Integrated instrumentation amplifier with an output stage for the amplification of differential signals and with an internal current source for the supply of external signal sources. The output signal is a voltage between 0.5 and 4.5V, ratiometrical to the supply voltage. The output span could be adjusted by the changeable gain of the output stage.

\[ V_{cc} = 5V \pm 5\% \]

\[ V_{out} = 0.5\ldots4.5V \quad \text{ratiometric} \]

\[ I_{IR} = 1mA \]

### TYPICAL APPLICATIONS

- Amplification of resistor bridge signals
- Voltage measurement e.g. temperature sensors
- Current measurement via Shunt resistors
- Amplification circuitry for sensing elements e.g. silicon pressure sensing elements
- Differential input circuit for microprocessors/ADC-applications
- Automotive bridge signal conditioning
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FEATURES

- Instrumentation amplifier input for positive input voltages: 0...200mV
- Adjustable gain
- Common mode input range (CMIR): 1.3...VCC - 2.2V
- Output voltage ratiometric to the supply: 0.5...4.5V
- Low offset
- Low offset drift
- Supply voltage range: 5V ± 5% (ratiometric range)
- Wide operating temperature range: -40°C...+125°C
- Ratiometric current source for the supply of external measuring cells
- Output driver (PNP open collector): IOUT = +11mA
- No limited resolution
- Output current limitation
- Low internal noise
- Integrated EMC protection
- Small SO8 package
- Low cost

DESCRIPTION

AM417 is a low-cost ratiometric interface IC which has been specifically designed for the conditioning of differential signals. The IC is particularly suitable for the signal evaluation of sensor elements which have to be powered by an internal current source (OP). These include piezoresistive and magnetoresistive silicon measuring cells and temperature sensing elements based on a resistor setup. In essence AM417 consists of a precision instrumentation amplifier, a ratiometric operational amplifier and a protected voltage output which has been configured as a driver stage. The amplifier can be adjusted across a wide range using two external resistors and the offset of an additional resistor affixed to the measuring bridge.

Precision amplifier AM417 has been engineered in such a way that it can be used as an instrumentation amplifier for follow-on processors or A/D converters to make optimum use of the converter range.

BLOCK DIAGRAM

![Block diagram of AM417](image)

Figure 1: Block diagram of AM417.
ELECTRICAL SPECIFICATIONS

\( T_{\text{amb}} = 25^\circ \text{C}, \ V_{\text{CC}} = 5\text{V} \) (unless otherwise stated). Currents flowing into the IC are negative.

Symbols in the table refer to Figure 1 and Figure 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage Range</td>
<td>( V_{\text{CC}} )</td>
<td>Ratiometric range</td>
<td>4.75</td>
<td>5</td>
<td>5.25</td>
<td>V</td>
</tr>
<tr>
<td>Maximum Supply Voltage</td>
<td>( V_{\text{CCmax}} )</td>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td>V</td>
</tr>
<tr>
<td>Quiescent Current</td>
<td>( I_{\text{CC}} )</td>
<td>( V_{\text{CC}} = 5\text{V}, R_1 = 500\Omega, I_{\text{IP}} = 1\text{mA} )</td>
<td></td>
<td></td>
<td>7.6</td>
<td>mA</td>
</tr>
</tbody>
</table>

Temperature Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating temperature</td>
<td>( T_{\text{op}} )</td>
<td></td>
<td>-40</td>
<td>125</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Storage temperature</td>
<td>( T_a )</td>
<td></td>
<td>-55</td>
<td>125</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Junction temperature</td>
<td>( T_J )</td>
<td></td>
<td></td>
<td>150</td>
<td>°C</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage</td>
<td>( V_{\text{IN}} )</td>
<td>Ratiometric with ( V_{\text{CC}} = 5\text{V} )</td>
<td>0.5</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Input current</td>
<td>( I_{\text{IN}} )</td>
<td></td>
<td>100</td>
<td></td>
<td>nA</td>
<td></td>
</tr>
<tr>
<td>Output Current Range</td>
<td>( I_{\text{OA}} )</td>
<td></td>
<td>0.50</td>
<td>1.25</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td>Output Current accuracy</td>
<td>( I_{\text{OA}} )</td>
<td>Ratiometric with ( V_{\text{CC}} = 5\text{V}, R_1 = 500\Omega )</td>
<td>0.98</td>
<td>1</td>
<td>1.02</td>
<td>mA</td>
</tr>
<tr>
<td>Ratiometric Error</td>
<td>( \text{RAT} @IB )</td>
<td>( \text{RAT} @IB = 1.05 V_{\text{IN}} (V_{\text{CC}} = 5\text{V}) )</td>
<td>-1</td>
<td></td>
<td>1</td>
<td>mV</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Voltage Range</td>
<td>( V_{\text{IB}} )</td>
<td>( I_{\text{IB}} = 1.25\text{mA} )</td>
<td>2.0</td>
<td></td>
<td>( V_{\text{CC}} - 0.2\text{V} )</td>
<td>V</td>
</tr>
<tr>
<td>Output Resistance</td>
<td>( R_{\text{IB}} )</td>
<td>( R_{\text{IB}} = V_{\text{IB}}/I_{\text{IB}}, V_{\text{IB}} = 2\text{V}, \Delta V_{\text{IB}} = 2.8\text{V} )</td>
<td>1.5</td>
<td></td>
<td>30</td>
<td>MΩ</td>
</tr>
</tbody>
</table>

Instrumentation Amplifier

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common Mode Input Voltage Range</td>
<td>( CMIRR )</td>
<td></td>
<td>1.3</td>
<td></td>
<td>( V_{\text{CC}} - 2\text{V} )</td>
<td>V</td>
</tr>
<tr>
<td>Differential Input Voltage Range</td>
<td>( AV_{\text{IN}} )</td>
<td></td>
<td>0</td>
<td></td>
<td>200</td>
<td>mV</td>
</tr>
<tr>
<td>Internal Gain</td>
<td>( G_{\text{IA}} )</td>
<td></td>
<td>9.8</td>
<td>10.0</td>
<td>10.2</td>
<td></td>
</tr>
<tr>
<td>Input Offset Voltage</td>
<td>( V_{\text{OIA}} )</td>
<td></td>
<td>25</td>
<td></td>
<td>75</td>
<td>nA</td>
</tr>
<tr>
<td>Voltage vs. temperature</td>
<td>( dV_{\text{OIA}}/dT )</td>
<td>( T_{\text{amb}} = -40…100^\circ\text{C} )</td>
<td>-10</td>
<td></td>
<td>10</td>
<td>µV/°C</td>
</tr>
<tr>
<td>Voltage vs. temperature</td>
<td>( dV_{\text{OIA}}/dT )</td>
<td>( T_{\text{amb}} = 100…125^\circ\text{C} )</td>
<td>-30</td>
<td></td>
<td>30</td>
<td>µV/°C</td>
</tr>
<tr>
<td>Output Voltage Range</td>
<td>( V_{\text{OIA}} )</td>
<td></td>
<td>0.05</td>
<td></td>
<td>( V_{\text{CC}} - 2\text{V} )</td>
<td>V</td>
</tr>
<tr>
<td>Nonlinearity</td>
<td>( NL_{\text{IA}} )</td>
<td>( V_{\text{IN}} = 1.3\text{V}, \Delta V_{\text{IN}} = 100\text{mV}, 200\text{mV} )</td>
<td></td>
<td></td>
<td>0.15</td>
<td>% FS</td>
</tr>
<tr>
<td>Common Mode Rejection Ratio</td>
<td>( CMIRR )</td>
<td>( V_{\text{IN}} = 1.3\text{V}, \Delta V_{\text{IN}} = 100\text{mV} )</td>
<td>80</td>
<td></td>
<td>90</td>
<td>dB</td>
</tr>
<tr>
<td>Power Supply Rejection Ratio</td>
<td>( PSRR )</td>
<td>( V_{\text{IN}} = 1.3\text{V}, \Delta V_{\text{IN}} = 100\text{mV} )</td>
<td>74</td>
<td></td>
<td>80</td>
<td>dB</td>
</tr>
<tr>
<td>Input Voltage Noise</td>
<td>( e_{\text{IN}} )</td>
<td>( G_{\text{IA}} = 10 )</td>
<td></td>
<td></td>
<td>35</td>
<td>nV/√Hz</td>
</tr>
</tbody>
</table>
## AM417 – Ratiometric instrumentation amplifier with adjustable output stage

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Output Stage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjustable Gain</td>
<td>G_OUT</td>
<td></td>
<td>2</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Voltage Range</td>
<td>V_IN</td>
<td></td>
<td>0.05</td>
<td></td>
<td>2.25</td>
<td>V</td>
</tr>
<tr>
<td>Input Current</td>
<td>I_IN</td>
<td>V_IN = 2V, ∆V_IN = 50mV</td>
<td></td>
<td>20</td>
<td>75</td>
<td>nA</td>
</tr>
<tr>
<td>Input Offset Voltage</td>
<td>V_OS</td>
<td></td>
<td>-3</td>
<td>3</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>V OS vs. temperature</td>
<td>∆V_OS</td>
<td>V_IN = 2V, ∆V_IN = 50mV, T scrip = -40…100°C</td>
<td>-15</td>
<td>15</td>
<td></td>
<td>µV/°C</td>
</tr>
<tr>
<td>V OS vs. temperature</td>
<td>∆V_OS</td>
<td>V_IN = 2V, ∆V_IN = 50mV, T scrip = 100…125°C</td>
<td>-100</td>
<td>0</td>
<td></td>
<td>µV/°C</td>
</tr>
<tr>
<td>Output Current</td>
<td>I_OUT</td>
<td>Pin VOUT</td>
<td>65</td>
<td>150</td>
<td>350</td>
<td>µA</td>
</tr>
<tr>
<td>Output Voltage Range</td>
<td>V_OUT</td>
<td>With external transistor*</td>
<td>0.5</td>
<td>4.5</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Output Current</td>
<td>I_OUT</td>
<td>With external transistor*</td>
<td>11</td>
<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>Output Resistance</td>
<td>R_OUT</td>
<td>With external transistor*</td>
<td>0.1</td>
<td>0.85</td>
<td></td>
<td>Ω</td>
</tr>
<tr>
<td>Power Supply Rejection</td>
<td>PSRR</td>
<td></td>
<td>-72</td>
<td>-90</td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>Current Limitation Threshold</td>
<td>V THRESH</td>
<td>V THRESH = V_IN - V OUT, R2 = 2Ω, I OUT = 14mA</td>
<td>1.00</td>
<td>1.15</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>V THRESH vs. Temperature</td>
<td>∆V THRESH</td>
<td>-40…+125°C without external transistor*</td>
<td>-4.2</td>
<td>-1.8</td>
<td></td>
<td>mV/°C</td>
</tr>
</tbody>
</table>

### System Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage Range</td>
<td>∆V IN</td>
<td>@ V OUT max = 4.5V and G OUT = 10</td>
<td>0</td>
<td>40</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>Gain Bandwidth Product</td>
<td>GBW</td>
<td>C OUT = 1nF</td>
<td>400</td>
<td>1,500</td>
<td></td>
<td>kHz</td>
</tr>
<tr>
<td>Nonlinearity</td>
<td>NL</td>
<td></td>
<td></td>
<td>0.15</td>
<td></td>
<td>%FS</td>
</tr>
</tbody>
</table>

**Table 1: Electrical specifications**

System parameters: specifications which refer to the AM417 circuit as a whole.

* Output current dependent on resistor R2 (see Equation 4).

## BOUNDARY CONDITIONS / EXTERNAL COMPONENTS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistor Adjustment Current Source</td>
<td>R1</td>
<td></td>
<td>400</td>
<td>1000</td>
<td></td>
<td>Ω</td>
</tr>
<tr>
<td>Resistor Sense Current Limitation</td>
<td>R2</td>
<td></td>
<td>0</td>
<td>50</td>
<td></td>
<td>Ω</td>
</tr>
<tr>
<td>Gain Resistor Sum</td>
<td>R3 + R4</td>
<td>V OUT = (R1 + R4)/R4 G OUT</td>
<td>0.41</td>
<td>2.1</td>
<td></td>
<td>kΩ</td>
</tr>
<tr>
<td>Capacitor Power Supply</td>
<td>C1</td>
<td></td>
<td>100</td>
<td>330</td>
<td></td>
<td>nF</td>
</tr>
<tr>
<td>Capacitor Frequency Compensation</td>
<td>C2</td>
<td>X7R capacitor, ±10%</td>
<td>4.7</td>
<td>4.7</td>
<td></td>
<td>nF</td>
</tr>
<tr>
<td>Capacitor Load</td>
<td>C2</td>
<td>X7R capacitor, ±10%</td>
<td>1.0</td>
<td>10.0</td>
<td></td>
<td>nF</td>
</tr>
<tr>
<td>Output PNP Transistor</td>
<td>βT1</td>
<td>e.g. BCW68H or BC557C, low drop, high β for T scrip = -40…125°C</td>
<td>180</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2: Electrical boundary conditions**
DESCRIPTION OF FUNCTIONS

AM417 is a ratiometric, adjustable interface IC which has been specially developed for the conditioning of bridge signals for automotive applications. With its integrated, ratiometric current source it is particularly suitable for the excitation of piezoresistive bridge devices in a constant current mode. The IC enables simple calibration and temperature compensation of the input signals. AM417 consist of three functional units:

Instrumentation amplifier

Using the input stage of the instrumentation amplifier (IA) the input signal is preamplified by $G_{IA} = 10$. The IA can only process positive input signals. A negative input voltage or negative input offset must be balanced by using additional resistor at positive input pin $V_{IN+}$ (c.f. Setting the output offset).

Current source

The additional operational amplifier (OP) is linked internally to supply voltage $V_{CC}$ via a voltage divider (10:1). With the OP acting as a ratiometric current source a resistor measuring cell can be supplied with constant current within a range of 0.5 – 1.25mA.

The supply current of the external sensing element $I_{IB}$ can be set by varying resistor $R_1$ at the minus input of the OP ($V_{IN-}$) using the following ratio:

$$I_{IB} = \frac{V_{CC}}{10 R_1} \quad (1)$$

Output stage

A voltage amplifier with an external PNP open collector stage ($T_1$) acts as a voltage output and can provide a maximum current of $I_{OUT} = 11$mA. Using external resistors $R_3$ and $R_4$ the Gain $G_{OUT}$ can be adjusted between 2 and 11.

$$G_{OUT} = \frac{R_3 + R_4}{R_4} \quad (2)$$

The gain of the entire circuit AM417 is thus: $G_{SYS} = G_{IA} G_{OUT}$.

A current limitation has been integrated into the output stage. The limit circuit restricts output voltage $V_{OUTmin}$ with reference to $V_{CC}$, where $V_{BE}$ is the basic emitter voltage of external transistor $T_1$.

$$V_{OUTmin} = V_{CC} - 1.5 V_{BE} (T_1) \quad (3)$$

With this the maximum output current can be adjusted using resistor $R_2$ in series with the $T_1$ transistor emitter (see Figure 2). The current is thus calculated as:

$$I_{OUTmax} = \frac{V_{THRESH} - V_{BE}(T_1)}{R_2} \approx \frac{380mV}{R_2} \quad (4)$$
where $V_{THRFSH}$ is current limitation threshold.

Should no current limit be necessary, the $T_1$ transistor emitter can be directly connected up to pin $VCC$ ($R_2 = 0$). Good thermal coupling between $T_1$ and the IC reduces the temperature drift of output current $I_{OUT}$, thus raising the quality of the current limit.

The output stage is not protected against reverse polarity. Reverse polarity of $VCC$ referenced to ground can be realized using a simple additional circuit, see [3].

**CALIBRATION WITH A RESISTOR BRIDGE CIRCUIT**

![Diagram of AM417 circuit](image)

**Figure 2**: Measuring a constant-current sensing element using a Wheatstone bridge circuit.

**Setting the output span**

The output signal span can be set using gain $G_{OUT}$ of the output stage (see Equation 2):

$$G_{OUT} = \frac{V_{SPAN}}{V_{OUTME} \cdot G_{IA}}$$  \hspace{1cm} (5)

where $V_{SPAN} = V_{OUTmax} - V_{OUTmin}$ and $V_{OUTME}$ is the output voltage of the sensing element.

**Setting the output offset**

In a Wheatstone bridge circuit, such as those frequently used with piezoresistive sensors, the offset of the output voltage $V_{OUTmin}$ must be calibrated depending on the required degree of accuracy and with reference to the offset of both the sensing element and the IC. To this end, a compensating
resistor \( R_O \) is inserted into the measuring bridge (see Figure 2). By using this compensating resistor
the instrumentation amplifier input voltage \( \Delta V_{IN} \) is set in such a way, that output voltage \( V_{OUT\text{min}} \)
has a value of 0.5V, for example. The voltage drop \( V_{RO} \) across resistor \( R_O \) is given by:

\[
V_{RO} = \left[ \Delta V_{IN} - V_{BR} \left( \frac{R_{B4}}{R_{B3} + R_{B4}} - \frac{R_{B2}}{R_{B1} + R_{B2}} \right) \right] \left( 1 - \frac{R_{B3}}{R_{B3} + R_{B4}} \right)
\]

(6)

where \( V_{BR} \) is the voltage drop across the entire sensing element, \( R_{BR} \) the total bridge resistance and
\( R_{B1,2,3,4} \) the individual bridge resistors. Assuming that the four separate bridge resistors have the
same value, the following approximation formula is valid:

\[
V_{RO} = 2 \Delta V_{IN}
\]

(7)

\( \Delta V_{IN} \) is the voltage to be set at the input of the instrumentation amplifier where there are no offsets.

\[
\Delta V_{IN} = \frac{V_{OUT\text{min}}}{G_{SYS}} = \frac{V_{OUT\text{min}}}{G_{IA} \cdot G_{OUT}}
\]

(8)

Taking the offset of the sensing element (\( V_{OSME} \)) and that of the IC (\( V_{OSIC} \) ) into account
(\( V_{OSIC} = V_{OSIA} + 0.1 V_{OSOUT} \), where \( V_{OSIA} \) is the instrumentation amplifier offset and \( V_{OSOUT} \) the
output stage offset), the adjustable voltage is calculated as:

\[
\Delta V_{IN}' = \Delta V_{IN} - V_{OSIC} - V_{OSME}
\]

(9)

From (9) and (8) it follows that:

\[
\Delta V_{IN}' = \frac{V_{OUT\text{min}}}{G_{IA} \cdot G_{OUT}} - V_{OSIC} - V_{OSME}
\]

(10)

Applying (7) and (10), the necessary voltage drop across \( R_O \) required to calibrate the offset of the
output voltage \( V_{OUT\text{min}} \) is expressed thus:

\[
V_{RO} = 2 \cdot \left( \frac{V_{OUT\text{min}}}{G_{IA} \cdot G_{OUT}} - V_{OSIC} - V_{OSME} \right)
\]

(11)

On condition, the sensing element offset is low referenced to the sensing element output voltage
(\( V_{OSME} < 10 V_{OUT\text{me}} \)), the resistor \( R_O \) is calculated with sufficient accuracy as:

\[
R_O = \frac{2 \cdot V_{RO}}{I_{IB}}
\]

(12)

Applying (11) and the condition, that the voltage drop across \( R_O \) may only be positive, the
maximum compensatable offset is computed thus:

\[
V_{OSIC} + V_{OSME} \leq \frac{V_{OUT\text{min}}}{G_{IA} \cdot G_{OUT}}
\]

(13)
If when calculating $V_{RO}$ (Equation 11) a negative value is produced, the resistor $R_0$ must be placed in the left arm of the bridge ($R_0'$; see Figure 3):

![Figure 3: Circuit as in Figure 2 with $R_0'$ (instead $R_0$) at input pin 5 (IN-)](image)

Doing so changes the effective direction of $R_O$ and its resistance is now expressed as:

$$R_0' = \frac{2 \cdot (-V_{RO})}{I_{IB}}$$

(12a)
EXAMPLES

By way of example the equations shall be calculated using typical values for piezoresistive sensing elements [2] in an attempt to illustrate how various sensing elements can be calibrated and compensated with very few external components. The aim of the exercise is to calibrate the output voltage of AM417 to $V_{OUTmin} = 0.5V$ and $V_{OUTmax} = 4.5V$.

Example 1: Piezoresistive pressure sensing element in a bridge circuit with a positive offset

- $V_{OUTME} = 160mV$ at $V_{BR} = 5V$
- $V_{CC} = 5V$
- $V_{OUT} = 0.5...4.5V$, $V_{SPAN} = 4V$, $V_{OUTmin} = 0.5V$
- $V_{OSIC} = -2mV$
- $V_{OSME} = +10mV$ at $V_{BR} = 5V$
- $R_{BR} = 3K\Omega$

The sensing element is to be supplied with constant current as this provides a simple way of compensating the temperature behavior of the span (see: TEMPERATURE COMPENSATION OF THE OUTPUT SPAN).

Taking the maximum output voltage at pin 2 ($I_B$) into account the supply current is selected as $I_B = 1mA$ ($R_J = 500\Omega$).

At pin 2 ($I_B$) the voltage is:

$$V_{IB} = R_{BR} \cdot I_B + V_{VR} = 3k\Omega \cdot 1mA + 0.5V = 3.5V$$

Considering a typical positive temperature coefficient of the sensing element bridge resistor $R_{BR}$ of $TCR = +0.0028/°C$ the maximum voltage at pin 2 ($I_B$) is not overshot ($V_{IBmax} = 4.8V$ at $V_{CC} = 5V$).

The bridge voltage is:

$$V_{km} = V_{BR} \frac{R_{BR}}{R_{BR} + R_{BR}'} = \frac{3.5V \cdot R_{BR}}{2R_{BR}}$$

The output voltage of the sensing element given for $V_{BR} = 5V$ must be corrected by the ratio of the bridge voltages:

$$V_{OUTME'} = \frac{160mV \cdot 3V}{5V} = 96mV$$

The offset voltage of the sensing element given for $V_{BR} = 5V$ must be corrected by the ratio of the bridge voltages:

$$V_{OSME'} = \frac{10mV \cdot 3V}{5V} = 6mV$$

Applying Equation 5 the following is accrued:

$$G_{OUT} = \frac{4V}{96mV \cdot 10} = 4.166$$
and from Equation 11 we are presented with:

\[ V_{RO} = 2 \cdot \left( \frac{0.5V}{10 \cdot 4.166} + 2mV - 6mV \right) = 16mV \]

Referring to Equation 12 the resistance for offset calibration is thus:

\[ R_0 = \frac{2 \cdot V_{RO}}{I_B} = 32\Omega \]

If \( R_O \) is set to 32\( \Omega \) and if we take the offsets of sensing element and IC into consideration, the output signal offset of the overall circuit is set to \( V_{OUT_{min}} = 0.5V \) and the maximum output signal is \( V_{OUT_{max}} = 4.5V \).

**Example 2: Piezoresistive pressure sensing element in a bridge circuit with a negative offset**

- \( V_{OUT_{ME}} = 100mV \) at \( V_{BR} = 5V \)
- \( V_{CC} = 5V \)
- \( V_{OUT} = 0.5...4.5V, \Rightarrow V_{SPAN} = 4V, V_{OUT_{min}} = 0.5V \)
- \( V_{OSIC} = 2mV \)
- \( V_{OSME} = -10mV \) at \( V_{BR} = 5V \)

The sensing element is supplied with constant current. Taking the maximum output voltage of the OP into account (see Example 1) \( I_B \) is again selected as \( I_B = 1mA \) (\( R_f = 500\Omega \)).

The bridge voltage is:

\[ V_{BR} = I_B \cdot R_{BR} = 1mA \cdot 3k\Omega = 3V \]

The output voltage of the sensing element is corrected by the ratio of the bridge voltages:

\[ V_{OUT_{ME}}' = \frac{100mV \cdot 3V}{5V} = 60mV \]

The offset voltage of the sensing element is also corrected by the ratio of the bridge voltages:

\[ V_{OSM} = \frac{-10mV \cdot 3V}{5V} = -6mV \]

Applying Equation 5 the following is accrued:

\[ G_{OUT} = \frac{4V}{60mV \cdot 10} = 6.67 \]
and from Equation 11 we are presented with:

\[ V_{RO} = 2 \cdot \left( \frac{0.5V}{10 \cdot 6.67} - 2mV + 6mV \right) = 23mV \]

Referring to Equation 12 the resistance for offset calibration is thus:

\[ R_o = \frac{2 \cdot V_{RB}}{I_B} = 46\Omega \]

If \( R_o \) is set to 46\( \Omega \) and if we take the offsets of sensing element and IC into consideration, the output signal offset of the overall circuit is set to \( V_{OUTmin} = 0.5V \) and the maximum output signal is \( V_{OUTmax} = 4.5V \).

Example 3: Piezoresistive pressure sensing element in a bridge circuit with a high positive offset

- \( V_{OUTME} = 100mV \) at \( V_{BR} = 5V \)
- \( V_{CC} = 5V \)
- \( V_{OUT} = 0.5 \ldots 4.5V, \Rightarrow V_{SPAN} = 4V, V_{OUTmin} = 0.5V \)
- \( V_{OSIC} = 2mV \)
- \( V_{OSME} = 10mV \) at \( V_{BR} = 5V \)
- \( R_{BR} = 3K\Omega \)

The sensing element is supplied with constant current. Taking the maximum output voltage of the OP into account \( I_B \) is again selected as \( I_B = 1mA \) (\( R_I = 500\Omega \)).

The bridge voltage is: \( V_{BR}' = I_{BR} \cdot R_{BR} = 1mA \cdot 3k\Omega = 3V \).

The output voltage of the sensing element is corrected by the ratio of the bridge voltages:

\[ V_{OUTME}' = \frac{100mV \cdot 3V}{5V} = 60mV \]

The offset voltage of the sensing element is also corrected by the ratio of the bridge voltages:

\[ V_{OSME}' = \frac{10mV \cdot 3V}{5V} = 6mV \]

Applying Equation 5 the following is accrued:

\[ G_{OUT} = \frac{4V}{60mV \cdot 10} = 6.67 \]
and from Equation 11 we are presented with:
\[ V_{RO} = 2 \cdot \left( \frac{0.5V}{10 \cdot 6.67} - 2mV - 6mV \right) = -6.5mV \]

Referring to Equation 12a the resistance for offset calibration is thus:
\[ R_0' = \frac{2 \cdot (V_{RO})}{I_{IB}} = 13\Omega \]

If \( R_0' \) (resistor on the left) is set to 13\( \Omega \) and if we take the offsets of sensing element and IC into consideration, the output signal offset of the overall circuit is set to \( V_{OUTmin} = 0.5V \) and the maximum output signal is \( V_{OUTmax} = 4.5V \).

**TEMPERATURE COMPENSATION OF THE OUTPUT SPAN**

Supplying a piezoresistive sensing element with constant current makes compensation of the temperature of the span a relatively simple affair. With a constant current supply the negative temperature coefficient of sensor sensitivity \( S \) can be compensated by the positive temperature coefficient of bridge resistor \( R_{BR} \).

![Figure 4: Bridge array for the compensation of TC with \( R_{BR} = \) bridge resistor](image)
The output signal of a piezoresistive sensing element is accrued from:

\[ V_{OUTME} = S \cdot P \cdot V_{BR} = S \cdot P \cdot I_{IB} \cdot R_{BR} \]  
(14)

\( S \) is the sensor sensitivity of the sensing element and \( P \) is the applied pressure. Sensor sensitivity \( S \) and bridge resistor \( R_{BR} \) are the dominant temperature-dependent variables in Equation 14. The following applies:

\[ S = S_0 \cdot (1 + TCS \cdot (T - T_0)) \]  
(15)

\[ R_{BR} = R_{BR0} \cdot (1 + TCR \cdot (T - T_0)) \]  
(16)

\( S_0 \) is the basic value of the sensitivity and \( R_{BR0} \) the basic value of the bridge resistance at \( T_0 \) (usually room temperature). \( T \) is the actual temperature.

\( TCS \) and \( TCR \) are the linear temperature coefficients of sensitivity and bridge resistance. Typical values are:

\[ TCS = -0.0019/\degree C \text{ and } TCR = +0.0028/\degree C \text{ [3].} \]

Good temperature compensation of sensing element output signal \( V_{OUTME} \) would be automatically achieved if both temperature coefficients had the same value. If both are different, however, an attempt is made to equalize them. This is done by adding an additional compensatory TCS resistor \( R_{TCS} \) which is inserted parallel to the sensing element (see Figure 4). The \( TCR \) value of the entire system is thus amended so that it is the same as \( TCS \) of the sensing element.

In the temperature compensation of the sensing element output signal described above the following applies to the compensatory TCS resistor:

\[ R_{TCS} = R_{BR} \cdot \frac{-TCS}{TCR + TCS} \]  
(17)

As part of the set bridge supply current \( I_{IB} \) flows through the shunt resistor \( R_{TCS} \) the circuit output signal is reduced after TCS compensation according to the following equation:

\[ I_{IB}' = \frac{R_{TCS}}{R_{TCS} + R_{BR}} \]  
(18)

In order to reinstate the original output signal of the circuitry the circuit gain must be increased by the reciprocal ratio:

\[ \text{TCS Factor} = \frac{I_{IB}}{I_{IB}'} = \frac{(R_{TCS} + R_{BR})}{R_{TCS}} \]  
(19)
In order to achieve a maximum a sensing element output signal it is best to increase set bridge supply current $I_{IB}$ by the TCS Factor. Gain $G_{OUT}$ can also be increased by the same factor if, for example, maximum bridge current $I_{IB_{max}} = 1.25\text{mA}$ or if the maximum voltage at pin 2 ($IB$) is overshot during an increase.

**EXAMPLE**

Example 4: TCS compensation of a piezoresistive pressure sensing element [2]

- $TCS = -0.0019^\circ\text{C}$
- $V_{CC} = 5\text{V}$
- $R_{BR} = 3\text{K}\Omega$
- $TCR = +0.0028^\circ\text{C}$
- Temperature range: -20°C – 80°C

Bridge supply current $I_{IB}$ is selected according to the following. Assuming that the maximum operating temperature of the circuit is 80°C, the maximum bridge resistance is calculated using Equation (16):

$$R_{RB_{max}} = 3k\Omega \cdot (1 + 0,0028 / ^\circ\text{C} \cdot (80^\circ\text{C} - 25^\circ\text{C})) = 3,46k\Omega$$

With a bridge current of $I_{IB} = 0.8\text{mA}$, at 80°C and $V_{CC} = 5\text{V}$, pin 2 ($IB$) has a potential of:

$$V_{IB} = 3.46k\Omega \cdot 0.8mA + 0.5V = 3.27V$$

Applying Equation (17):

$$R_{TCS} = 6.33K\Omega$$

Using Equation (19) the following is calculated for $T_{0}$:

$$TCS\text{Factor} = 1.47$$

If bridge current $I_{IB}$ is now increased by a factor of $TCS\text{Factor}$, the result is a new amended bridge current of:

$$I_{IB_{new}} = 1.18\text{mA}$$

The original output signal of the sensing element is thus reinstated following TCS compensation. Output stage gain $G_{OUT}$ could also be increased by a factor of $TCS\text{Factor}$ by adjusting resistors $R_{3}$ and $R_{4}$ according to Equation (2).
AM417 – Ratiometric instrumentation amplifier with adjustable output stage

BLOCK DIAGRAM AND PINOUT

Figure 5: Circuit diagram of AM417

Figure 6: AM417 Pin out

<table>
<thead>
<tr>
<th>PIN</th>
<th>NAME</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GND</td>
<td>IC Ground</td>
</tr>
<tr>
<td>2</td>
<td>IB</td>
<td>Current Source Output</td>
</tr>
<tr>
<td>3</td>
<td>RB</td>
<td>Current Source Set</td>
</tr>
<tr>
<td>4</td>
<td>IN+</td>
<td>Positive IA Input</td>
</tr>
<tr>
<td>5</td>
<td>IN–</td>
<td>Negative IA Input</td>
</tr>
<tr>
<td>6</td>
<td>VR</td>
<td>Gain Set</td>
</tr>
<tr>
<td>7</td>
<td>VOUT</td>
<td>Voltage Output</td>
</tr>
<tr>
<td>8</td>
<td>VCC</td>
<td>Supply Voltage</td>
</tr>
</tbody>
</table>

Table 3: Pin out

DELIVERY

AM417 is available as:

- An SOP08
- Dice on 5“ blue foil
EXAMPLE APPLICATIONS

- Interface IC for sensing elements in a resistor bridge circuit (e.g. piezoresistive pressure sensing elements) with electronic compensation of errors via an external microcontroller. In this application AM417 is used as a preamplifier to set the operating point.

![Figure 7: Application for sensing elements with an external microcontroller or ADC](image)

- Signal conditioning IC with an external, analog compensation network, in which the offset can be adjusted using additional resistors on the sensing element and the gain using AM417.

![Figure 8: Application as a signal conditioning IC with an external compensation network](image)

How to protect the output of the AM467 against reverse polarity see [3]
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FURTHER READING


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