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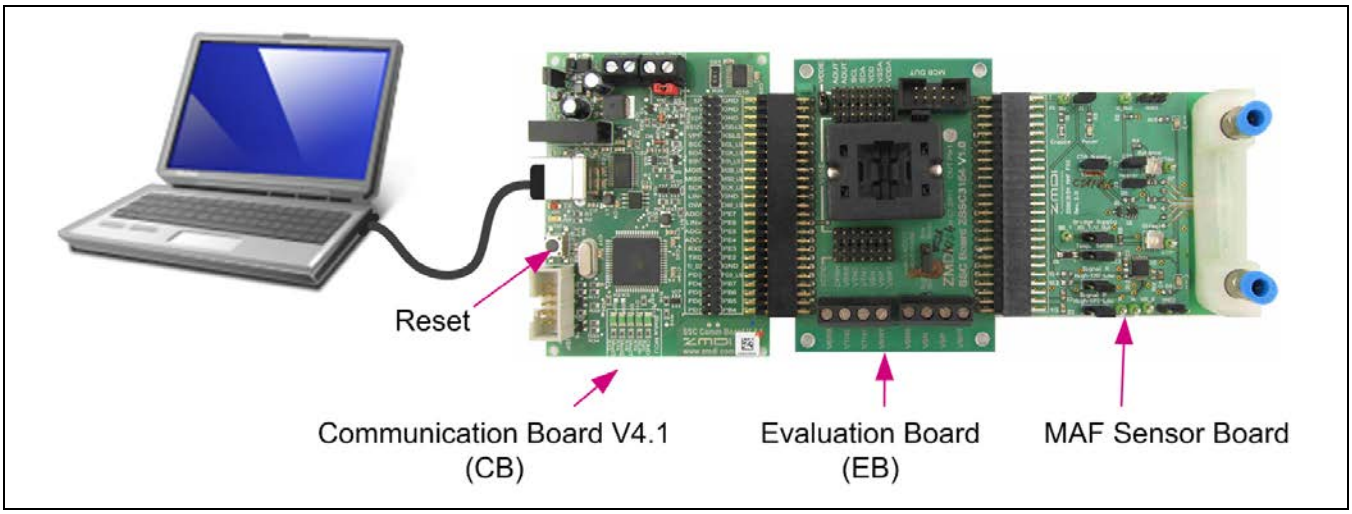
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1 Introduction

The ZSSC3154 Sensor Signal Conditioner (SSC) can enable mass air flow sensing applications by conditioning the air flow sensor signal. The ZSSC3154 is optimized for resistive bridge sensor measurements commonly used in air flow sensing applications. To expedite the design of these applications, IDT provides the ZSSC3154 Mass Air Flow (MAF) Sensor Board option for use with the ZSSC3154 Evaluation Kit in place of the kit's Sensor Replacement Board as shown in Figure 1.1. The MAF Sensor Board also includes a flow channel for the measurement. The ZSSC3154 is installed in a socket on the kit's ZSSC3154 Evaluation Board.

This application note covers the general principles of air flow sensing and the specific details for using the MAF Sensor Board with the ZSSC3154 Evaluation Kit. Reading the *ZSSC3154 Data Sheet* and *ZSSC3154 Evaluation Kit Description* first is strongly recommended.

Figure 1.1 ZSSC3154 Evaluation Kit

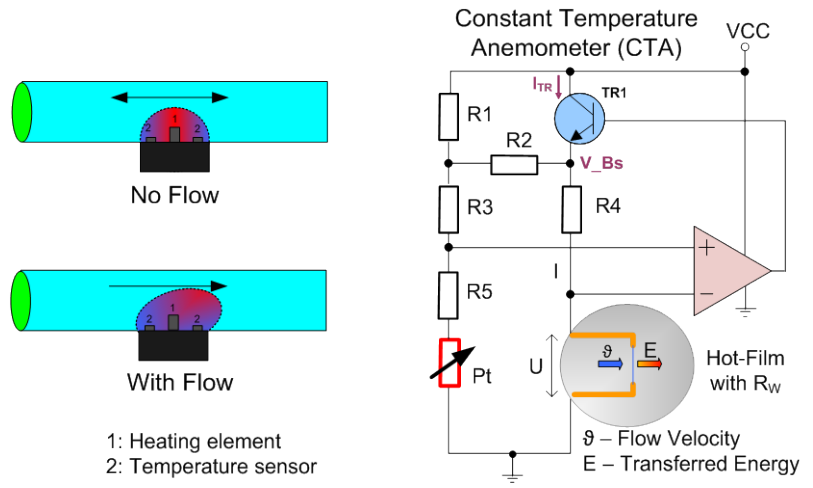


2 Hot-Film Flow Measurement Principles

A mass air flow (MAF) sensor converts the amount of air into a voltage signal. Units used are usually kilogram per second (kg/s). For example, air flow mass is a necessary parameter in engine operation in order to determine how much fuel to inject, ignition timing, and when to shift the gears. Used in conjunction with an oxygen sensor, the mass air flow sensor measurement can enable very accurate control of the fuel ratio.

There are different types of MAF sensors. The hot-film type sensor is more common. It consists of a heating element (typically a temperature-dependent, low-ohm platinum resistor) and an additional temperature sensor. Flow direction can also be determined with specific sensor configurations. The temperature sensor (Pt in Figure 2.1) is used as a reference for the heating element to maintain a constant reference to the ambient temperature, which can be provided by an electronic control circuit such as a constant temperature anemometer (CTA) as shown in Figure 2.1. The voltage needed to heat the element in order to maintain thermal equilibrium with the ambient temperature is proportional to the air mass flow through the sensor. Higher flow increases the cooling of the element, which is compensated by raising the voltage of the heating element. This measuring principal covers large operational ranges with high accuracy and a wide temperature operating range.

Figure 2.1 Hot-Film Flow Measurement



Transfer of energy:

$$\frac{dE}{dt} = W - H$$

where E is the transferred thermal energy; $W=I^2R_W$ is power generated by Joule heating; and H is the heat transfer to surroundings.

Based on this, according to King's Law,

$W = E^2 = (T_W - T_a)(A + B * \vartheta^n)$,

where the voltage drop is a measure of velocity:

$$U = U_0\sqrt{1 + k * \vartheta^n}$$

The air density can vary, which changes the thermal capacity of the air. The density is function of the ambient temperature, altitude, and pressure, which makes mass flow meters more appropriate for determining the quantity of the air.

Another factor that should be taken in account is the air humidity. An increase in the humidity decreases the air density. This is because the molecule mass of water is less than the molecule mass of air, and for any gas at a given pressure and temperature, there is a constant number of molecules for a particular volume. This results in a decrease in the gas mass per unit volume.

MAF sensors feature a quick response time, small overall package, less sensitivity to mounting and orientation, durability, and lower costs.

Care should be taken to prevent contamination of the sensor, which reduces the accuracy. Possible thermocoupling between the heating element and the temperature sensor should be taken in account as well.

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3 Mass Air Flow Measurement with the ZSSC3154

3.1. Advantages, Applications, Technical Details, and Test Data

The ZSSC3154 Sensor Signal Conditioner and the ZSSC3154 Evaluation Kit with the ZSSC3154 Mass Air Flow (MAF) Sensor Board (Figure 3.1) can be used to demonstrate measurements of the mass and direction of air flow and to expedite design of the user's application. See Figure 3.3 for the schematics for the MAF Sensor Board. Settings for the jumpers on the board are provided in section 3.3.

The ZSSC3154 Evaluation Kit enables calibration and evaluation of the ZSSC3154.

This method offers simple signal processing and calibration with excellent reproducibility and long-term stability. There are no moving mechanical components. The sensor module allows easy adaptation for different applications and housings.

Possible air flow sensing applications for the ZSSC3154:

- HVAC and building-control solutions
- Medical devices
- Automotive industry products
- Device monitoring

The air flow sensor element used on the MAF Sensor Board is the FS2 sensor by IST AG, which consists of four temperature-dependent platinum-resistors, all on-chip. See Figure 3.2. A low-ohm resistor with a small area is used as a heating element (top center of Figure 3.2), and the two high-ohm resistors at the top to the right and left of the element are for measuring the mass flow and the direction. These two sensors placed on each side of the heating element are connected in a bridge circuit, which gives a clear signal for measuring the volume and the direction of the flow. When there is no flow of the air medium, the heating element heats both sensors equally. When there is air flow, one sensor is cooled more than the other depending on the direction of the flow. Depending on the temperature difference between the two resistances, the flow volume can be determined. As a result of its small thermal mass, this flow sensor has fast heating and cooling response times. This system allows measuring a very small flow volume and can simultaneously detect the direction of the flow. The resistor on the lower left in Figure 3.2 functions as the Pt ambient temperature sensor.

To measure higher mass flow volumes, an optional on-board constant temperature anemometer (CTA) can be used.

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Figure 3.1 Mass Air Flow Sensor Board

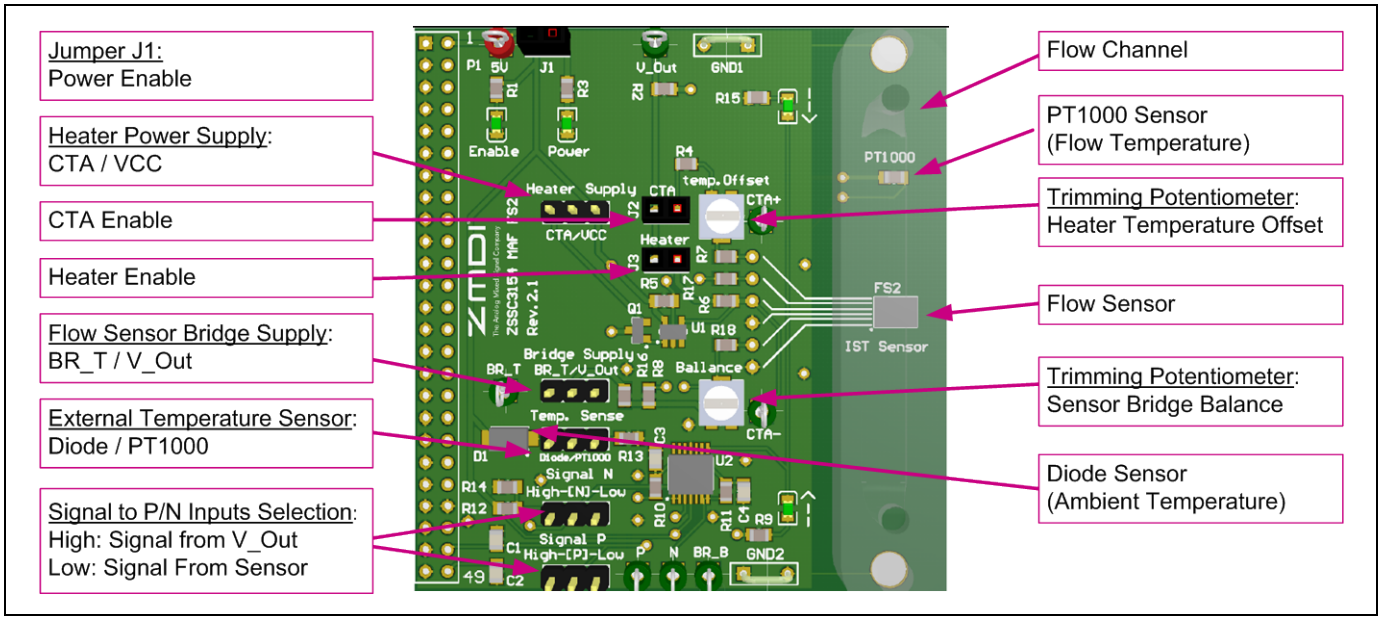
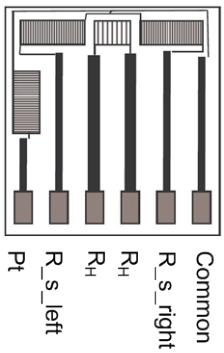


Figure 3.2 FS2 Flow Sensor Layout

FS2 (http://www.ist-ag.com/; http://www.ist-usadivision.com)

(Note: View is rotated 90° counter-clockwise relative to Figure 3.1)



R_H(25°C) = 34Ω ±10%

R_{s_left} (25°C) = 425Ω ±10%

R_{s_right} (25°C) = 425Ω ±10%

Pt (25°C) = 710Ω ±10%

(© Copyright IST AG. Used with permission.)

3.2. ZSSC3154 MAF Sensor Board Schematic

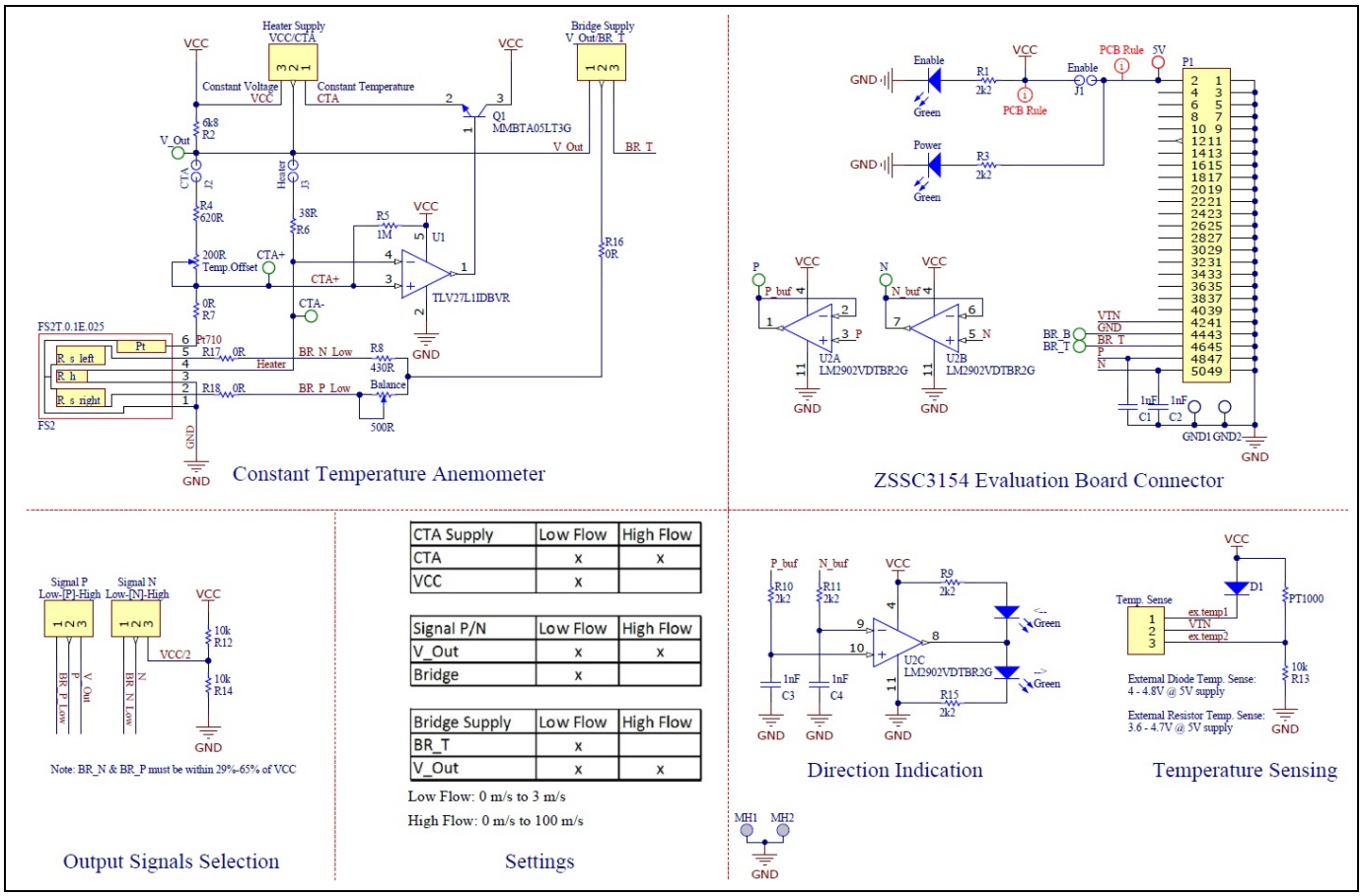
Figure 3.3 provides the schematic for the MAF Sensor Board, which is designed to be connected to the ZSSC3154 Evaluation Kit. The functionality of the circuit blocks is described in subsequent sections.

The P1 connector transfers the signals from the MAF Sensor Board to the pins of ZSSC3154 on the Evaluation Board via the following connector pins.

Table 3.1 Signal Connections

P1 Connector	ZSSC3154 Pin
VTN	VTN1
GND (BR_B)	VBR_B (bottom of bridge)
BR_T	VBR_T (top of bridge)
P	VBP
N	VBN

Figure 3.3 MAF Sensor Board Schematic



3.3. Constant Temperature Anemometer (CTA) Operation

The optional CTA can extend the operation range of the sensors on the MAF Sensor Board. The CTA is needed for high flow rates. To select the CTA option, install jumpers on both the “CTA” connector (J2) and across pins 1 and 2 (CTA position on the left) on the “Heater Supply CTA/VCC” connector identified in Figure 3.1. In this configuration, the hot-film of the FS2 sensor (the “Heater” signal line in Figure 3.3) is connected to the temperature sensor (Pt710) in a bridge configuration. The bridge is balanced when the heater reaches a specific elevated temperature above the ambient temperature (usually approximately 20°C higher), defined by the rest of the resistors in the bridge. The bridge supply voltage (V_Out) must be selected via a jumper across pins 1 and 2 on the “Bridge Supply V_out/BR_T” connector. V_Out changes with the change of the air flow around the sensor; this change in voltage is a measure of the mass air flow.

This configuration allows direct placement of the sensor in the flow without an individual flow channel. It also allows measuring high flow rates. Resistor values in the CTA circuit are application-specific and would be adapted in the final user application.

3.4. Low Flow Operation

For low flows, the sensors can be supplied directly from the BR_T pin on the ZSSC3154 instead of using the CTA. The BR_T supply is selected via a jumper across pins 2 and 3 on the “Bridge Supply V_out/BR_T” connector. In this configuration, bridge resistance must be adapted to a minimum 1k ohm and the signal range must be placed in the acceptable common mode voltage region by resistors R16, R17 and R18 (see Table 4.1 or Figure 3.1 for jumper settings depending on flow range).

3.5. Flow Direction Indication

Flow direction can also be detected with the FS2 sensors aligned in series to the flow. The “←” and “→” LEDs on the MAF Sensor Board indicate the direction of the air flow as a result of comparison of the “P” and “N” inputs.

Balancing the “P” and “N” inputs can be done with the “Offset” trimming potentiometer for proper operation.

For this application, a laminar flow is required and a separate channel (bypass) is needed for high flow rates. However, signals can be connected to the ZSSC3154 sensor conditioner directly where calibration and offset compensation are performed.

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4 ZSSC3154 Evaluation Kit Setup

4.1. Hardware Setup

Connect the ZSSC3154 Evaluation Kit boards as shown in Figure 4.1 and use the USB cable to connect the Communication Board to a USB port on the user's PC. Install the ZSSC3154 in the socket on the ZSSC3154 Evaluation Board (pin 1 is at the top right).

Install the jumpers on the MAF Sensor Board according to the application as indicated in Table 4.1. Refer to Figure 3.1 for the options for jumper positions.

Figure 4.1 Setting up the ZSSC3154 Evaluation Kit

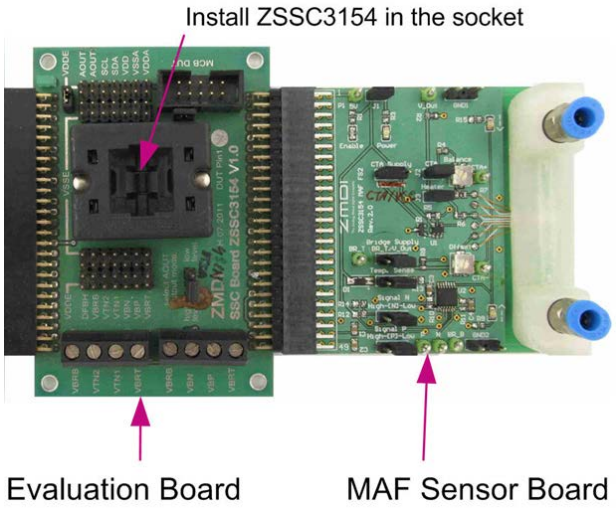


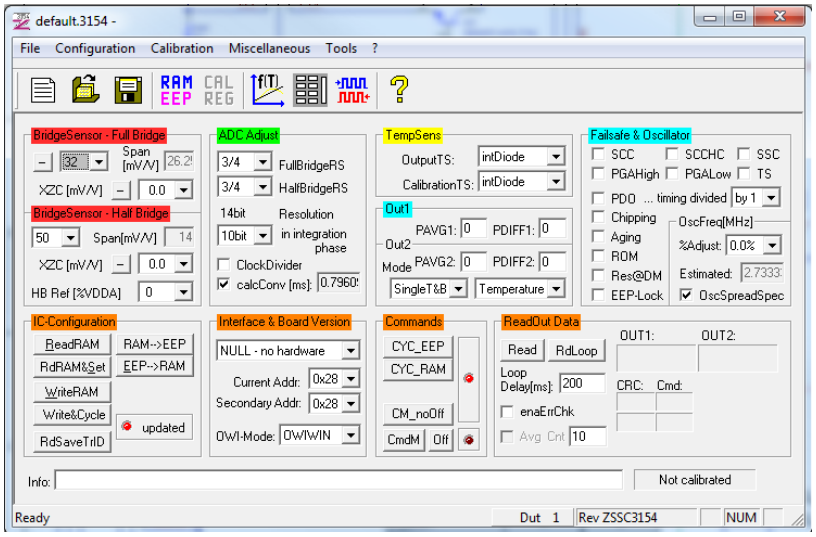
Table 4.1 ZSSC3154 Evaluation Board Jumper Setting Options Depending on the Flow Range

Connector Position	Low Flow (0m/s to 3m/s)	High Flow (0m/s to 100m/s)
CTA Supply (Connector labeled "Heater Supply")		
CTA	✓	✓
VCC	✓	
Signal P/N (Connectors labeled "Signal P High-[P]-Low" and "Signal N High-[N]-Low")		
V_Out (Signal P) or VCC/2 (Signal N)	✓	✓
Sensor Bridge	✓	
Bridge Supply		
BR_T	✓	
V_Out	✓	✓

4.2. ZSSC3154 Evaluation Software

Follow the instructions given in the *ZSSC3154 Evaluation Kit Description* to download the ZSSC3154 Evaluation Kit Software from www.IDT.com/ZSSC3154KIT and install it on the user's PC. The software provides a graphical user interface (GUI) for configuring and calibrating the ZSSC3154 as well as taking sensor measurements and reading registers.

Figure 4.2 ZSSC3154 Evaluation Software



4.3. ZSSC3154 Input Signal Adaptation and Configuration

All sensor signals that are input to the ZSSC3154 (i.e., flow and temperature for this application) must be within the ZSSC3154 specifications for common mode voltage (CMV) for signal level and bridge resistance. The ZSSC3154 is capable of supplying a maximum of 5.5mA driving current. The components in the “Output Signals Selection” section of the MAF Sensor Board (see Figure 3.3) allow adapting the sensor signals to meet the ZSSC3154 requirements.

Table 4.2 ZSSC3154 Input Signal Adaptation and Configuration for User Applications

Parameter	Specifications
Common Mode Voltage (Signal_N and Signal_P)	From 29% BR_T to 65% BR_T
Bridge Resistance	From 1k to 10kΩ
Maximum BR_T Current	5.5mA
VTN Input Range	Diode: BR_T-0.2V to BR_T-1V; Resistor: BR_T-1.4V to BR_T-0.3V
Heater Voltage Range (FS2)	2 V DC to 5 V DC
Heater Power Dissipation	6.6mW at 2V heater voltage; 14.9mW at 3 V heater voltage 26.4mW at 4V heater voltage; 41.3mW at 5 V heater voltage
MAF Board Current Consumption	50mA
Supply Voltage	5V external supply (no reverse polarity protection)

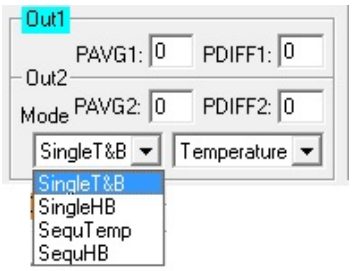
When the ZSSC3154 is in a continuous measurement cycle, the conditioned full-bridge (FB) sensor signal is output at the AOUT1 pin.

At the AOUT2 pin, there are several options for the output mode, which can be configured in the EEPROM via the GUI. A separate temperature measurement is available for the output of a conditioned temperature signal. A half-bridge (HB) measurement is available for validating the main bridge sensor signal.

The half-bridge sensor signal can be used to validate the bridge sensor signal output at the AOUT1 pin.

The necessary settings can be configured using the GUI as illustrated in Figure 4.3. For more information, refer to the *ZSSC3154 Evaluation Kit Description.*

Figure 4.3 Operational Modes



In Table 4.3 all modes of the AOUT2 pin are listed with the corresponding configuration settings.

Recommendation: If the filter function is used for the bridge sensor signal, set the coefficients for filtering the half-bridge signal to the same value (PAVG1/2 and PDIFF1/2).

The sequential AOUT2 output enables the system to evaluate more measurement parameters with the same number of outputs or connections to the ZSSC3154.

Note: Validating the main signal channel via the half-bridge sensor signal disables the analog front-end built-in self-test (BIST) functionality.

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Table 4.3 AOUT2 Modes of Operation

Mode	AOUT2	Configuration Word CFGAPP2, Bits 14:11
Single Temperature and Bridge Signal	Selected temperature sensor	0000
	1 – FB	0001
	FB / 2	0010
	(1 - FB)/2	0011
Single Half Bridge	Half-Bridge	01xx
Sequential Temperature	Selected temperature sensor and FB	1000
	Selected temperature sensor and 1 - FB	1001
	Selected temperature sensor and FB / 2	1010
	Selected temperature sensor and (1 - FB) / 2	1011
Sequential Half Bridge	HB and FB	1100
	HB and 1 - FB	1101
	HB and FB / 2	1110
	HB and (1- FB) / 2	1111

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5 ZSSC3154 Configuration and Calibration

All necessary settings for the ZSSC3154 can be configured via the ZSSC3154 Evaluation KIT GUI with the MAF Sensor Board can be connected. Table 5.1describes the set of the parameters that will enable the flow measurement described in the previous sections:

Table 5.1 Configuration and Calibration

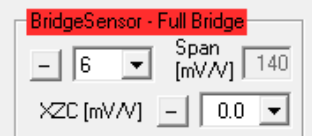
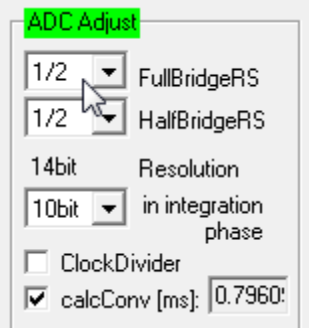
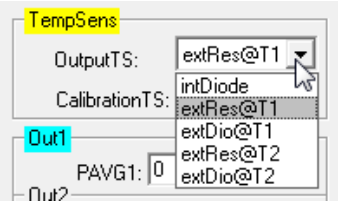
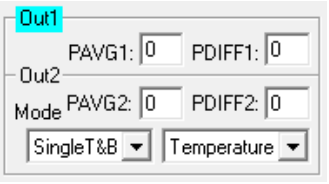
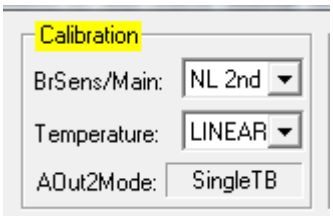
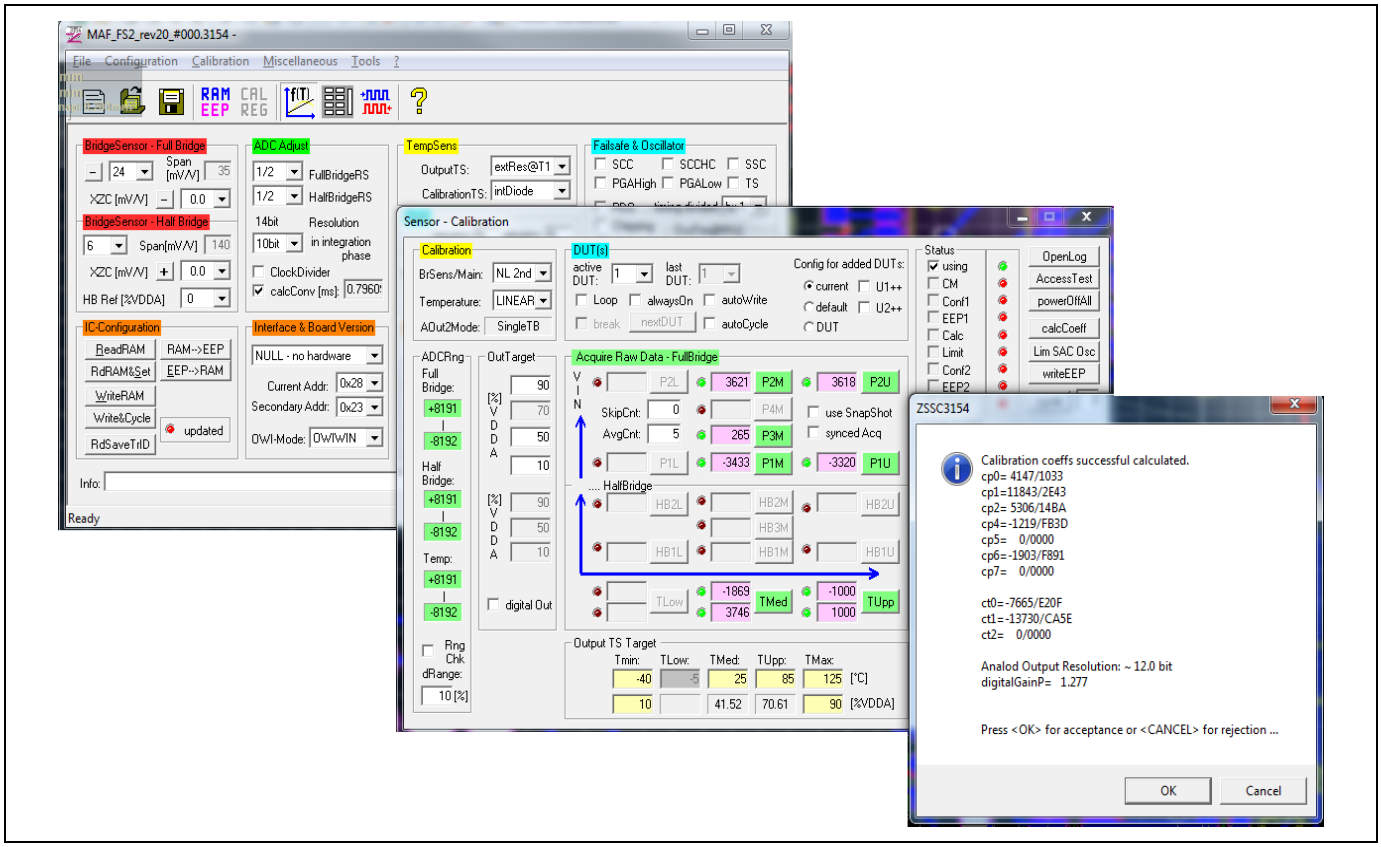
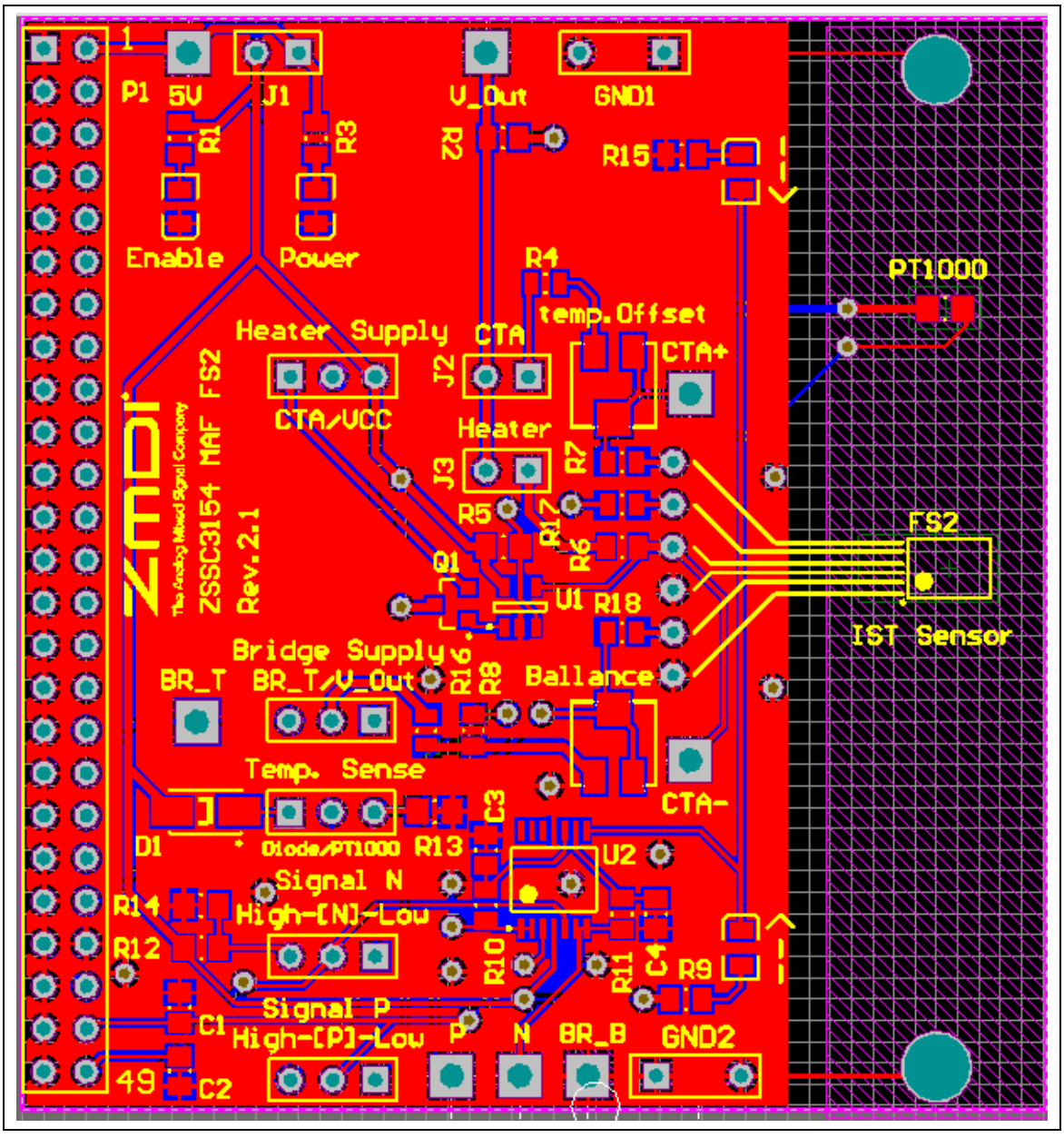
	Selects sensor sensitivity and sets the AFE gain. For a large sensor signal offset (sensor signal present without actual air mass flow), the XZC function can be enabled to compensate it. Half-bridge measurement and settings are not used in this application.
	The input signal range is fitted to the ADC output by selecting a range shift corresponding to the input signal symmetry. ½ for symmetrical signals ¾, $^{7}/_{8}$ and $^{15}/_{16}$ for non-symmetrical signals The selected “Range Shift” value of the digital output corresponds to the analog input’s common mode voltage (CMV) (the analog ground = ½ V_{ADC_REF}). For this application, ½ range shift should be selected (bi-directional flow).
	Temperature measurement is configurable for an internal sensor and up to two external sensors (resistive or diode types). It can be used for temperature drift compensation during sensor measurement (Calibration TS setting) and ambient temperature measurement (external or internal sensor).
	PAVG and PDIFF are parameters for the digital output signal. Mode selection: single bridge and temperature measurement.
	The recommended setting for the main bridge sensor measurement (BrSens/Main) is second-order calibration (3 flow speeds, where the middle one is at 0m/s corresponding to 50% output signal) and linear for the temperature measurement (2 points at maximum and minimum temperatures).

Figure 5.1 ZSSC3154 Evaluation Software



6 PCB Layout

Figure 6.1 MAF Sensor Board



7 Bill of Materials (BOM)

Designator	Description	Part Number	Quantity
R5	1M 0.125W 1% 0805 (2012 Metric) SMD		1
R1, R3, R9, R10, R11, R15	2K2 0.125W 1% 0805 (2012 Metric) SMD		6
R2	6K8 0.125W 1% 0805 (2012 Metric) SMD		1
R12, R13, R14	10K 0.125W 1% 0805 (2012 Metric) SMD		3
R6	38R 0.125W 1% 0805 (2012 Metric) SMD		1
R8	430R 0.125W 5% 0805 (2012 Metric) SMD		1
R4	620R 0.125W 1% 0805 (2012 Metric) SMD		1
C1, C2, C3, C4	CAP 1nF 25V ±1% 0805 (2012 Metric) Thickness 1mm SMD		4
D1	Diode, 2-Pin SMA Package, RoHS	S1M-13-F	1
Bridge Supply	Header, 3-Pin		1
Heater Supply	Header, 3-Pin		1
Signal N	Header, 3-Pin		1
Signal P	Header, 3-Pin		1
Temp. Sense	Header, 3-Pin		1
PT1000	IST P1K0.0805.2P.B	IST P1K0.0805.2P.B	1
J1	Jumper 2p Closed		1
J2	Jumper 2p Closed		1
J3	Jumper 2p Closed		1
R7, R16, R17, R18	Jumper 0805 (2012 Metric)		4
MH1, MH2	Mounting Hole		2
Q1	NPN Silicon, SOT-23, Pb-Free	MMBTA05LT3G	1
U1	Operational Amplifier RR, 5-pin SOT23, RoHS	TLV27L1IDBVR	1
U2	Operational Amplifier, TSSOP, Pb-Free	LM2902VDTBR2G	1
P1	RECEPTACLE, 2.54MM, R/A DUAL, 50WAY		1
Temp.Offset	Square Trimming Potentiometer 200R		1
Balance	Square Trimming Potentiometer 500R		1
5V	Test Point Single, Black		1
BR_B, BR_T, CTA+, CTA-, N, P, V_Out	Test Point Single, Black		7
GND1, GND2	Test Point		2
FS2	Thermal Mass Flow Sensor FS2T.0.1E.025	FS2T.0.1E.025	1
-->, <--, Enable, Power	Typical INFRARED GaAs LED		4

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8 Additional Documents

Document
ZSSC3154 Data Sheet
ZSSC3154 Functional Description
*SSC Command Syntax **
ZSSC3154 Evaluation Kit Description
ZSSC3154 Technical Note – Power Management

Visit www.IDT.com/ZSSC3154 and www.IDT.com/ZSSC3154KIT or contact your nearest sales office for the latest version of these documents.

* Note: Documents marked with an asterisk are available on: www.IDT.com.

9 Abbreviations

Term	Description
ADC	Analog-to-Digital Converter
AFE	Analog Front End
SSC	Sensor Signal Conditioner
BIST	Built-in Self-Test
XZC	Extended Zero Compensation (analog offset compensation)
GUI	Graphical User Interface

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10 Document Revision History

Revision	Date	Description
1.00	March 9, 2012	First release
2.00	June 2, 2014	Schematic and PCB updated.
2.10	March 17, 2015	Schematic and PCB updated. Software illustrations updated. Update for contact information. Minor edits for clarity.
2.11	March 26, 2015	Update for FS2 resistance specifications in Figure 3.2 and change from Pt600 to Pt710 in Figure 3.3 and section 3.3.
	April 1, 2016	Changed to IDT branding.

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