

## Simplified Thermocouple Interface For Hot Only Or Cold Only Measurement With Linearization Circuit

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### ABSTRACT:

This paper presents the simplified thermocouple interface with linearization circuit. Thermocouples are widely used temperature sensors because of their ruggedness and broad temperature range. Two dissimilar metals are used in the Seebeck-effect temperature-to-emf junction with transfer relationships. The widespread use of microelectronics and computers is having a profound effect on the design of sensor systems. Signal processing functions increasingly are being integrated within sensors, and digital-type sensors directly compatible with computer inputs are emerging. Here in this paper a novel linearization technique is applied to the j type thermocouple for a better linearized out put.

**KEYWORDS:-**Thermocouples; microelectronics; linearization techniques; gain, scaling; seebeck-effect; slope; intercept.

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### 1. INTRODUCTION:

Modern technology leans heavily on the science of measurement. The control of industrial processes and automated systems would be very difficult without accurate sensor measurements. The widespread use of microelectronics and computers is having a profound effect on the design of sensor systems. Signal processing functions increasingly are being integrated within sensors, and digital-type

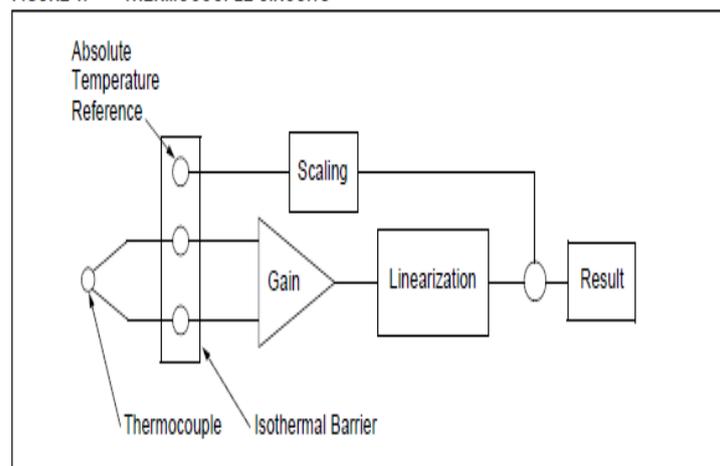
sensors directly compatible with computer inputs are emerging. Nevertheless, measurement is an inexact science requiring the use of reference standards and an understanding of the energy translations involved more directly as the need for accuracy increases. This paper presents the simplified thermocouple interface with linearization circuit. Thermocouples are widely used temperature sensors because of their ruggedness and broad temperature range. Two dissimilar metals are used in the Seebeck-effect temperature-to-emf junction with transfer relationships

Thermocouples are the simplest form of temperature sensors. Thermocouples are normally:

- Very inexpensive
- Easily manufactured
- Effective over a wide range of temperatures

All thermocouple systems share the basic characteristic components shown in Figure 1.

FIGURE 1: THERMOCOUPLE CIRCUITS



The thermocouple must pass through an isothermal barrier so the absolute temperature of the cold junction can be determined. Ideally, the amplifier should be placed as close as possible to this barrier so there is no drop in temperature across the traces that connect the thermocouple to the amplifier. The amplifier should have enough gain to cover the required temperature range of the

thermocouple. When the thermocouple will be measuring colder temperatures than ambient temperatures, there are three options:

1. Use an Op Amp that operates below the negative supply.
2. Bias the thermocouple to operate within the Op Amp's supply.
3. Provide a negative supply.

Some thermocouples are electrically connected to the device they are measuring. When this is the case, make sure that the voltage of the device is within the Common mode range of the Op Amp. The most common case is found in thermocouples that are grounded. In this case, option 2 is not appropriate because it will force a short circuit across the thermocouple to ground.

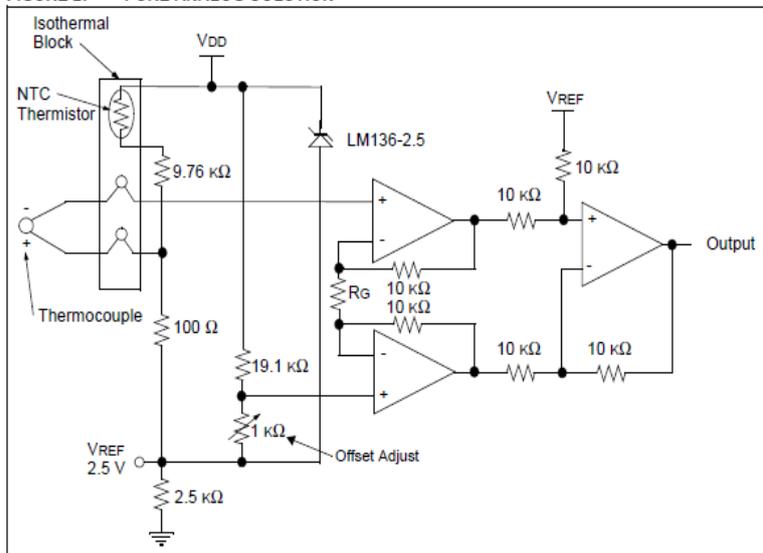
### 1.1 ABSOLUTE TEMPERATURE SCALING

Thermocouples are relative measuring devices. In other words, they measure the temperature difference between two thermal regions. Some applications are only interested in this thermal difference, but most applications require the absolute temperature of the device under test. The absolute temperature can be easily found by adding the thermocouple temperature to the absolute temperature of one end of the thermocouple. This can be done at any point in the thermocouple circuit. Figure 1 shows the scaling occurring after the linearization.

### 2. PURE ANALOG CIRCUIT

A pure analog solution to measuring temperatures with a thermocouple is shown in Figure 2. In the analog solution, the thermocouple is biased up 2.5V. This allows the thermocouple to be used to measure temperatures hotter and colder than the isothermal block.

FIGURE 2: PURE ANALOG SOLUTION



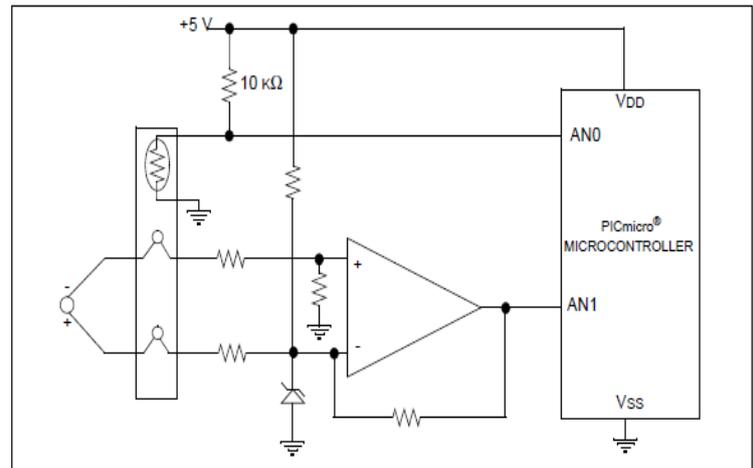
This implementation cannot be used with a grounded thermocouple. The bias network that biases the thermocouple to 2.5V contains a thermistor. The thermistor adjusts the bias voltage making the thermocouple voltage track the absolute voltage. Both the thermistor and the thermocouple are non-linear devices, so a linearization system would have to be created that takes both curves into account.

### 3. SIMPLIFIED DIGITAL CIRCUIT

Most analog problems can be converted to a digital problem and thermocouples are no exception. If an analog-to-digital converter (ADC) were placed at the end of the analog solution shown in Figure 2, the result would be a simple digital thermometer (at least the software would be simple). However, the analog/linear circuitry could be made less expensive to build and calibrate by adding a microcontroller.

As you can see, the circuit got a lot simpler (see Figure3). This system still uses a thermistor for the absolute temperature reference, but the thermistor does not affect the thermocouple circuit. This makes the thermocouple circuit much simpler.

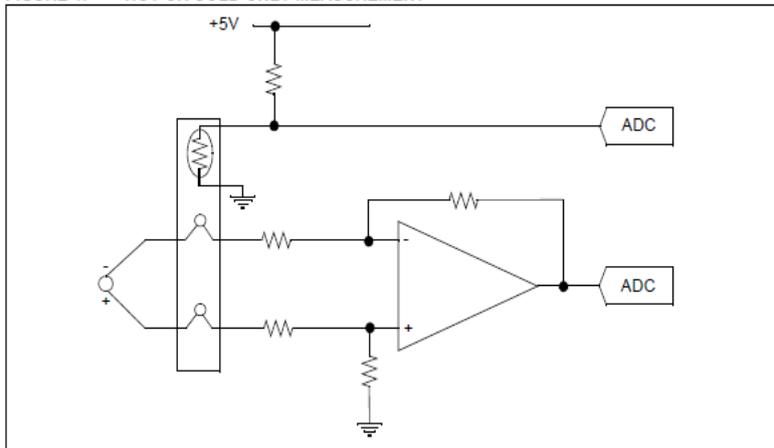
FIGURE 3: SIMPLIFIED DIGITAL CIRCUIT



### 4. HOT ONLY OR COLD ONLY MEASUREMENT

If the application can only measure hot or cold objects, the circuit gets even simpler (see Figure 4). If only one direction is going to be used in an application, a simple difference amplifier can be used. The minimum temperature that can be measured depends on the quality of the Op Amp. If a good single supply, rail-rail Op Amp is used, the input voltage can approach 0V and temperature differences of nearly 0 degrees can be measured. To switch from hot to cold measurement, the polarity of the thermocouple wires could be switched.

FIGURE 4: HOT OR COLD ONLY MEASUREMENT



#### 4.1 FAULT DETECTION

When thermocouples are used in automotive or aerospace applications, some sort of FAULT detection is required since a life may be depending on the correct performance of the thermocouple. Thermocouples have a few possible failure modes that must be considered when the design is developed:

1. Thermocouple wire is brittle and easily broken in high vibration environments.
2. A short circuit in a thermocouple wire looks like a new thermocouple and will report the temperature of the short.
3. A short to power or ground can saturate the high gain amplifiers and cause an erroneous hot or cold reading.

#### 5. LINEARIZATION

Linearization is the task of conversion that produces a linear output, or result, corresponding to a linear change in the input. Thermocouples are not inherently linear devices, but there are two cases when linearity can be assumed:

1. When the active range is very small.
2. When the required accuracy is low.

Pilot lights in water heaters for example, are typically monitored by thermocouples. No special electronics is required for this application, because the only accuracy required is the ability to detect a 600 degree increase in temperature when the fire is lit. A fever thermometer on the other hand, is an application where the active range is very small (90° F - 105° F). If the temperature gets higher than the effective range, either the thermometer is not being used correctly, or the patient needs to be in the hospital.

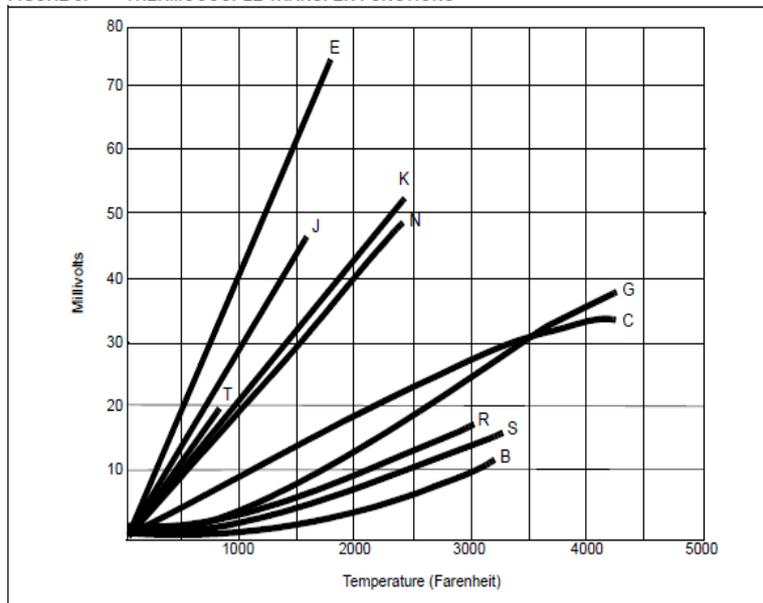
There are many ways to linearize the thermocouple results. Figure 1 shows linearization following the gain stage. Sometimes, the linearization follows the addition of the absolute temperature reference. No matter where it occurs, or

to what degree, linearization is critical to the application.

#### 5.1 LINEARIZATION TECHNIQUES

Thermocouple applications must convert the voltage output from a thermocouple into the temperature across the thermocouple. This voltage response is not linear and it is not the same for each type of thermocouple. Figure 5 shows a rough approximation of the family of thermocouple transfer functions.

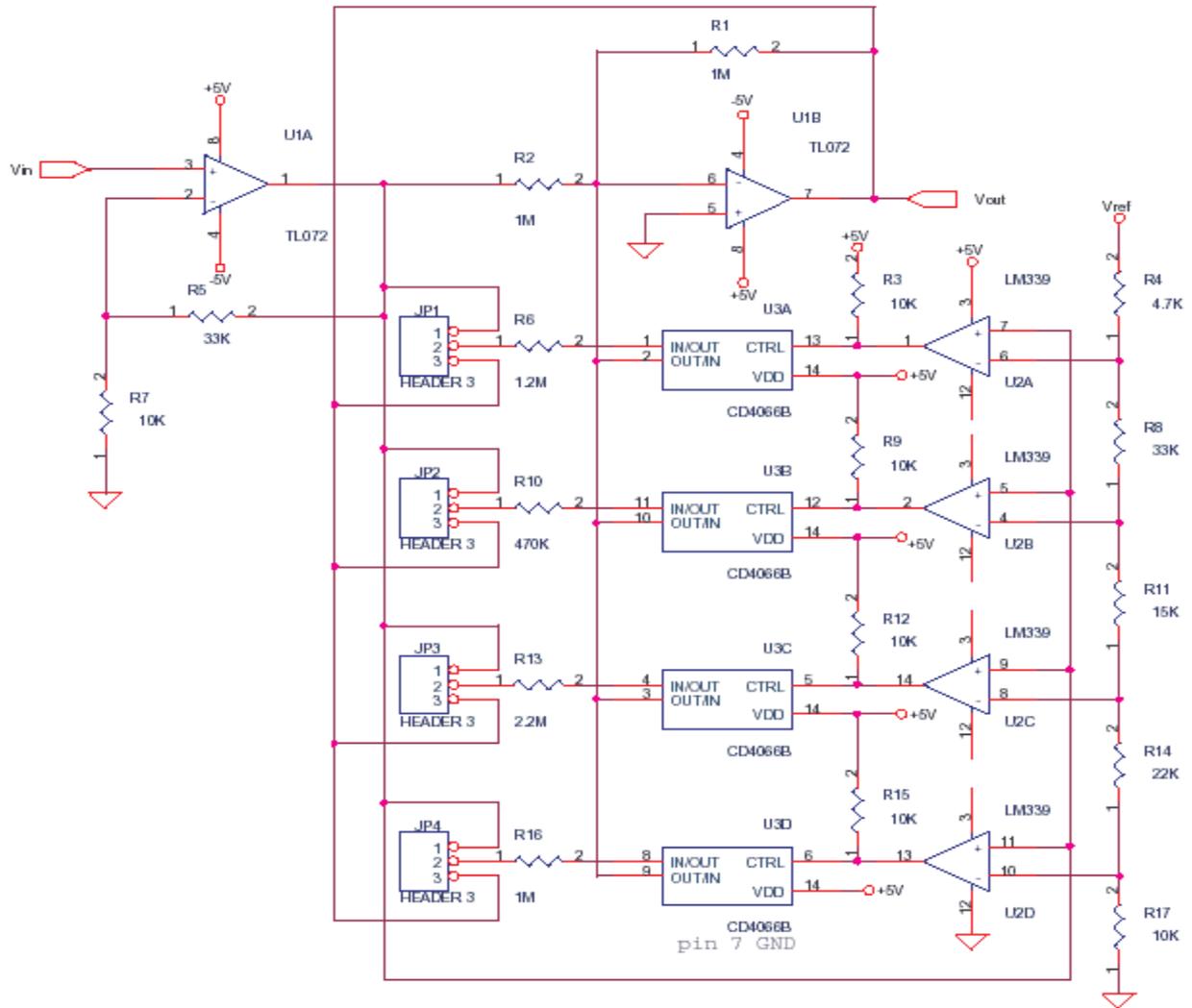
FIGURE 5: THERMOCOUPLE TRANSFER FUNCTIONS



#### 5.2 LINEAR APPROXIMATION

The simplest method of converting the thermocouple voltage to a temperature is by linear approximation. This is simply picking a line that best approximates the voltage-temperature curve for the appropriate temperature range. For some thermocouples, this range is quite large. For others, this is very small. The range can be extended if the accuracy requirement is low. J and K thermocouples can be linearly approximated over their positive temperature range with a 30 degree error. For many applications this is acceptable, but to achieve a better response other techniques are required.

This circuit changes the gain of op-amp U1B in four steps or segments. It can be used to get a linear output from most transducers to 1% levels. U1A is a amplifying buffer use it to boost the signal to the required level. The resistor values are for an imaginary transducer, the buffered input signal is compared to reference switching points by LM339. LM339 changes the gain resistors of U1B thru the mux switch 4066. JP1 to JP4 can select either amplification or attenuation of signal.



The resistor switched by 4066 can be across R1 or R2 based on JP1 to JP4. You may have to input transducer values into a spreadsheet and draw a graph. Then divide the graph into 5 segments and deduce the switch points and gain.

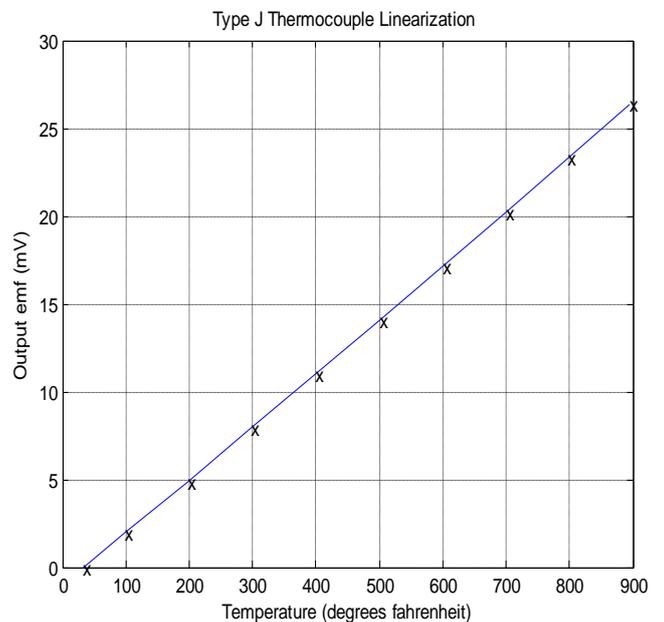
### 6. RESULTS OF THE J THERMOCOUPLE (WITH OUT LINEARIZATION)

Type J Thermocouple

SL.NO	Y °F	X mV
1	32	0.000
2	100	1.942
3	200	4.907
4	300	7.949
5	400	11.025
6	500	14.110
7	600	17.188
8	700	20.255
9	800	23.320
10	900	26.400

Y: true temperature ; X: thermocouple signal ;

Graphical representation of the J type thermocouple (with out linearization)



**6.1 RESULTS OF THE J THERMOCOUPLE (WITH LINEARIZATION)**

Type J Thermocouple linearization:

SLNO	Y °F	X mV	y °F	€% FS
1	32	0	32.0	0
2	100	1.942	97.6	-2.4
3	200	4.906	197.1	-1.45
4	300	7.947	298.3	-0.56
5	400	11.023	400.0	0
6	500	14.108	501.0	0.2
7	600	17.186	601.0	0.17
8	700	20.253	699.9	0
9	800	23.317	797.1	-0.36
10	900	26.369	895.3	-0.56

Where,

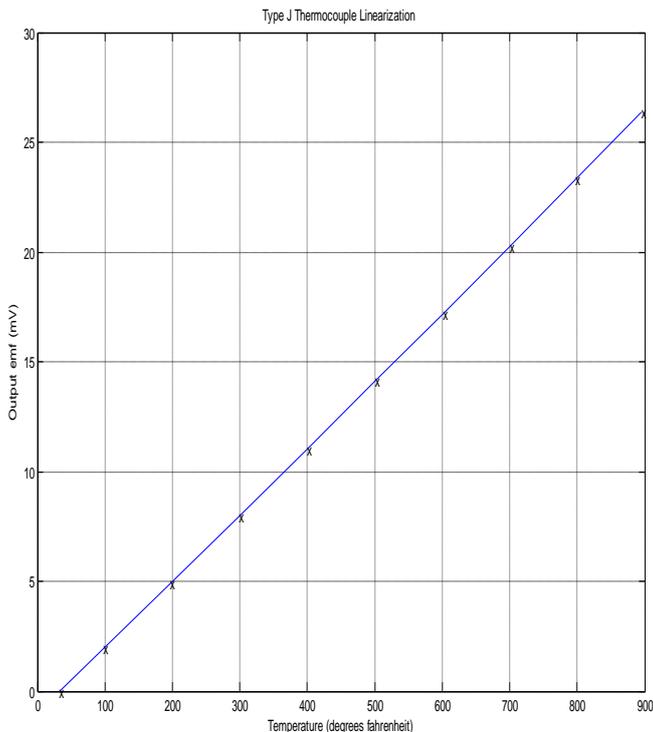
Y: true temperature ; X: thermocouple signal  
 ; y: linearized temperature

Slope: 35.71°F/mV

Intercept: 32°F

y = slope • X + intercept - slope • f(X)

Graphical representation of the linearized output of the J type thermocouple



**7. CONCLUSION:**

A Type-J thermocouple is linearized to a straight-line response over a 100°F to 1,000°F range by the Quadratic linearization function AX + BX<sup>2</sup>. Trial coefficients are solved at one third and two-

thirds of full scale with the (0.028 mV/T)<sup>1</sup> thermocouple output signal slope and 32°F intercept. Solution of the identity of equation provides the linearized output temperature whose values are tabulated in Table. A figure without linearization and with linearization describes the linearized thermocouple characteristic. The reader should compare these results to linearization choices of 200°F and 600°F. Thus the above paper has solved the problem of j type thermocouple linearization.

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