Linearity correction voltage output
V_{REG}	11	Output	5.1V regulator voltage output

5 Specifications

5.1 Absolute Maximum Ratings (1)

		MIN	MAX	UNIT
V+	Power supply (referenced to the I_O pin)		40	V
V_{IN}	Input voltage, V_{IN+} – V_{IN-} (referenced to the I_O pin)	0	V+	V
	Output current limit		Continuous	
T_A	Operating temperature	–40	125	°C
T_J	Junction temperature		165	°C
T_{stg}	Storage temperature	–55	125	°C
	Lead temperature (soldering, 10s)		300	°C

(1) Operation outside the *Absolute Maximum Ratings* may cause permanent device damage. *Absolute Maximum Ratings* do not imply functional operation of the device at these or any other conditions beyond those listed under *Recommended Operating Conditions*. If used outside the *Recommended Operating Conditions* but within the *Absolute Maximum Ratings*, the device may not be fully functional, and this may affect device reliability, functionality, performance, and shorten the device lifetime.

5.2 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

		MIN	NOM	MAX	UNIT
V+	Power supply (referenced to the I_O pin)	7.5	24	36	V
T_A	Specified temperature	−40		85	°C

5.3 Thermal Information

THERMAL METRICS(1)		XTR105		UNIT
		D (SOIC)	N (PDIP)	
		14 PINS		
$R_{\theta JA}$	Junction-to-ambient thermal resistance	87.3	54.4	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	47.3	31.4	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	46.6	25.8	°C/W
ψ_{JT}	Junction-to-top characterization parameter	9.9	9.6	°C/W
ψ_{JB}	Junction-to-board characterization parameter	46.1	25.3	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	N/A	N/A	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC package thermal metrics* application note.

5.4 Electrical Characteristics

at T_A = +25°C, V+ = 24V, and TIP29C external transistor (unless otherwise noted)

PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNITS
OUTPUT						
Output current equation	V_{IN} in volts, R_G in ohms			$I_O = V_{IN} \times (40 / R_G) + 4mA$		
Output current, specified range			4		20	mA
Overscale limit			24	27	30	mA
Underscale limit	I_{REG} = 0V		1.8	2.2	2.6	mA
ZERO OUTPUT (1)	V_{IN} = 0V, R_G = ∞			4		mA
Initial error	XTR105P, XTR105U			±5	±25	µA
	XTR105PA, XTR105UA			±5	±50	
vs temperature	T_A = –40 °C to +85°C	XTR105P, XTR105U		±0.07	±0.5	µA/°C
		XTR105PA, XTR105UA		±0.07	±0.9	
vs supply voltage, V+	V+ = 7.5V to 36V			0.04	0.2	µA/V
vs common-mode voltage	V_{CM} = 1.25V to 3.5V(2)			0.02		µA/V
vs V_{REG} output current				0.3		µA/mA
Noise, 0.1Hz to 10Hz				0.03		μA_{PP}
SPAN						
Span equation (transconductance)				S = 40/R_G		A/V
Initial error(3)	Full-scale (V_{IN}) = 50mV	XTR105P, XTR105U		±0.05	±0.2	%
		XTR105PA, XTR105UA		±0.05	±0.4	
vs temperature(3)	T_A = –40 °C to +85°C			±3	±25	ppm/°C
Nonlinearity, ideal input(4)	Full-scale (V_{IN}) = 50mV			0.003	0.01	%
INPUT (5)						
Offset voltage	V_{CM} = 2V	XTR105P, XTR105U		±50	±100	µV
		XTR105PA, XTR105UA		±50	±250	
vs temperature	T_A = –40 °C to +85°C	XTR105P, XTR105U		±0.4	±1.5	µV/°C
		XTR105PA, XTR105UA		±0.4	±3	
vs supply voltage, V+	V+ = 7.5V to 36V			±0.3	±3	µV/V
vs common-mode voltage, RTI (CMRR)	V_{CM} = 1.25V to 3.5V(2)	XTR105P, XTR105U		±10	±50	µV/V
		XTR105PA, XTR105UA		±10	±100	
Common-mode input range(2)			1.25		3.5	V
Input bias current	XTR105P, XTR105U			5	25	nA
	XTR105PA, XTR105UA			5	50	
vs temperature	T_A = –40 °C to +85°C			20		pA/°C
Input offset current	XTR105P, XTR105U			±0.2	±3	nA
	XTR105PA, XTR105UA			±0.2	±10	
vs temperature	T_A = –40 °C to +85°C			5		pA/°C
Impedance, differential				0.1 || 1		GΩ || pF
Common-mode				5 || 10		GΩ || pF
Noise, 0.1Hz to 10Hz				0.6		μA_{PP}

5.4 Electrical Characteristics（续）

at T_A = +25°C, V+ = 24V, and TIP29C external transistor (unless otherwise noted)

PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNITS
CURRENT SOURCES (6)						
Current				800		µA
Accuracy	XTR105P, XTR105U			±0.05	±0.2	%
	XTR105PA, XTR105UA			±0.05	±0.4	
vs temperature	T_A = –40 °C to +85°C	XTR105P, XTR105U		±15	±35	ppm/°C
		XTR105PA, XTR105UA		±15	±75	
vs power supply, V+	V+ = 7.5V to 36V			±10	±25	ppm/V
Matching	XTR105P, XTR105U			±0.02	±0.1	%
	XTR105PA, XTR105UA			±0.02	±0.2	
vs temperature	T_A = –40 °C to +85°C	XTR105P, XTR105U		±3	±15	ppm/°C
		XTR105PA, XTR105UA		±3	±30	
vs power supply, V+	V+ = 7.5V to 36V			1	10	ppm/V
Compliance voltage	Positive		(V+) – 3	(V+) – 2.5		V
	Negative(2)		0	–0.2		
Output impedance				150		MΩ
Noise, 0.1Hz to 10Hz				0.003		$µA_{PP}$
V_{REG} (2)				5.1		V
Accuracy				±0.02	±0.1	V
vs temperature	T_A = –40 °C to +85°C			±0.5		mV/°C
vs supply voltage, V+				1		mV/V
Output current				±1		mA
Output impedance				75		Ω
LINEARIZATION						
R_{LIN} (internal)				1		kΩ
Accuracy	XTR105P, XTR105U			±0.2	±0.5	%
	XTR105PA, XTR105UA			±0.2	±1	
vs temperature	T_A = –40 °C to +85°C			±25	±100	ppm/°C

(1) Describes accuracy of the 4mA low-scale offset current. Does not include input amplifier effects. Can be trimmed to zero.
(2) Voltage measured with respect to I_{RET} pin.
(3) Does not include initial error or TCR of gain-setting resistor, R_G.
(4) Increasing the full-scale input range improves nonlinearity.
(5) Does not include zero output initial error.
(6) Current source output voltage V_O = 2V, with respect to I_{RET} pin.

5.5 Typical Characteristics

at T_A = +25°C and V+ = 24V (unless otherwise noted)

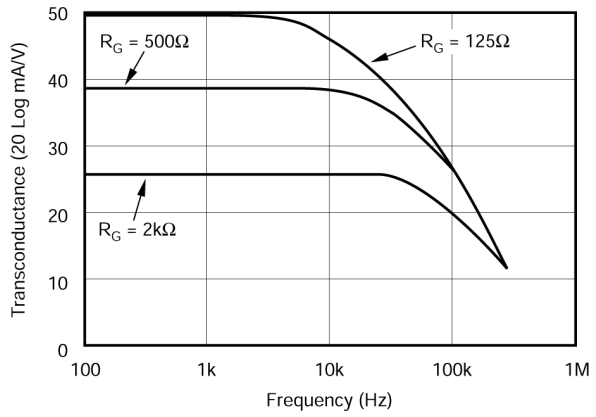


图 5-1. Transconductance vs Frequency

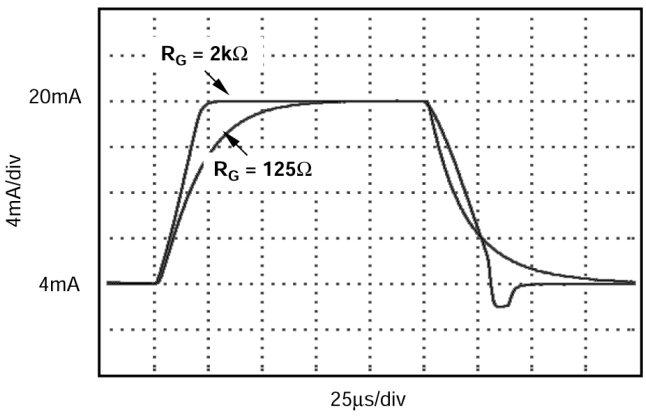


图 5-2. Step Response

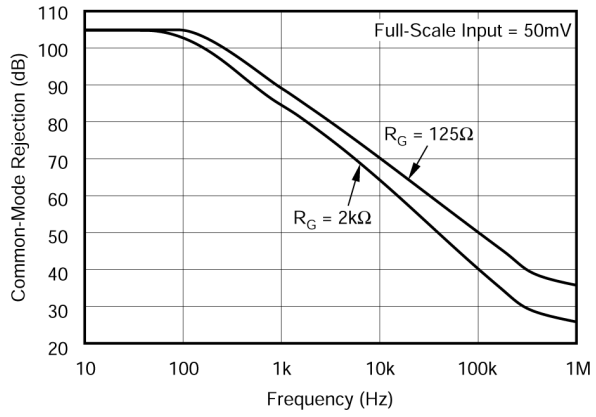


图 5-3. Common-Mode Rejection vs Frequency

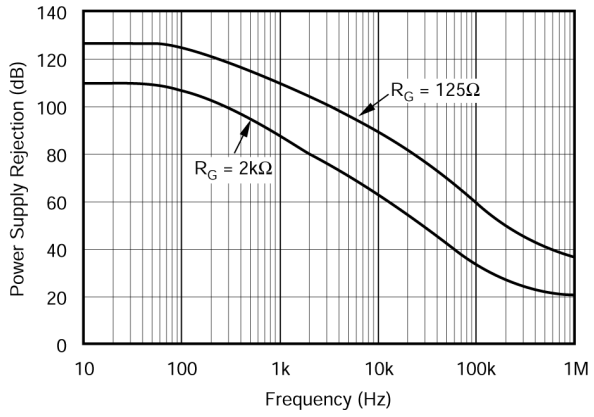


图 5-4. Power-Supply Rejection vs Frequency

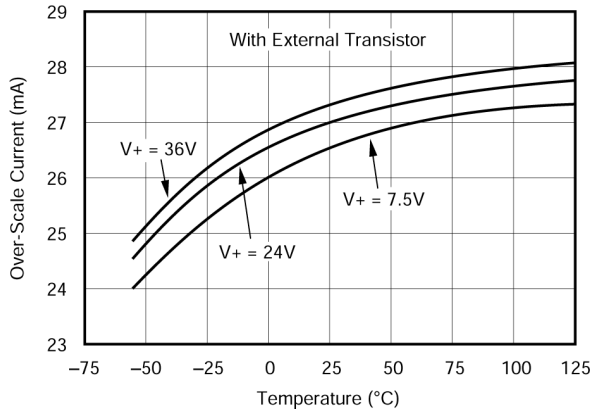


图 5-5. Overscale Current vs Temperature

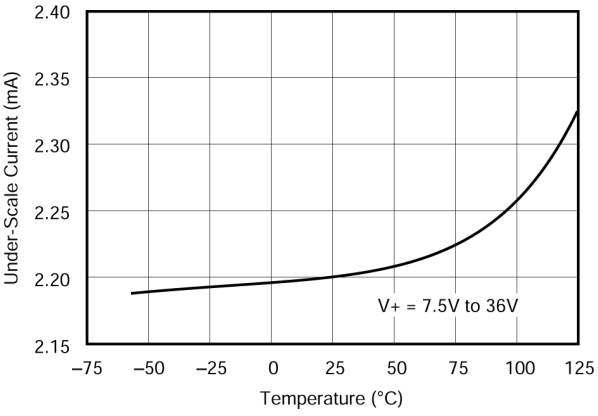


图 5-6. Underscale Current vs Temperature

5.5 Typical Characteristics (continued)

at T_A = +25°C and V+ = 24V (unless otherwise noted)

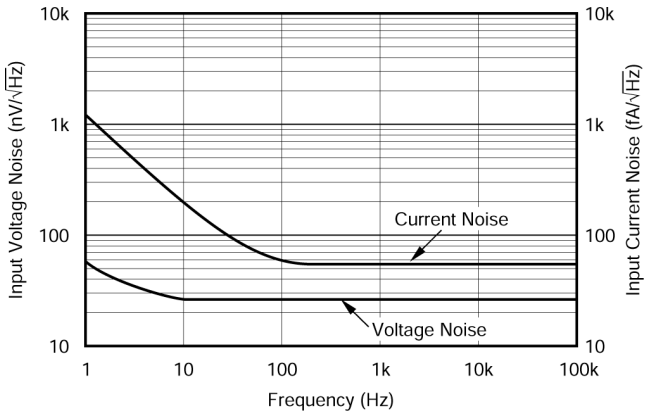


图 5-7. Input Voltage and Current Noise Density vs Frequency

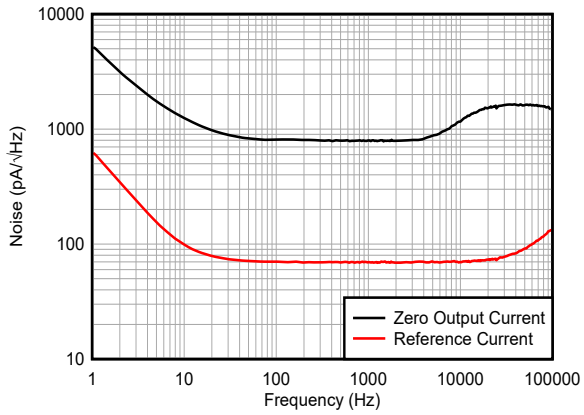


图 5-8. Zero Output and Reference Current Noise vs Frequency

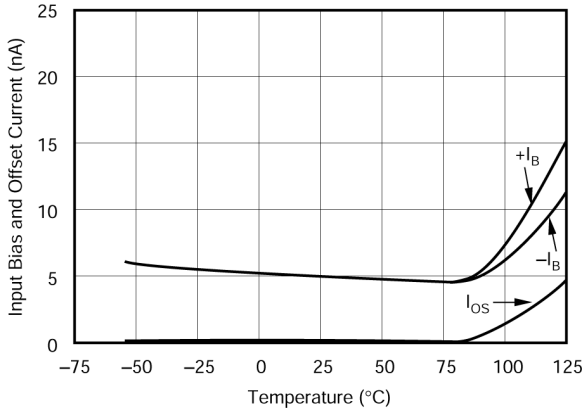


图 5-9. Input Bias and Offset Current vs Temperature

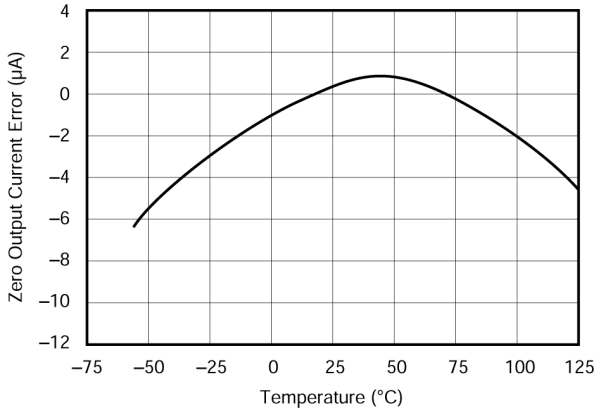


图 5-10. Zero Output Current Error vs Temperature

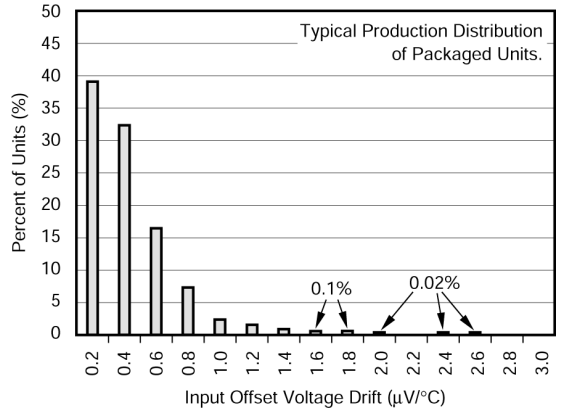


图 5-11. Input Offset Voltage Drift Production Distribution

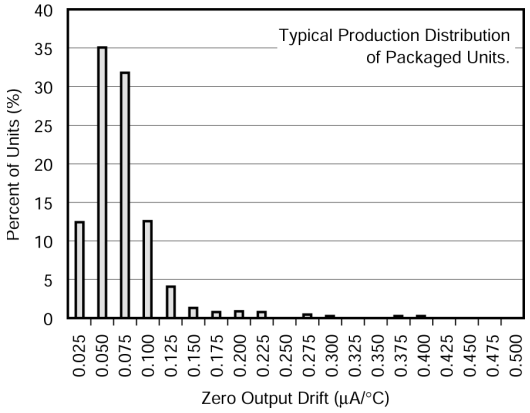


图 5-12. Zero Output Drift Production Distribution

5.5 Typical Characteristics (continued)

at T_A = +25°C and V+ = 24V (unless otherwise noted)

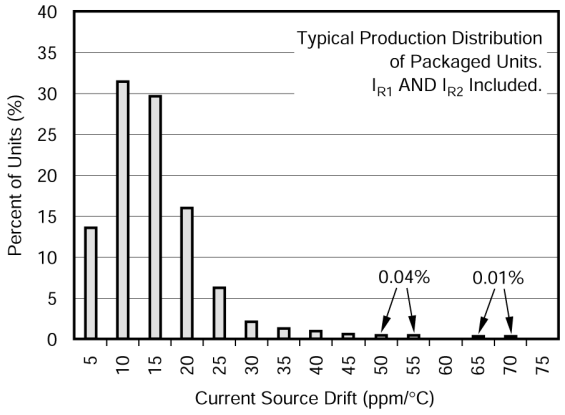


图 5-13. Current Source Drift Production Distribution

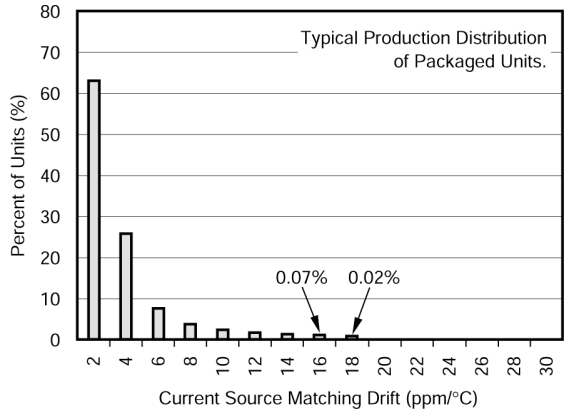


图 5-14. Current Source Matching Drift Production Distribution

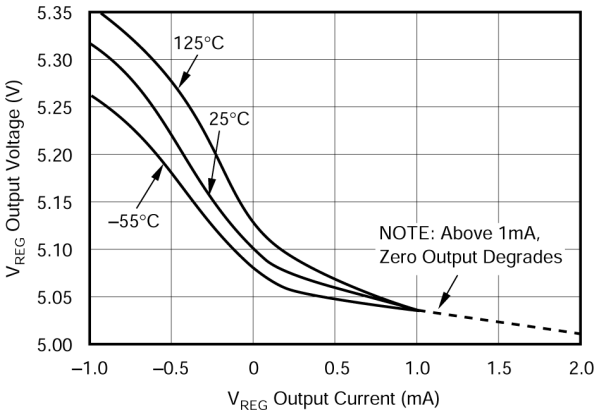


图 5-15. V_{REG} Output Voltage vs v_{REG} Output Current

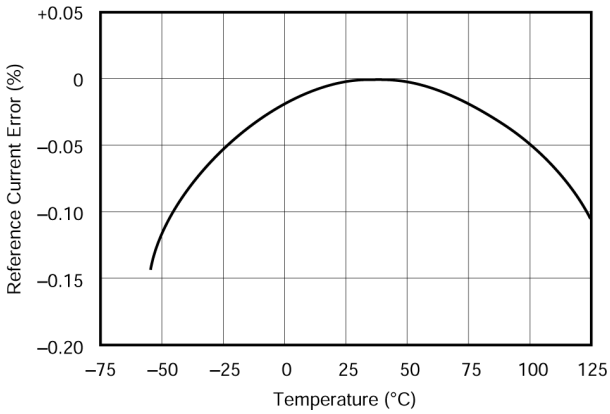


图 5-16. Reference Current Error vs Temperature

6 Detailed Description

6.1 Overview

The XTR105 is a monolithic 4mA-to-20mA, 2-wire current transmitter with a differential voltage input. 图 6-1 shows the simplified schematic of the XTR105. The loop power supply, V_+, provides power for all circuitry. The output loop current is modulated by the XTR105 and is typically measured as a voltage across a series load resistor (R_L).

The instrumentation amplifier input of the XTR105 measures the voltage difference between the noninverting and inverting inputs. This difference is then gained up according to the value of R_G, and expressed as a regulated current output.

The two matched 0.8mA current sources are typically used to drive an RTD and zero-setting resistor (R_Z). R_Z determines the static offset of the current output and can be adjusted to correct for offset errors. A linearity correction feature is provided to further improve the RTD response. An additional 5.1V voltage regulator output is provided to power external circuitry such as buffer amplifiers.

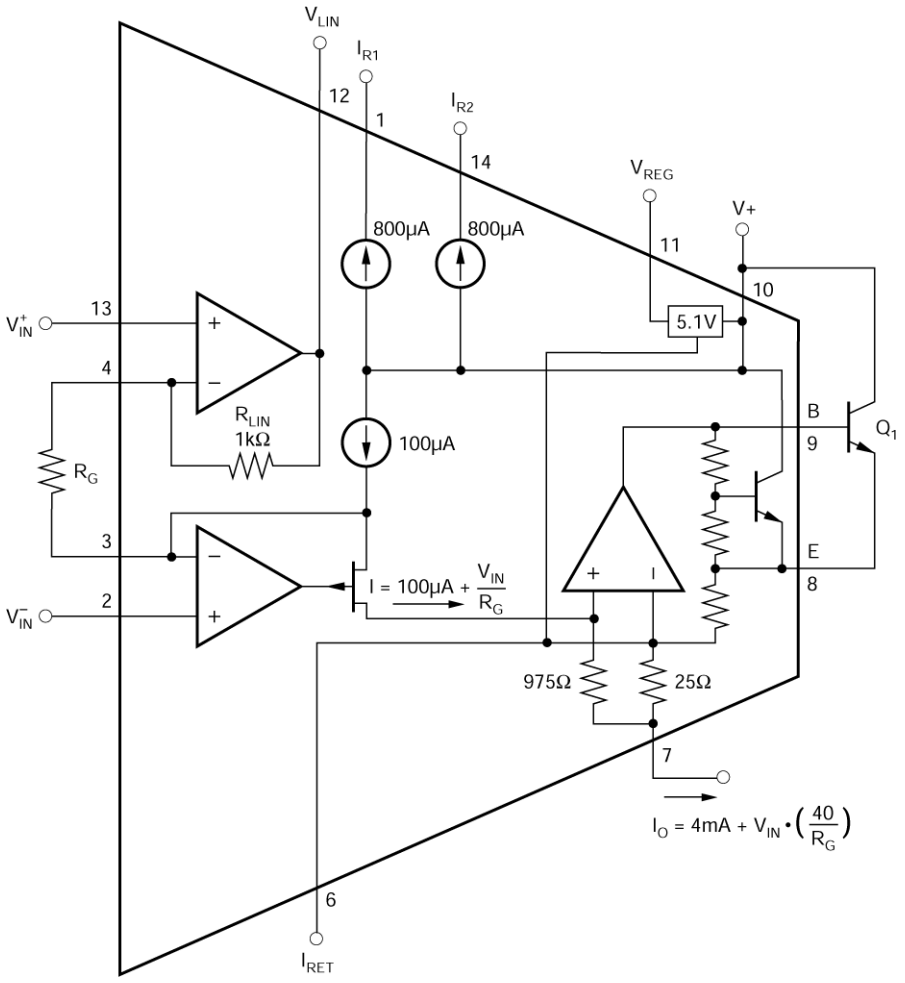
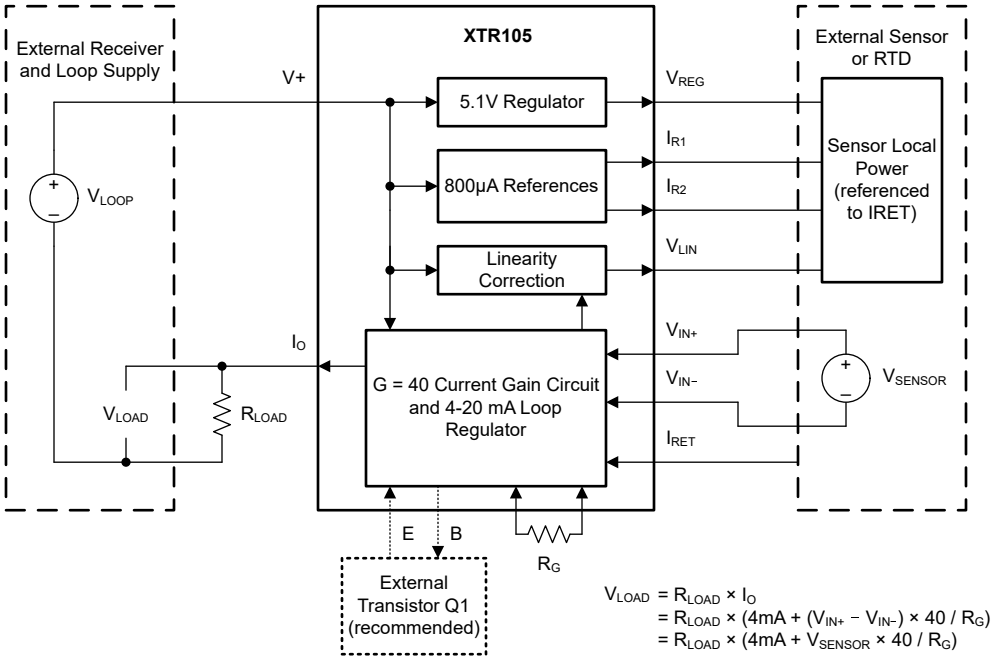


图 6-1. Simplified Schematic

6.2 Functional Block Diagram



6.3 Feature Description

6.3.1 Linearization

RTD temperature sensors are inherently (but predictably) nonlinear. With the addition of one or two external resistors, R_{LIN1} and R_{LIN2}, compensation is possible for most of this nonlinearity by using the V_{LIN} linearity correction feature of the XTR105. This results in a 40:1 improvement in linearity over the uncompensated output.

See 图 7-1 for a typical 2-wire RTD application with linearization. Resistor R_{LIN1} provides positive feedback and controls linearity correction. R_{LIN1} is chosen according to the desired temperature range. An equation is given in 图 7-1.

In 3-wire RTD connections, an additional resistor, R_{LIN2}, is required. As with the 2-wire RTD application, R_{LIN1} provides positive feedback for linearization. R_{LIN2} provides an offset canceling current to compensate for wiring resistance encountered in remotely located RTDs. R_{LIN1} and R_{LIN2} are chosen such that the currents are equal. This makes the voltage drop in the wiring resistance to the RTD a common-mode signal that is rejected by the XTR105. The nearest standard 1% resistor values for R_{LIN1} and R_{LIN2} are adequate for most applications. 表 7-1 provides the 1% resistor values for a 3-wire Pt100 RTD connection.

If no linearity correction is desired, leave the V_{LIN} pin open. With no linearization, $R_G = 2500m \times V_{FS}$, where V_{FS} = full-scale input range.

6.3.1.1 High-Resistance RTDs

The text and figures thus far have assumed a Pt100 RTD. With higher resistance RTDs, evaluate the temperature range and input voltage variation to maintain proper common-mode biasing of the inputs. As mentioned previously, R_{CM} can be adjusted to provide an additional voltage drop to bias the inputs of the XTR105 within the common-mode input range.

6.3.2 Voltage Regulator

The V_{REG} pin provides an on-chip voltage source of approximately 5.1V and is designed for powering external input circuitry (as shown in 图 6-2). This source is a moderately accurate voltage reference, and is not the same reference used to set the 800µA current references. V_{REG} is capable of sourcing approximately 1mA of current. Exceeding 1mA can affect the 4mA zero output.

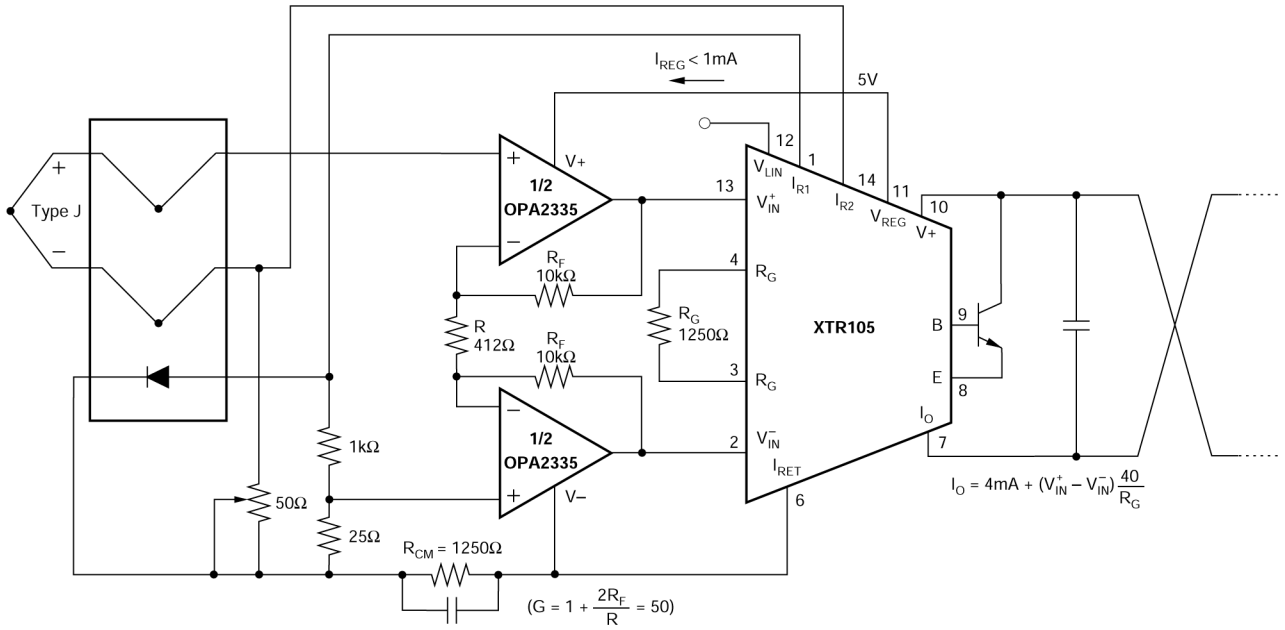


图 6-2. Thermocouple Low Offset, Low Drift Loop Measurement With Diode Cold Junction Compensation

6.3.3 Open-Circuit Protection

Optional transistor Q_2 in 图 6-3 provides predictable behavior with open-circuit RTD connections. If any one of the three RTD connections is broken, the XTR105 output current goes to either the high current limit (≅ 27mA) or low current limit (≅ 2.2mA). This state is easily detected as an out-of-range condition.

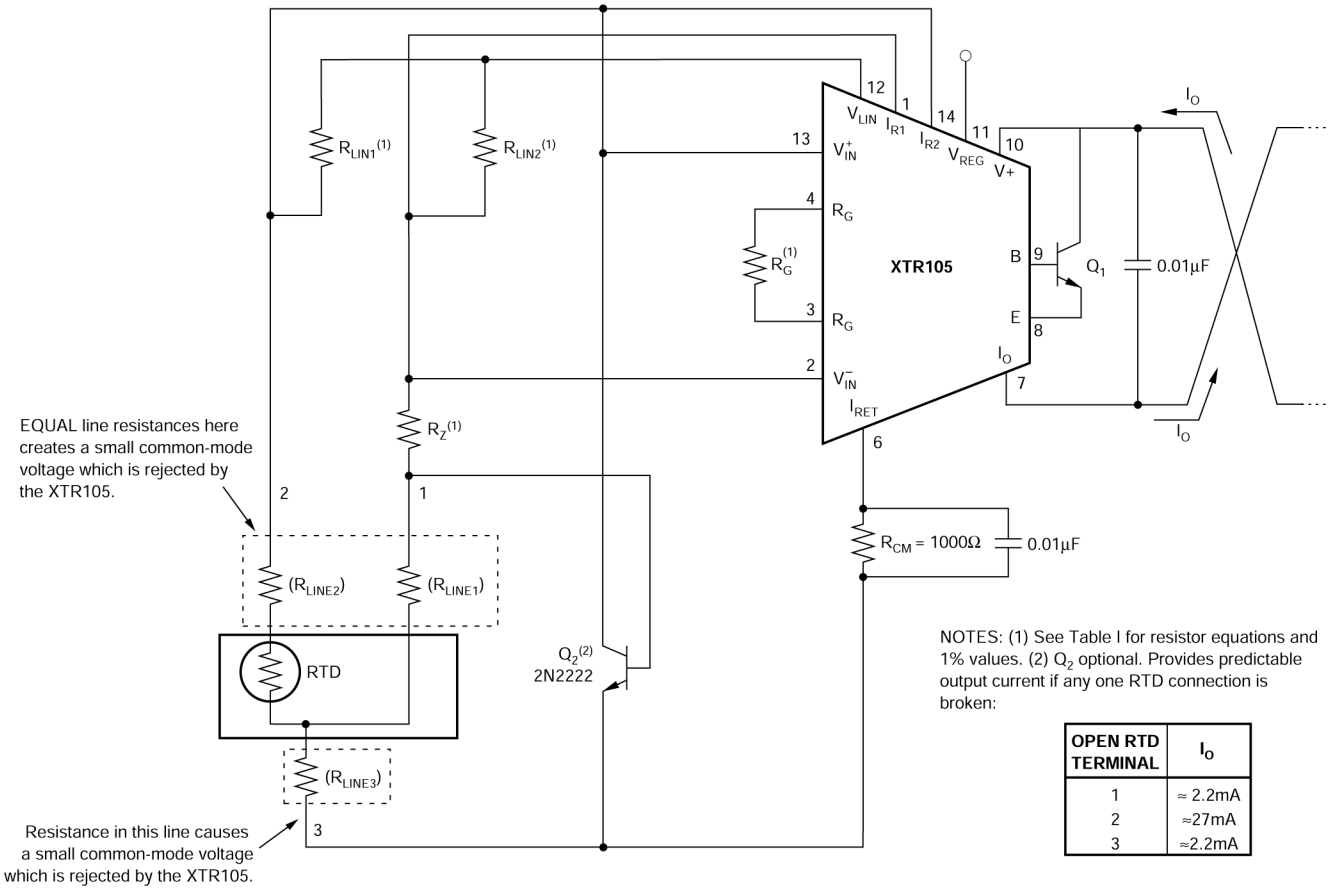


图 6-3. Remotely Located RTDs With a 3-Wire Connection

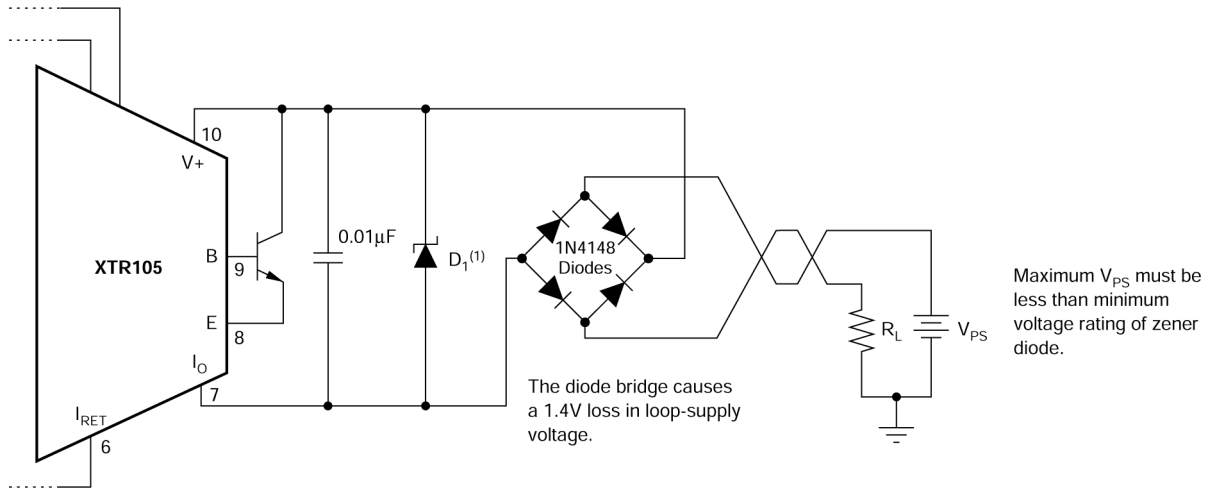
6.3.4 Reverse-Voltage Protection

The XTR105 low compliance rating (7.5V) permits the use of various voltage protection methods without compromising operating range. 图 6-4 shows a diode bridge circuit that allows normal operation even when the voltage connection lines are reversed. The bridge causes a two diode drop (approximately 1.4V) loss in loop-supply voltage. This results in a compliance voltage of approximately 9V—satisfactory for most applications. If a 1.4V drop in loop supply is too much, a diode can be inserted in series with the loop-supply voltage and the V+ pin. This protects against reverse output connection lines with only a 0.7V loss in loop-supply voltage.

6.3.5 Surge Protection

Remote connections to current transmitters are sometimes subjected to voltage surges. Limit the maximum surge voltage applied to the XTR105 to the lowest practical value. Various zener diodes and surge clamping diodes are specially designed for this purpose. Select a clamp diode with as low a voltage rating as possible for best protection. For example, a 36V protection diode allows proper transmitter operation at normal loop voltages, yet provides an appropriate level of protection against voltage surges. The XTR105 is specified to an absolute maximum loop voltage of 40V.

Most surge protection zener diodes have a diode characteristic in the forward direction that conducts excessive current, possibly damaging receiving-side circuitry, if the loop connections are reversed. If a surge protection diode is used, use a series diode or diode bridge for protection against reversed connections.



(1) 36V Zener diode, such as 1N4753A or P6KE39A. Use lower-voltage Zener diodes with loop power-supply voltages < 30V for increased protection.

图 6-4. Reverse Voltage Operation and Overvoltage Surge Protection

6.4 Device Functional Modes

The device has one mode of operation that applies when operated within the *Recommended Operating Conditions*.

7 Application and Implementation

备注

以下应用部分中的信息不属于 TI 器件规格的范围，TI 不担保其准确性和完整性。TI 的客 户应负责确定器件是否适用于其应用。客户应验证并测试其设计，以确保系统功能。

7.1 Application Information

图 7-1 shows the basic connection diagram for the XTR105. The loop power supply, V_{PS}, provides power for all circuitry. Output loop current is measured as a voltage across the series load resistor, R_L.

Two matched 0.8mA current sources drive the RTD and zero-setting resistor, R_Z. The instrumentation amplifier input of the XTR105 measures the voltage difference between the RTD and R_Z. The value of R_Z is chosen to be equal to the resistance of the RTD at the low-scale (minimum) measurement temperature. R_Z can be adjusted to achieve 4mA output at the minimum measurement temperature to correct for input offset voltage and reference current mismatch of the XTR105.

R_{CM} provides an additional voltage drop to bias the inputs of the XTR105 within the common-mode input range. Bypass R_{CM} with a 0.01µF capacitor to minimize common-mode noise. Resistor R_G sets the gain of the instrumentation amplifier according to the desired temperature range. R_{LIN1} provides 2nd-order linearization correction to the RTD, typically achieving a 40:1 improvement in linearity. An additional resistor is required for 3-wire RTD connections (see 图 6-3).

The transfer function through the complete instrumentation amplifier and voltage-to-current converter is:

$I_O = 4mA + V_{IN} \times (40 / R_G)$

(V_{IN} in volts, R_G in ohms)

where V_{IN} is the differential input voltage.

A negative input voltage, V_{IN}, causes the output current to be less than 4mA. Increasingly negative V_{IN} causes the output current to limit at approximately 2.2mA. See also typical characteristic *Under-Scale Current vs Temperature*.

Increasingly positive input voltage (greater than the full-scale input) produces increasing output current according to the transfer function, up to the output current limit of approximately 27mA. See also typical characteristic *Over-Scale Current vs Temperature*.

As evident from the transfer function, if no R_G is used the gain is zero and the output is simply the XTR105’s zero current. The value of R_G varies slightly for 2-wire RTD and 3-wire RTD connections with linearization. R_G can be calculated from the equations given in 图 7-1 (2-wire RTD connection) and 表 7-1 (3-wire RTD connection).

The I_{RET} pin is the return path for all current from the current sources and V_{REG}. The I_{RET} pin allows any current used in external circuitry to be sensed by the XTR105 and to be included in the output current without causing an error.

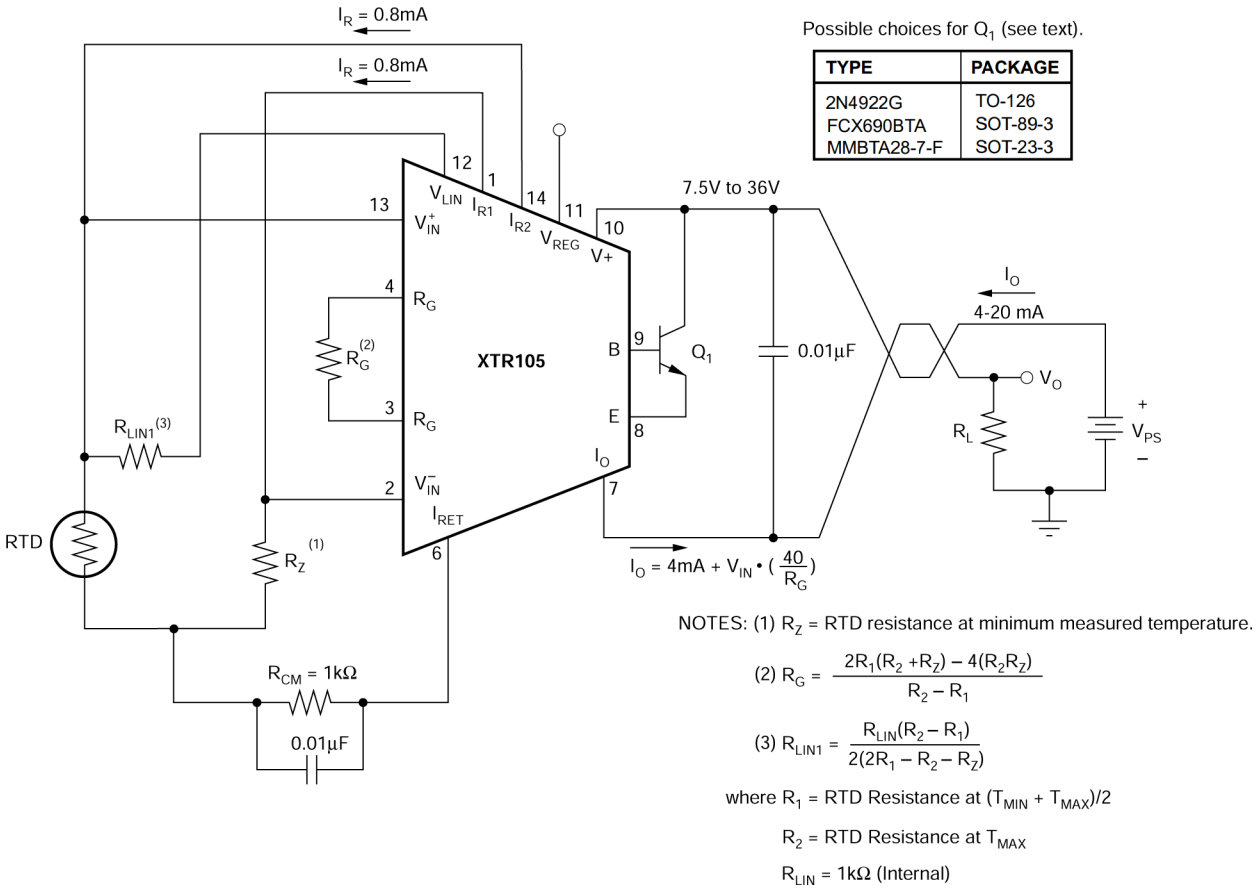


图 7-1. Basic 2-Wire RTD Temperature Measurement Circuit With Linearization

表 7-1. R_Z, R_G, R_{LIN1}, and R_{LIN2} Standard 1% Resistor Values for 3-Wire Pt100 RTD Connection With Linearization

MEASUREMENT TEMPERATURE SPAN ΔT (°C)

T_{MIN}	100°C	200°C	300°C	400°C	500°C	600°C	700°C	800°C	900°C	1000°C
–200°C	18.7/86.6 15000 16500	18.7/169 9760 11500	18.7/255 8060 10000	18.7/340 6650 8870	18.7/422 5620 7870	18.7/511 4750 7150	18.7/590 4020 6420	18.7/665 3480 5900	18.7/750 3090 5360	18.7/845 2740 4990
–100°C	60.4/80.6 27400 29400	60.4/162 15400 17800	60.4/243 10500 13000	60.4/324 7870 10200	60.4/402 6040 8660	60.4/487 4990 7500	60.4/562 4220 6490	60.4/649 3570 5900	60.4/732 3090 5360	
0°C	100/78.7 33200 35700	100/158 16200 18700	100/237 10500 13000	100/316 7680 10000	100/392 6040 8250	100/475 4870 7150	100/549 4020 6340	100/634 3480 5620		
100°C	137/75 31600 34000	137/150 15400 17800	137/226 10200 12400	137/301 7500 9760	137/383 5760 8060	137/453 4750 6810	137/536 3920 6040			
200°C	174/73.2 30900 33200	174/147 15000 17400	174/221 9760 12100	174/294 7150 9310	174/365 5620 7680	174/442 4530 6490				
300°C	210/71.5 30100 32400	210/143 14700 16500	210/215 9530 11500	210/287 6980 8870	210/357 5360 7320					
400°C	249/68.1 28700 30900	249/137 14000 16200	249/205 9090 11000	249/274 6650 8450						
500°C	280/66.5 28000 30100	280/133 13700 15400	280/200 8870 10500							
600°C	316/64.9 26700 28700	313/130 13000 14700								
700°C	348/61.9 26100 27400									
800°C	374/60.4 24900 26700									

R_Z/R_G
R_{LIN1}
R_{LIN2}

NOTE: The values listed in this table are 1% resistors (in Ω). Exact values may be calculated from the following equations:

R_Z = RTD resistance at minimum measured temperature.

$$R_G = \frac{2(R_2 - R_Z)(R_1 - R_Z)}{(R_2 - R_1)}$$

$$R_{LIN1} = \frac{R_{LIN}(R_2 - R_1)}{2(2R_1 - R_2 - R_Z)}$$

$$R_{LIN2} = \frac{(R_{LIN} + R_G)(R_2 - R_1)}{2(2R_1 - R_2 - R_Z)}$$

where: R_1 = RTD resistance at $(T_{MIN} + T_{MAX})/2$

R_2 = RTD resistance at T_{MAX}

R_{LIN} = 1kΩ (Internal)

EXAMPLE:

The measurement range is –100°C to +200°C for a 3-wire Pt100 RTD connection. Determine the values for R_S, R_G, R_{LIN1}, and R_{LIN2}. Look up the values from the chart or calculate the values according to the equations provided.

METHOD 1: TABLE LOOK UP

For T_{MIN} = –100°C and ΔT = –300°C, the 1% values are:

R_Z = 60.4Ω R_{LIN1} = 10.5kΩ

R_G = 243Ω R_{LIN2} = 13kΩ

METHOD 2: CALCULATION

Step 1: Determine R_Z, R_1, and R_2.

R_Z is the RTD resistance at the minimum measured temperature, T_{MIN} = –100°C. Using Equation 1 at right gives R_Z = 60.25Ω (1% value is 60.4Ω).

R_2 is the RTD resistance at the maximum measured temperature, T_{MAX} = 200°C. Using Equation 2 at right gives R_2 = 175.84Ω.

R_1 is the RTD resistance at the midpoint measured temperature, $T_{MID} = (T_{MIN} + T_{MAX})/2$ = 50°C. R_1 is NOT the average of R_Z and R_2. Using Equation 2 at right gives R_1 = 119.40Ω.

Step 2: Calculate R_G, R_{LIN1}, and R_{LIN2} using equations above.

R_G = 242.3Ω (1% value is 243Ω)
R_{LIN1} = 10.413kΩ (1% value is 10.5kΩ)
R_{LIN2} = 12.936kΩ (1% value is 13kΩ)

Calculation of Pt100 Resistance Values
(according to DIN IEC 751)

(Equation 1) Temperature range from –200°C to 0°C:
$R_{(T)} = 100\ [1 + 3.90802 \cdot 10^{-3} \cdot T - 0.5802 \cdot 10^{-6} \cdot T^2 - 4.27350 \cdot 10^{-12}\ (T - 100)\ T^3]$

(Equation 2) Temperature range from 0°C to +850°C:
$R_{(T)} = 100\ (1 + 3.90802 \cdot 10^{-3} \cdot T - 0.5802 \cdot 10^{-6} \cdot T_2)$

where: $R_{(T)}$ is the resistance in Ω at temperature T.
T is the temperature in °C.

NOTE: Most RTD manufacturers provide reference tables for resistance values at various temperatures.

7.1.1 External Transistor

Transistor Q_1 conducts the majority of the signal-dependent 4-20mA loop current. Using an external transistor isolates the majority of the power dissipation from the precision input and reference circuitry of the XTR105, maintaining excellent accuracy.

The external transistor is inside a feedback loop; therefore, the transistor characteristics are not critical. Requirements are: V_{CEO} = 45V min, β = 40 min, and P_D = 800mW. Power dissipation requirements can be lower if the loop power-supply voltage is less than 36V. Some possible choices for Q_1 are listed in 图 7-1.

The XTR105 operates without this external transistor; however, accuracy is somewhat degraded as a result of the internal power dissipation and resulting self-heating. Operation without Q_1 is not recommended for extended temperature ranges. A resistor (R = 3.3kΩ) connected between the I_{RET} pin and the E (emitter) pin is advised for operation below 0°C without Q_1 to support the full 20mA full-scale output, especially with V+ near 7.5V.

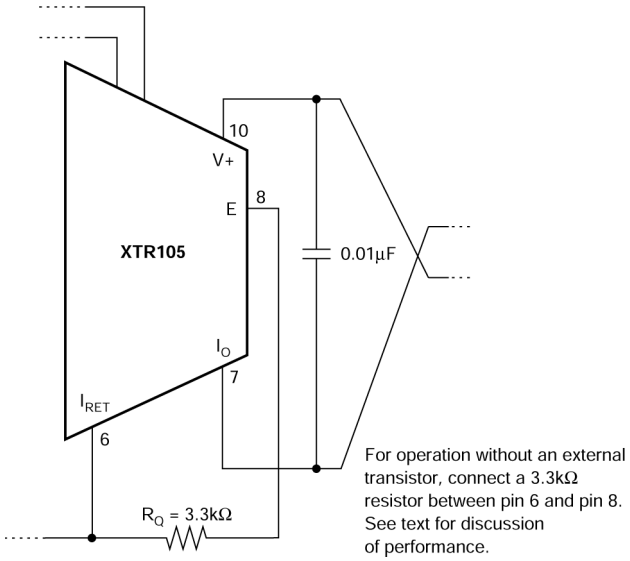


图 7-2. Operation Without an External Transistor

7.1.2 Loop Power Supply

The voltage applied to the XTR105, V+, is measured with respect to the I_O connection, pin 7. V+ can range from 7.5V to 36V. The loop-supply voltage, V_{PS}, differs from the voltage applied to the XTR105 according to the voltage drop on the current sensing resistor, R_L (plus any other voltage drop in the line).

If a low loop-supply voltage is used, R_L (including the loop wiring resistance) must be made a relatively low value so that V+ remains 7.5V or greater for the maximum loop current of 20mA:

$$R_L \text{ max} = \left(\frac{(V+) - 7.5V}{20mA} \right) - R_{WIRING}$$

For loop currents up to 30mA, design for V+ equal or greater than 7.5V to allow for out-of-range input conditions.

The low operating voltage (7.5V) of the XTR105 allows operation directly from personal computer power supplies (12V ±5%). When used with the RCV420 current loop receiver (see 图 7-3), the load resistor voltage drop is limited to 3V.

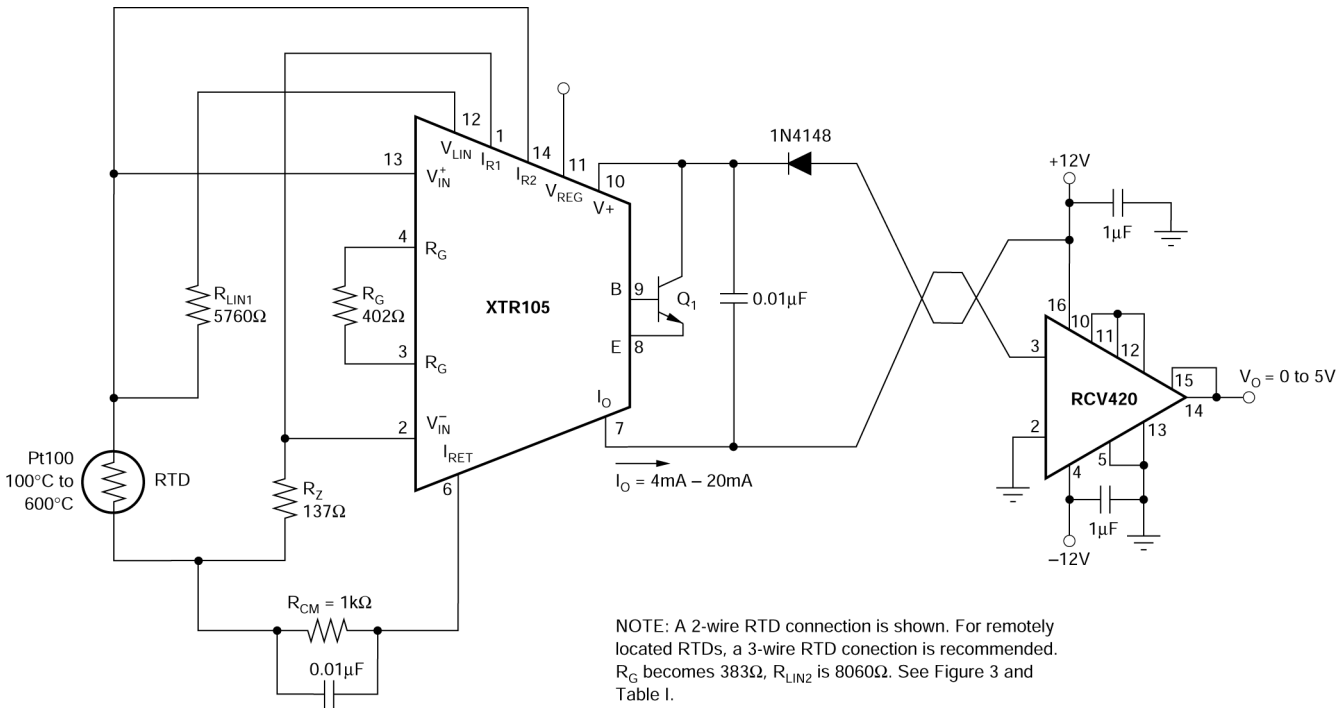


图 7-3. ±12V Powered Transmitter-Receiver Loop

7.1.3 2-Wire and 3-Wire RTD Connections

In 图 7-1, the RTD can be located remotely simply by extending the two connections to the RTD. With this remote 2-wire connection to the RTD, line resistance introduces error. This error can be partially corrected by adjusting the values of R_Z, R_G, and R_{LIN1}.

A better method for remotely located RTDs is the 3-wire RTD connection (see 图 6-3). This circuit offers improved accuracy. R_Z' s current is routed through a third wire to the RTD. Assuming line resistance is equal in RTD lines 1 and 2, this produces a small common-mode voltage that is rejected by the XTR105. A second resistor, R_{LIN2}, is required for linearization.

Note that although the 2-wire and 3-wire RTD connection circuits are very similar, the gain-setting resistor, R_G, has slightly different equations:

2-wire: $$R_G = \frac{2R_1(R_2 + R_Z) - 4(R_2R_Z)}{R_2 - R_1}$$

3-wire: $$R_G = \frac{2(R_2 - R_Z)(R_1 - R_Z)}{R_2 - R_1}$$

where

- R_Z = RTD resistance at T_{MIN}
- R_1 = RTD resistance at (T_{MIN} + T_{MAX}) / 2
- R_2 = RTD resistance at T_{MAX}

To maintain good accuracy, use at least 1% (or better) resistors for R_G. 表 7-1 provides standard 1% R_G resistor values for a 3-wire Pt100 RTD connection with linearization.

7.1.4 Radio Frequency Interference

The long wire lengths of current loops invite radio frequency (RF) interference. RF can be rectified by the sensitive input circuitry of the XTR105, causing errors. This generally appears as an unstable output current that varies with the position of loop supply or input wiring.

If the RTD sensor is remotely located, the interference can enter at the input terminals. For integrated transmitter assemblies with short connections to the sensor, the interference more likely comes from the current loop connections.

Bypass capacitors on the input reduce or eliminate this input interference. Connect these bypass capacitors to the I_{RET} terminal (see 图 7-4). Although the dc voltage at the I_{RET} terminal is not equal to 0V (at the loop supply, V_{PS}), this circuit point can be considered the transmitter *ground*. The 0.01µF capacitor connected between V+ and I_O can help minimize output interference.

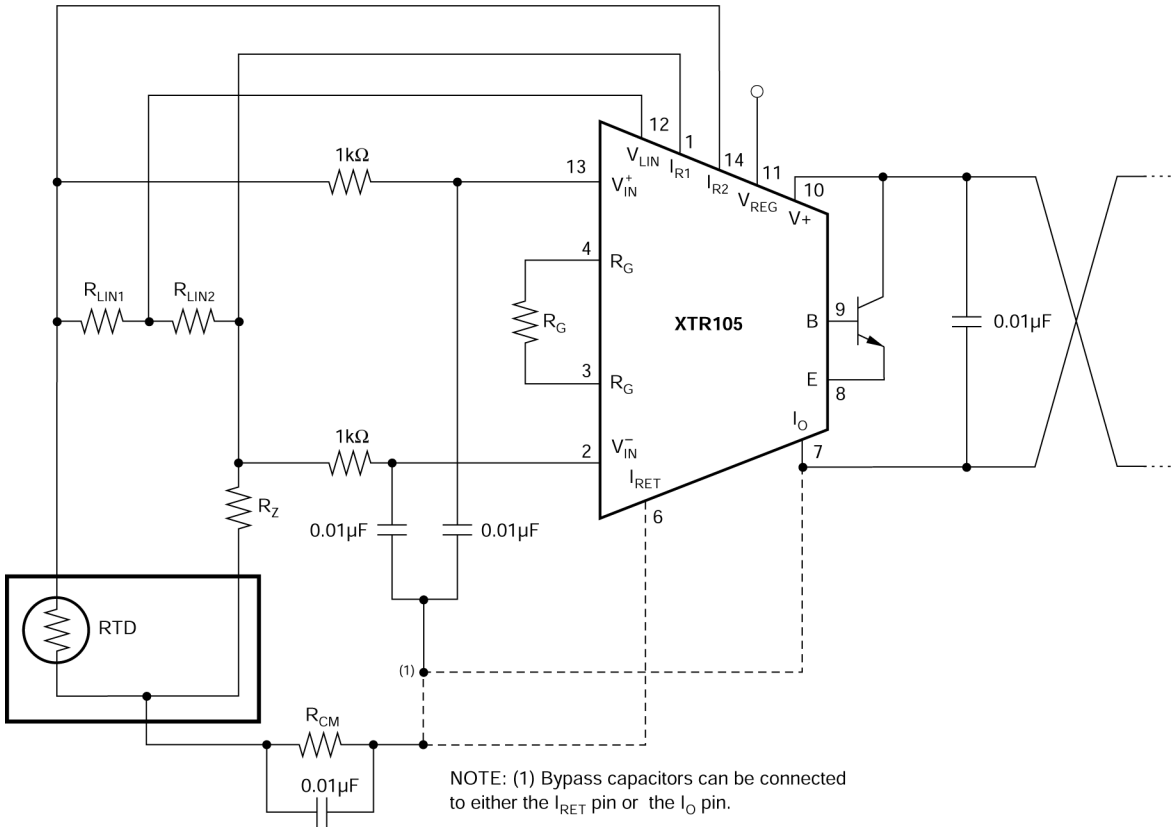


图 7-4. Input Bypassing Technique With Linearization

7.1.5 Error Analysis

Many applications require adjustment of initial errors. Input offset and reference current mismatch errors can be corrected by adjustment of the zero resistor, R_Z. Adjusting the gain-setting resistor, R_G, corrects any errors associated with gain.

表 7-2 shows how to calculate the effect of various error sources on the circuit accuracy. A sample error calculation for a typical RTD measurement circuit (Pt100 RTD, 200°C measurement span) is provided. The results reveal the XTR105 excellent accuracy, in this case 1.1% unadjusted. Adjusting resistors R_G and R_Z for gain and offset errors improves circuit accuracy to 0.32%. These are worst-case errors; maximum values were used in the calculations and all errors were assumed to be positive (additive). The XTR105 achieves performance that is difficult to obtain with discrete circuitry and requires less space.

表 7-2. Error Calculation

SAMPLE ERROR CALCULATION				
RTD value at 4mA output ($R_{RTD\ MIN}$): 100 Ω				
RTD measurement range: 200°C				
Ambient temperature range (ΔT_A): 20°C				
Supply voltage change (ΔV+): 5V				
Common-mode voltage change (ΔCM): 0.1V				
ERROR SOURCE	**ERROR EQUATION**	**SAMPLE ERROR CALCULATION(1)**	**ERROR (ppm of Full Scale) UNADJ.**	**ADJUST.**
INPUT				
Input offset voltage	V_{OS} / ($V_{IN\ MAX}$) × 10^6	100 µV / (800 µA × 0.38 Ω/°C × 200°C) × 10^6	1645	0
vs common-mode	CMRR · ΔCM/($V_{IN\ MAX}$) × 10^6	50 µV/V × 0.1V / (800 µA × 0.38 Ω/°C × 200°C) × 10^6	82	82
Input bias current	I_B / I_{REF} × 10^6	0.025 µA / 800 µA × 10^6	31	0
Input offset current	I_{OS}× $R_{RTD\ MIN}$ / ($V_{IN\ MAX}$) × 10^6	3nA × 100 Ω / (800 µA × 0.38 Ω/°C × 200°C) × 10^6	5	0
		Total Input Error:	**1763**	**82**
EXCITATION				
Current reference accuracy	I_{REF} accuracy (%) / 100% × 10^6	0.2% / 100% × 10^6	2000	0
vs supply	(I_{REF} vs V+) × ΔV+	25ppm/V × 5V	125	125
Current reference matching	I_{REF} matching (%) / 100% × 800 µA × $R_{RTD\ MIN}$ / ($V_{IN\ MAX}$) × 10^6	0.1% / 100% × 800 µA × 100 Ω / (800 µA × 0.38 Ω/°C × 200°C) × 10^6	1316	0
vs supply	(I_{REF} matching vs V+) × ΔV+ × $R_{RTD\ MIN}$ / ($V_{IN\ MAX}$)	10ppm/V × 5V × 800 µA × 100 Ω / (800 µA × 0.38 Ω/°C × 200°C)	66	66
		Total Excitation Error:	**3507**	**191**
GAIN				
Span	Span error (%) / 100% × 10^6	0.2% / 100% × 10^6	2000	0
Nonlinearity	Nonlinearity (%) / 100% × 10^6	0.01% / 100% × 10^6	100	100
		Total Gain Error:	**2100**	**100**
OUTPUT				
Zero output	(I_{ZERO} – 4mA) / 16000 µA × 10^6	25 µA / 16000 µA × 10^6	1563	0
vs supply	(I_{ZERO} vs V+) × ΔV+ / 16000 µA × 10^6	0.2 µA/V × 5V / 16000 µA × 10^6	63	63
		Total Output Error:	**1626**	**63**
DRIFT (ΔT_A = 20°C)				
Input offset voltage	Drift × ΔT_A / ($V_{IN\ MAX}$) × 10^6	1.5 µV/°C × 20°C / (800 µA × 0.38 Ω/°C × 200°C) × 10^6	493	493
Input bias current (typical)	Drift × ΔT_A / 800 µA × 10^6	20pA/°C × 20°C / 800 µA × 10^6	0.5	0.5
Input offset current (typical)	Drift × ΔT_A × $R_{RTD\ MIN}$ / ($V_{IN\ MAX}$) × 10^6	5pA/°C × 20°C × 100W / (800 µA × 0.38 Ω/°C × 200°C) × 10^6	0.2	0.2
Current reference accuracy	Drift · ΔT_A	35ppm/°C × 20°C	700	700
Current reference matching	Drift × ΔT_A × 800 µA × $R_{RTD\ MIN}$ / ($V_{IN\ MAX}$)	15ppm/°C × 20°C × 800 µA × 100 Ω / (800 µA × 0.38 Ω/°C × 200°C)	395	395
Span	Drift × ΔT_A	25ppm/°C × 20°C	500	500
Zero output	Drift × ΔT_A / 16000 µA × 10^6	0.5 µA/°C × 20°C / 16000 µA × 10^6	626	626
		Total Drift Error:	**2715**	**2715**
NOISE (0.1Hz to 10Hz, typical)				
Input offset voltage	v_n / ($V_{IN\ MAX}$) × 10^6	0.6 µV / (800 µA × 0.38 Ω/°C × 200°C) × 10^6	10	10
Current reference	I_{REF} noise × $R_{RTD\ MIN}$ / ($V_{IN\ MAX}$) × 10^6	3nA × 100 Ω / (800 µA × 0.38 Ω/°C × 200°C) × 10^6	5	5
Zero output	I_{ZERO} noise / 16000 µA × 10^6	0.03 µA / 16000 µA × 10^6	2	2
		Total Noise Error:	**17**	**17**

表 7-2. Error Calculation（续）

SAMPLE ERROR CALCULATION				
RTD value at 4mA output ($R_{RTD\ MIN}$): 100 Ω				
RTD measurement range: 200°C				
Ambient temperature range (ΔT_A): 20°C				
Supply voltage change (ΔV+): 5V				
Common-mode voltage change (ΔCM): 0.1V				
ERROR SOURCE	ERROR EQUATION	SAMPLE ERROR CALCULATION(1)	ERROR (ppm of Full Scale)	
			UNADJ.	ADJUST.
		TOTAL ERROR:	11728 (1.17%)	3168 (0.32%)

(1) All errors are minimum and maximum, and referred to input, unless otherwise stated.

7.2 Typical Applications

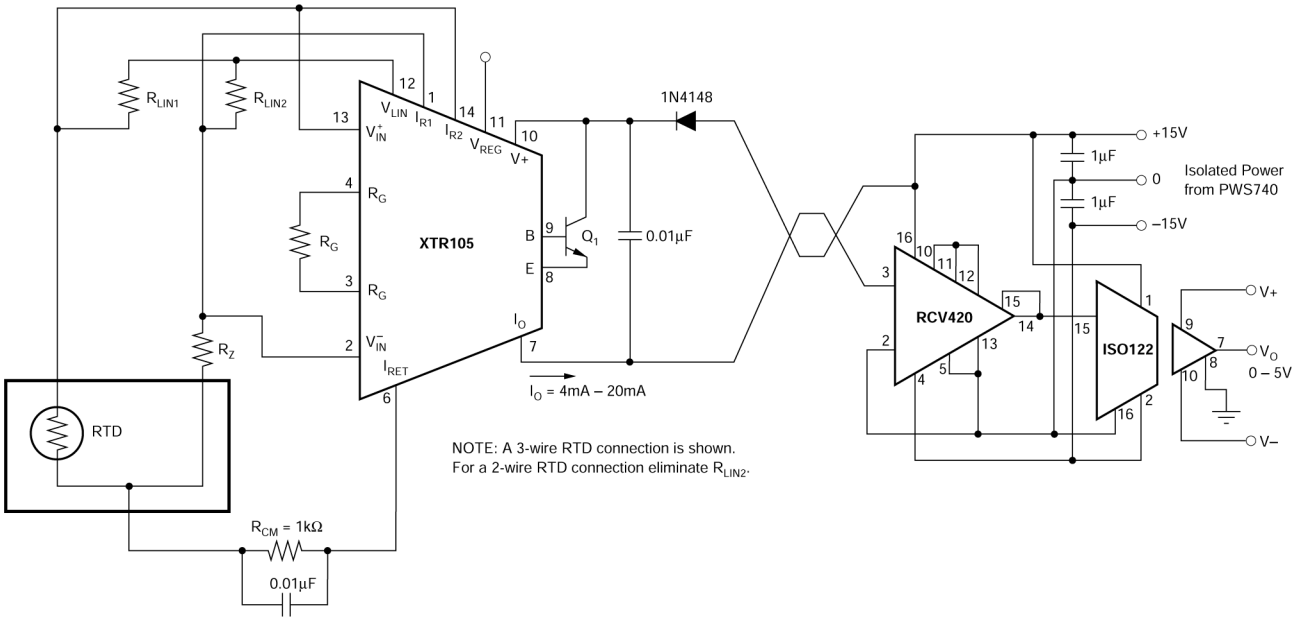


图 7-5. Isolated Transmitter-Receiver Loop

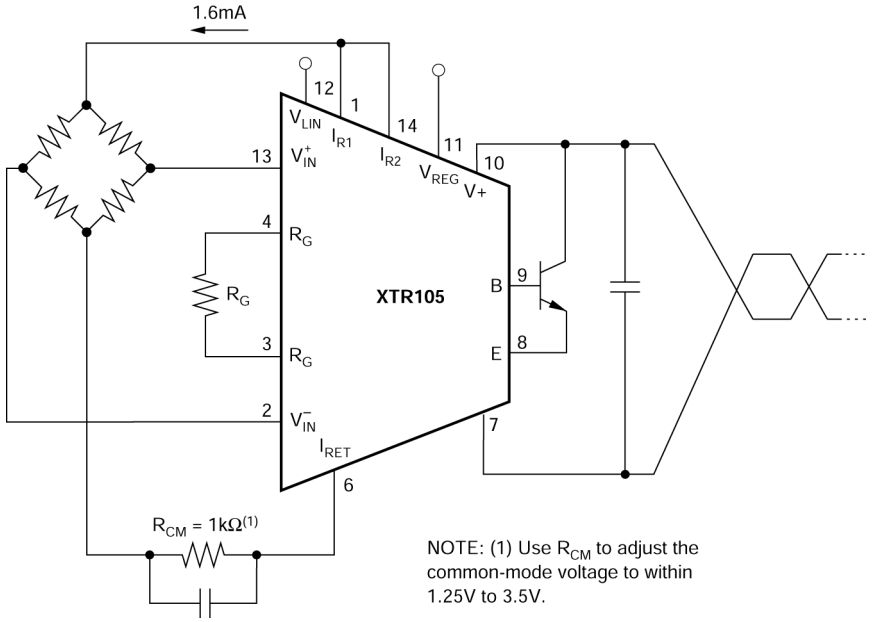


图 7-6. Bridge Input, Current Excitation

7.3 Layout

7.3.1 Layout Guidelines

The XTR105 is typically used with an external transistor (Q_1) to regulate the power dissipation of the 4-20mA loop. This allows the resulting localized self-heating to be distanced from the precision circuitry of the XTR105 and reduces over-temperature drift errors.

The XTR105 can be used without the Q_1 transistor if the application requirements do not lead to violation of the device *Absolute Maximum Requirements*, such as the maximum junction temperature. Calculate the peak power dissipation and multiply by thermal resistance to determine the associated junction temperature rise. Minimize overheat conditions for reliable long-term operation.

Place supply bypass capacitors close to the package and make connections with low-impedance conductors. Reduce trace lengths for R_G to minimize coupled environmental noise. If the loop power supply is electrically noisy, implement filtering using decoupling capacitors and small resistors or dampening inductors in series with V+.

8 Device and Documentation Support

TI offers an extensive line of development tools. Tools and software to evaluate the performance of the device, generate code, and develop solutions are listed below.

8.1 Documentation Support

8.1.1 Related Documentation

For related documentation see the following:

- Texas Instruments, *Special Function Amplifiers* Precision Labs video series on Current Loop Transmitters
- Texas Instruments, *Analog Linearized 3-Wire PT100 RTD to 2-Wire 4-20mA Current Loop Transmitter reference design* with XTR105
- Texas Instruments, *Analog Linearization of Resistance Temperature Detectors* technical article
- Texas Instruments, *A Basic Guide to RTD Measurements* application note

8.2 接收文档更新通知

要接收文档更新通知，请导航至 ti.com 上的器件产品文件夹。点击*通知* 进行注册，即可每周接收产品信息更改摘要。有关更改的详细信息，请查看任何已修订文档中包含的修订历史记录。

8.3 支持资源

TI E2E™ 中文支持论坛是工程师的重要参考资料，可直接从专家处获得快速、经过验证的解答和设计帮助。搜索现有解答或提出自己的问题，获得所需的快速设计帮助。

链接的内容由各个贡献者“按原样”提供。这些内容并不构成 TI 技术规范，并且不一定反映 TI 的观点；请参阅 TI 的使用条款。

8.4 Trademarks

TI E2E™ is a trademark of Texas Instruments.
所有商标均为其各自所有者的财产。

8.5 静电放电警告

静电放电 (ESD) 会损坏这个集成电路。德州仪器 (TI) 建议通过适当的预防措施处理所有集成电路。如果不遵守正确的处理和安装程序，可能会损坏集成电路。

ESD 的损坏小至导致微小的性能降级，大至整个器件故障。精密的集成电路可能更容易受到损坏，这是因为非常细微的参数更改都可能会导致器件与其发布的规格不相符。

8.6 术语表

TI 术语表　　本术语表列出并解释了术语、首字母缩略词和定义。

9 Revision History

注：以前版本的页码可能与当前版本的页码不同

Changes from Revision B (August 2004) to Revision C (October 2024)	Page
• 添加了 *引脚配置和功能*、*规格*、*ESD 等级*、*建议运行条件*、*热性能信息*、*详细说明*、*概述*、*功能方框图*、*特性说明*、*器件功能模式*、*应用和实现*、*典型应用*、*布局*、*布局指南*、*器件和文档支持* 和 *机械、封装和可订购信息* 部分	1
• 向 *应用* 部分添加了终端设备	1
• 更新了整个文档中的表格、图和交叉参考的编号格式	1
• Added *Pin Functions* table	3
• Moved operating and storage temperature parameters from *Electrical Characteristics* to *Absolute Maximum Ratings*	4
• Changed minimum operating temperature from −55°C to −40°C in *Absolute Maximum Ratings*	4

- Moved specified temperature and power-supply parameters from *Electrical Characteristics* to *Recommended Operating Conditions* 4
- Deleted thermal resistance, θ_{JA} parameters in *Electrical Characteristics* and replaced with detailed thermal model parameters in *Thermal Information* 4
- Updated formatting of *Electrical Characteristics* table....5
- Changed Voltage accuracy vs temperature typical specification from ±0.2mV/°C to ±0.5mV/°C in *Electrical Characteristics* 5
- Updated Figure 5-2, *Step Response* 7
- Updated Figure 5-8, *Zero Output and Reference Current Noise vs Frequency* 7
- Changed description of maximum loop-supply voltage to specified absolute maximum rating in *Surge Protection* 14
- Updated suggested Zener diode part numbers in Figure 6-4, *Reverse Voltage Operation and Overvoltage Surge Protection* 14
- Updated suggested transistor part numbers in Figure 7-1, *Basic 2-Wire RTD Temperature Measurement Circuit with Linearization* 15
- Moved *Adjusting Initial Errors* into *Error Analysis* section 20

10 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGING INFORMATION

Orderable part number	Status (1)	Material type (2)	Package | Pins	Package qty | Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
XTR105P	Active	Production	PDIP (N) | 14	25 | TUBE	Yes	Call TI	N/A for Pkg Type	-40 to 85	XTR105P A
XTR105P.A	Active	Production	PDIP (N) | 14	25 | TUBE	Yes	Call TI	N/A for Pkg Type	-40 to 85	XTR105P A
XTR105PA	Active	Production	PDIP (N) | 14	25 | TUBE	Yes	Call TI	N/A for Pkg Type	-40 to 85	XTR105P A
XTR105PA.A	Active	Production	PDIP (N) | 14	25 | TUBE	Yes	Call TI	N/A for Pkg Type	-40 to 85	XTR105P A
XTR105U	Obsolete	Production	SOIC (D) | 14	-	-	Call TI	Call TI	-40 to 85	XTR105U
XTR105UA	Obsolete	Production	SOIC (D) | 14	-	-	Call TI	Call TI	-40 to 85	XTR105U A
XTR105UA/2K5	Active	Production	SOIC (D) | 14	2500 | LARGE T&R	Yes	NIPDAU	Level-3-260C-168 HR	-40 to 85	(XTR105U, XTR105UA) A
XTR105UA/2K5.B	Active	Production	SOIC (D) | 14	2500 | LARGE T&R	Yes	NIPDAU	Level-3-260C-168 HR	-40 to 85	(XTR105U, XTR105UA) A

(1) **Status:** For more details on status, see our product life cycle.

(2) **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) **RoHS values:** Yes, No, RoHS Exempt. See the TI RoHS Statement for additional information and value definition.

(4) **Lead finish/Ball material:** Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

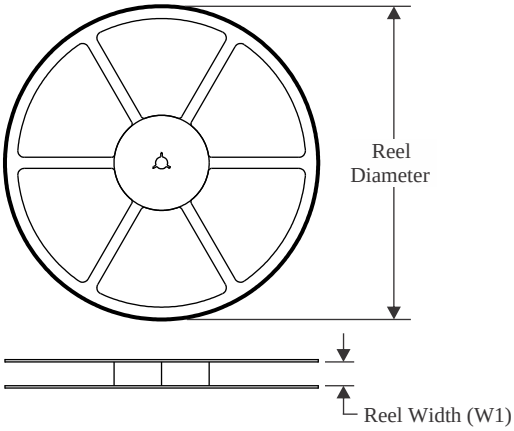
(5) **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

(6) **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

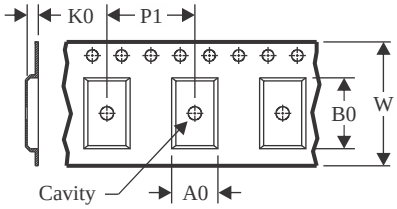
Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

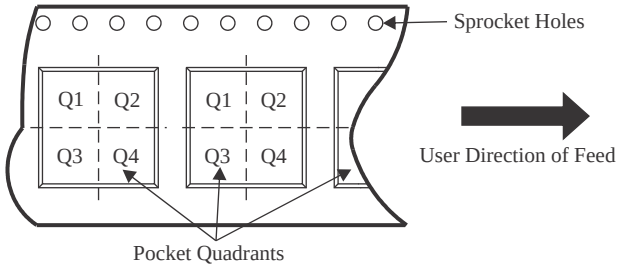


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

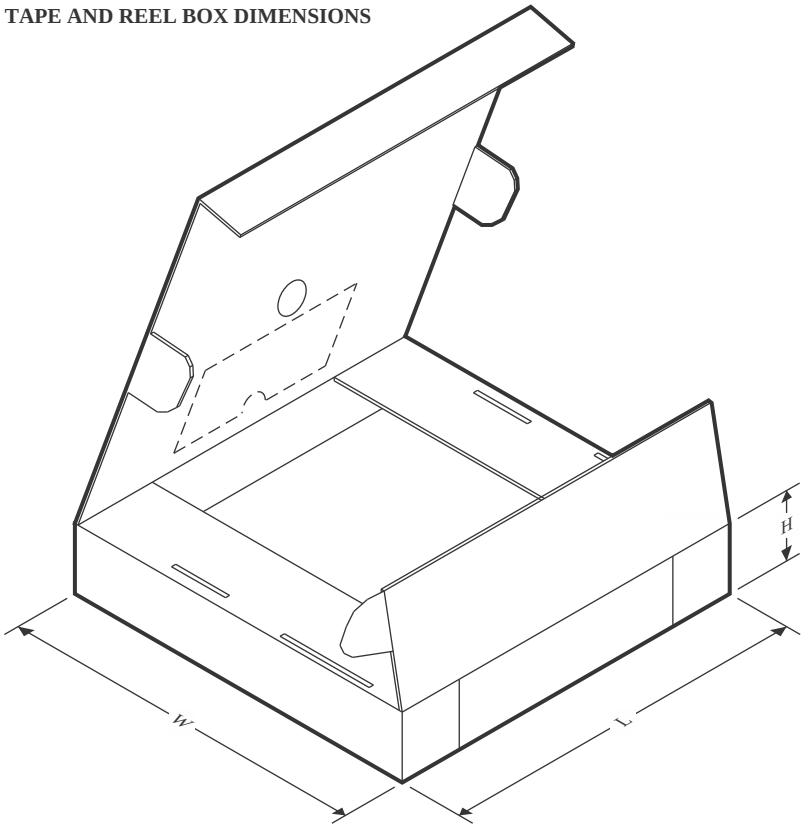
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
XTR105UA/2K5	SOIC	D	14	2500	330.0	16.4	6.5	9.0	2.1	8.0	16.0	Q1

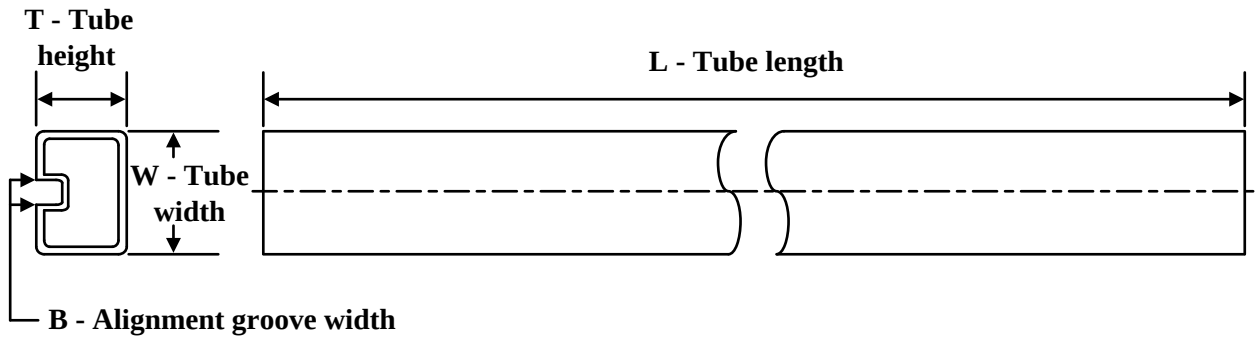
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

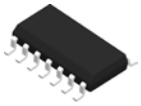
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
XTR105UA/2K5	SOIC	D	14	2500	353.0	353.0	32.0

TUBE



*All dimensions are nominal

Device	Package Name	Package Type	Pins	SPQ	L (mm)	W (mm)	T (µm)	B (mm)
XTR105P	N	PDIP	14	25	506	13.97	11230	4.32
XTR105P.A	N	PDIP	14	25	506	13.97	11230	4.32
XTR105PA	N	PDIP	14	25	506	13.97	11230	4.32
XTR105PA.A	N	PDIP	14	25	506	13.97	11230	4.32

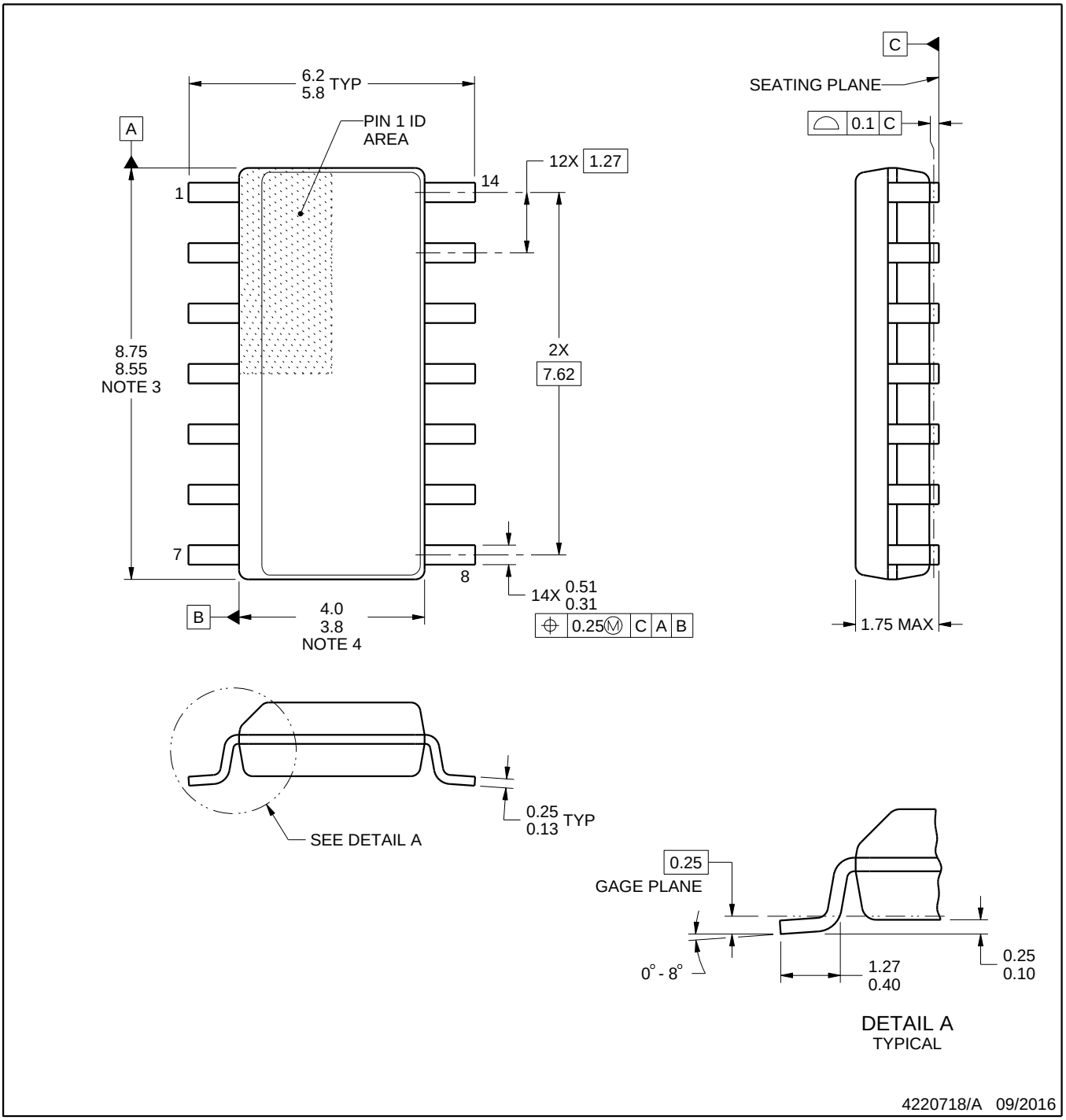


PACKAGE OUTLINE

D0014A

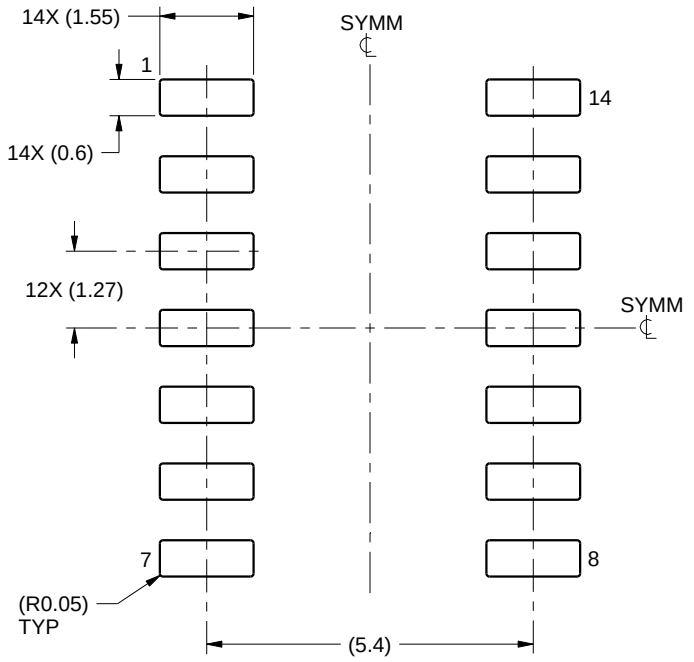
SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT

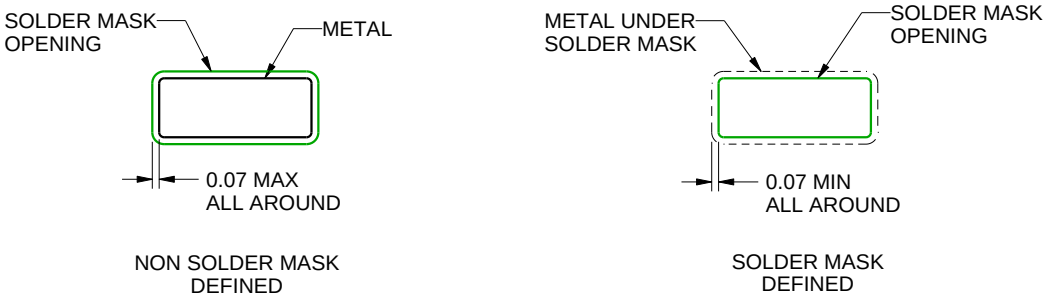


NOTES:

1. All linear dimensions are in millimeters. Dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm, per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.43 mm, per side.
5. Reference JEDEC registration MS-012, variation AB.



LAND PATTERN EXAMPLE
SCALE:8X



SOLDER MASK DETAILS

4220718/A 09/2016

NOTES: (continued)

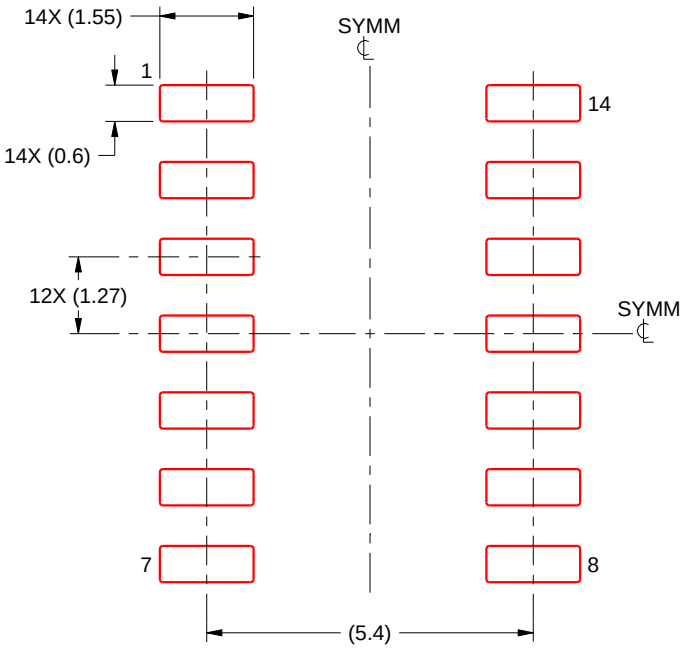
6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

EXAMPLE STENCIL DESIGN

D0014A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL
SCALE:8X

4220718/A 09/2016

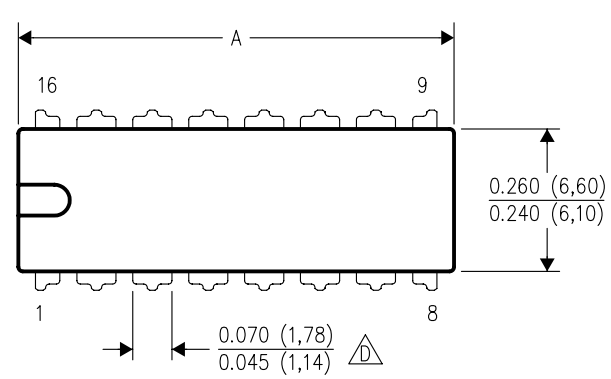
NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

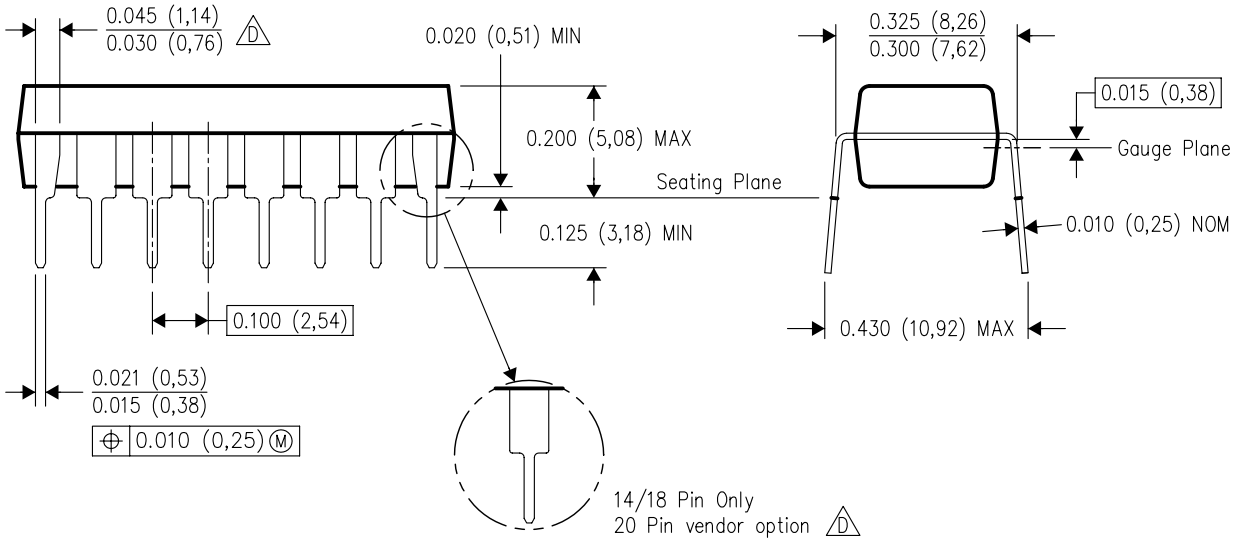
N (R–PDIP–T**)

PLASTIC DUAL–IN–LINE PACKAGE

16 PINS SHOWN



DIM \ PINS **	14	16	18	20
A MAX	0.775 (19,69)	0.775 (19,69)	0.920 (23,37)	1.060 (26,92)
A MIN	0.745 (18,92)	0.745 (18,92)	0.850 (21,59)	0.940 (23,88)
MS–001 VARIATION (C)	AA	BB	AC	AD



4040049/E 12/2002

NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Falls within JEDEC MS–001, except 18 and 20 pin minimum body length (Dim A).
D. The 20 pin end lead shoulder width is a vendor option, either half or full width.

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