

Temperature Sensor Circuit Provides Dual-Slope Output

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CIRCLE 520

The excellent linearity of integrated-circuit temperature sensors makes them ideal for direct analog compensation of the thermally induced errors inherent in many circuits. For example, a negative-sloped temperature sensor could compensate for an increase in amplifier bias current resulting from a rise in temperature.

Some circuits, however, exhibit a positive temperature coefficient in one temperature range and negative coefficient in another. One example is the frequency drift of XT-cut crystals, which have a parabolic curve with the center frequency typically specified at 25 °C. The dual-slope temperature sensor circuit in Figure 1 combines one negative-sloped and one positive-sloped temperature sensor to create a V-shaped output, which can be used to compensate for a dual-temperature-coefficient thermal response.

The transfer function of the LM19 (IC1) can be closely approximated at room temperature as a straight line with the equation:

$$V_{OUT19} = -\left(0.0117 \frac{V}{^{\circ}C}\right)T + 1.87V \quad (1)$$

where T is temperature in °C. The transfer function of the LM61 (IC2) is a straight line with the equation:

$$V_{OUT61} = \left(0.010 \frac{V}{^{\circ}C}\right)T + 0.60V \quad (2)$$

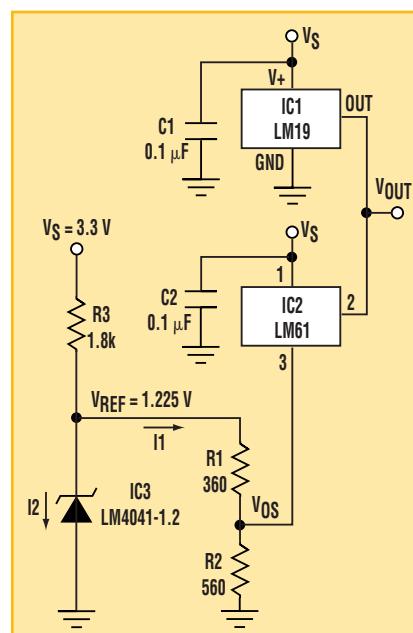
The two lines are plotted in Figure 2, which shows that the temperature of intersection (T_{INT}) is 58.55 °C. Since the LM19 and LM61 essentially do not

sink current (less than 10 μA), V_{OUT} will be equal to whichever device has the higher output voltage. This results in a V-shaped output curve with a minimum at T_{INT} .

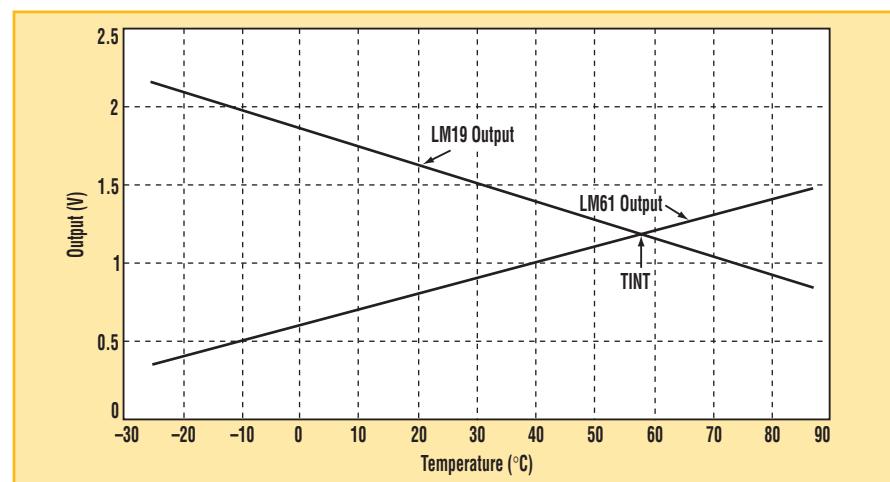
To use this circuit to compensate for a dual-temperature-coefficient circuit, it is desirable to have the minimum of the V-shaped curve occur at the same temperature as the maximum of the thermal response being compensated. To reduce T_{INT} to the desired temperature (e.g., 25 °C), an additional offset voltage V_{OS} is added to the LM61 via the R1-R2 voltage divider, giving a new equation for the LM61 output:

$$V_{OUT61} = \left(0.010 \frac{V}{^{\circ}C}\right)T + 0.60V + V_{OS} \quad (3)$$

V_{OS} is calculated by setting equations 1 and 3 equal to each other and substituting the desired T_{INT} for T. For a T_{INT} of 25 °C, the value of V_{OS} is 0.728 V.



1. This dual-slope temperature sensor circuit can help compensate for the frequency drift of XT-cut crystals.



2. The outputs of two individual temperature sensors are superimposed to create an overall response that allows compensation for both negative and positive temperature coefficients.

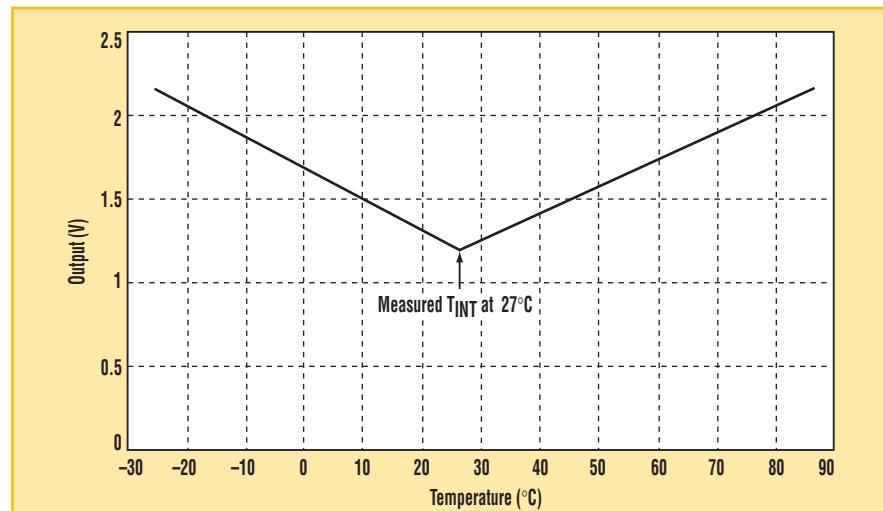
The values of R1 and R2 must therefore be selected such that

$$\frac{R_2}{(R_1 + R_2)} = \frac{V_{OS}}{V_{REF}} = \frac{0.728}{1.225} = 0.594 \quad (4)$$

I_1 is determined by R_1 and R_2 , and it should be set to significantly more than the quiescent current through the LM61 (125 μ A max) in order to reduce errors caused by this quiescent current passing through R_2 . Choosing I_1 to be 10 times greater than the quiescent current gives the condition:

$$\frac{1.225V}{(R_1 + R_2)} \geq 1.25mA \quad (5)$$

Solving the two equations 4 and 5 for the two variables R1 and R2 results in the values $R1 = 398 \Omega$ and $R2 = 582 \Omega$. The circuit in Figure 1 uses the standard resistor values of 360Ω and 560Ω to satisfy Equation 5 and gives a



3. The measured V_{OUT} demonstrates the V-shaped curve used to approximate the actual parabolic curve of XT crystals.

ratio of 0.636, very close to that of Equation 4.

Finally, R3 was selected so that I2 is within the operating range of the LM4041 voltage reference.

Figure 3 shows the output of the

dual-slope temperature sensor circuit, measured over a temperature range of -25°C to 85°C . The average error over the full temperature range was 25.4 mV (approximately 2.5°C), and the maximum error was 46.4 mV (4.6°C). 

Excel Formula Calculates Standard 1%-Resistor Values

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CIRCLE 521

The Excel cell formula below calculates the nearest standard 1% resistor value without using a lookup table or macro. Type or electronically paste the text below into any cell (other than A1). The formula will calculate the nearest 1%-resistor for the value in cell A1. This formula can be copied and replicated to other cells just like any standard Excel cell formula.

A properly constructed spreadsheet used to calculate standard circuit values can produce more accurate designs. When calculating interdependent component values, standard resistor values can be used to calculate subsequent component values. This approach avoids a buildup of tolerance errors. Also, it will sometimes yield a more accurate design than if "perfect" calculated values are converted to nearest standard 1% values following the completion of all other calculations.

Mantissas of the 96-value-per-decade sequence are derived by

$r \equiv 10^{j/96}$ where $j \equiv 0, 1, 2 \dots 96$

Each mantissa is then rounded to three significant digits, which creates small deviations from perfectly spaced values. The Excel formula calculates the two nearest standard values and tests them with the desired resistor value to select the closer.

```
=IF(A1>(INT(0.5+100*POWER(10,I
F(96*(LOG(A1)-INT(LOG(A1)))-
ROUND(96*(LOG(A1)-
INT(LOG(A1))),0)<0,
ROUND(96*(LOG(A1)-
INT(LOG(A1))),0)-1,
ROUND(96*(LOG(A1)-
INT(LOG(A1))),0))/96)) * *
POWER(10,INT(LOG(A1))-2) +
INT(0.5+100*POWER(10,(IF(96*(LO
G(A1)-INT(LOG(A1)))-
ROUND(96*(LOG(A1)-
INT(LOG(A1))),0)<0,
ROUND(96*(LOG(A1)-
INT(LOG(A1))),0)-1,
```

```

ROUND(96*(LOG(A1)-
INT(LOG(A1))),0))+1)/96))      *
POWER(10,INT(LOG(A1))-2))/2,
INT(0.5+100*POWER(10,(IF(96*(LO
G(A1)-INT(LOG(A1)))-
ROUND(96*(LOG(A1)-
INT(LOG(A1))),0)<0,
ROUND(96*(LOG(A1)-
INT(LOG(A1))),0)-1,
ROUND(96*(LOG(A1)-
INT(LOG(A1))),0))+1)/96))      *
POWER(10,INT(LOG(A1))-2),INT(0.5+100*POWER(10,IF(96*(L
OG(A1)-INT(LOG(A1))))-
ROUND(96*(LOG(A1)-
INT(LOG(A1))),0)<0,
ROUND(96*(LOG(A1)-
INT(LOG(A1))),0)-1,
ROUND(96*(LOG(A1)-
INT(LOG(A1))),0))/96))      *
POWER(10,INT(LOG(A1))-2))

```

Note: Type this formula into the spreadsheet cell as a continuous entry without carriage returns.

Wideband Filter Only Has Two Different Components

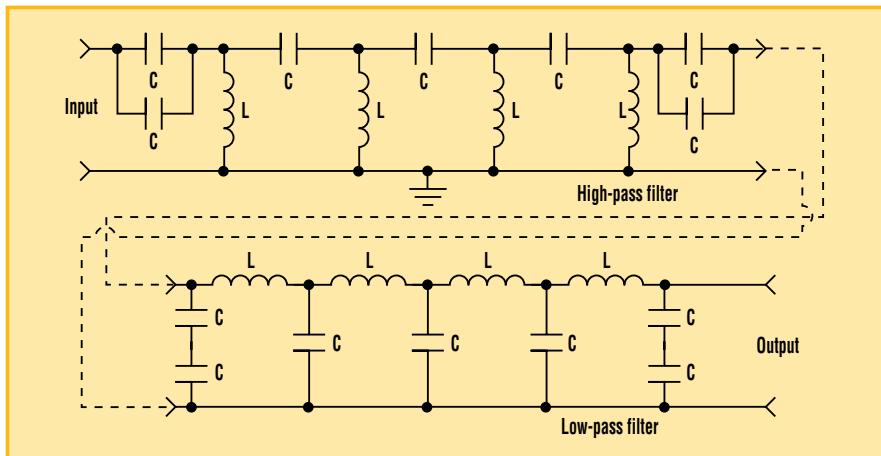
Richard M. Kurzrok

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CIRCLE 522

Wideband filters with bandwidths in excess of an octave can be created by cascading a high-pass filter and a low-pass filter. In this design idea, nine-pole high-pass and low-pass filters have been constructed using a modified equal-element design. A new, low-cost wideband filter has been created using a minimum number of different components.

The new wideband filter is realized using a high-pass filter with 3-dB cut-offs of 3.56 MHz. The high-pass filter is followed by a low-pass filter with 3-dB cutoffs of 12.88 MHz. Both of these filters have a design reference frequency of 6.77 MHz. The wideband



Judicious use of parallel and series combinations allows this filter to use only one value of capacitance and one value of inductance.

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filter uses only a single value of capacitance and a single value of inductance (*see the figure*).

This is achieved by judicious use of series and parallel combinations. While all filter capacitors have a value of $470\text{ pF} \pm 5\%$, all inductors feature a value of $1.175\text{ }\mu\text{H}$. The inductors are formed using 15 turns of #26 magnet wire on a Micro Metals T37-2 toroid. The high-pass and low-pass filters are designed for $50\text{-}\Omega$ impedance. Type BNC connectors are used at the inputs and outputs. The two filters

are interconnected using a male-male BNC adapter.

The measured amplitude response data for the wideband filter is shown in the table. The modified, low-pass, equal-element filter features reasonably good responses below the design reference frequency. By using a common design reference frequency for both filters, the pass-band regions with non-optimal responses are staggered in frequency. This avoids excessive interactions between the two filters.

FILTER RESPONSE			
Frequency (MHz)	Insertion loss (dB)	Frequency (MHz)	Insertion loss (dB)
2.8	39.6	10.0	0.4
3.1	26.6	10.5	0.7
3.4	17.2	11.0	1.4
3.6	5.1	12.0	1.8
4.0	3.0	12.5	1.0
4.5	0.8	12.7	2.0
5.0	0.2	12.9	4.0
6.0	0.2	13.5	12.2
7.0	0.5	14.0	18.6
8.0	0.4	15.0	29.4
9.0	0.7	17.0	>45.0

With modified equal-element units, the wideband filter provides design simplicity that reduces manufacturing costs. Wideband-filter-response shapes are not optimal. They may suit situations where cost reduction is necessary and filter-response

shape specifications are not too stringent. This design methodology can be extended readily to eleven-pole and thirteen-pole filters. □

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