MICRO ANALOG SYSTEMS

DA6501.001
27 October 2008

MAS6501

16-Bit Analog-to-Digital Converter

This is preliminary information on a new product under development. Micro Analog Systems Oy reserves the right to make any changes without notice.

Preliminary

- **Standby Current Consumption 0.1 µA**
- **Low Supply Current**
- **Low Power Consumption**
- **Resolution 16 Bits**
- **Ratiometric ΔΣ ADC**
- **ENOB 14 Bits**
- **Serial Data Output (I^2C bus)**

DESCRIPTION

The MAS6501 is a 16 bit Analog-to-Digital Converter (ADC), which employs a delta-sigma (ΔΣ) conversion technique. With the linear input signal range of 282 mV_{PP} its resolution is 14 bits.

The MAS6501 is designed especially to meet the requirement for low power consumption, thus making it an ideal choice for battery powered systems. The MAS6501 is equipped with a standby function, i.e. the ADC is in power down between each conversion. By utilizing this and overall low power consumption, current consumption values of 1.6 µA (one pressure conversion in a second with full 14-bit accuracy) or less can be achieved.

The MAS6501 has an on-chip second order decimator filter to process the output of the second order ΔΣ -modulator. The ADC also has two selectable conversion ranges with two optional offset levels.

A bi-directional 2-wire I^2C bus is used for configuring conversion parameters, starting conversion and reading out the A/D conversion result.

MAS6501 has one input channel suitable for piezo resistive pressure sensor. In addition to pressure measurement configuration the device can be configured to temperature measurement.

FEATURES

- Low Standby Current Consumption 0.1 µA Typ
- Low Supply Current: 0.2 µA..1.6 µA
- Supply Voltage: 2.0 V…3.6 V
- Ratiometric ΔΣ Conversion
- Two Input Signal Ranges (VDD=2.35V):
  - 325 mV_{PP} , 98 mV_{PP}
- Two Optional Offsets (VDD=2.35V):
  - 123 mV, 33 mV
- Over Sampling Ratio: 512, 256, 128, 64
- Conversion Times 32.2 ms…2.5 ms
- In Fast Mode: Over Sampling Ratio 64, Conversion Time 2.5 ms, Resolution 10 Bits
- Good Noise Performance due to ΔΣ Architecture
- 2-Wire I^2C Interface

APPLICATIONS

- Battery Powered Systems
- Low Frequency Measurement Applications
- Pressure and Temperature Measurement
- Current/Power Consumption Critical Systems
- Industrial and Process Control Applications in Noisy Environments

I^2C is a registered trademark of Philips Inc.

BLOCK DIAGRAM

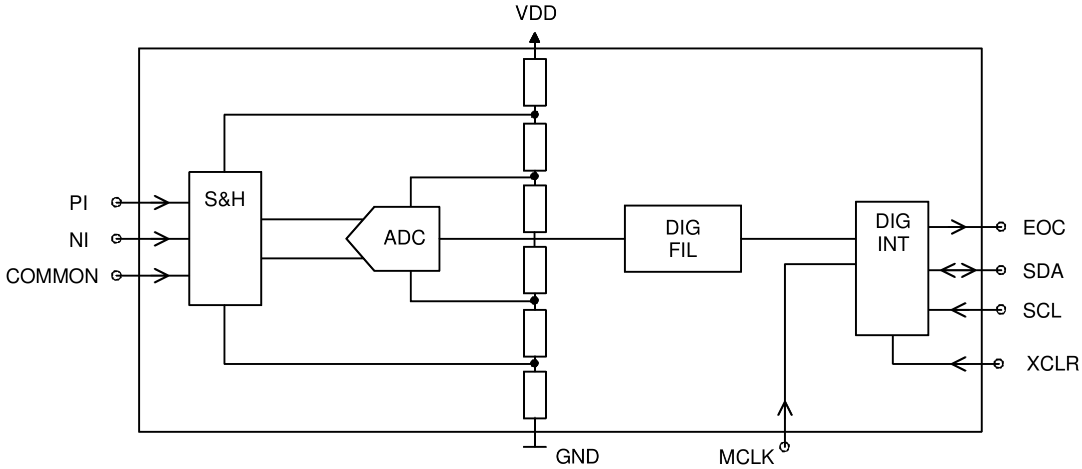


Figure 1. MAS6501 block diagram

ABSOLUTE MAXIMUM RATINGS

All Voltages with Respect to Ground

Parameter	Symbol	Conditions	Min	Max	Unit
Supply Voltage	V_{CC}	During conversion No conversion	- 0.3 - 0.3	3.8 6.0	V
Voltage Range for All Pins			- 0.3	V_{IN} + 0.3	V
Latchup Current Limit	I_{LUT}	For all pins, test according to Micro Analog Systems specification ESQ0141. See note below.	- 100	+ 100	mA
Junction Temperature	T_{Jmax}			+ 175	°C
Storage Temperature	T_S		- 55	+125	°C

Note: Stresses beyond the values listed may cause a permanent damage to the device. The device may not operate under these conditions, but it will not be destroyed.

Note: This is a CMOS device and therefore it should be handled carefully to avoid any damage by static voltages (ESD).

Note: In latchup testing the supply voltages are connected normally to the tested device. Then pulsed test current is fed to each input separately and device current consumption is observed. If the device current consumption increases suddenly due to test current pulses and the abnormally high current consumption continues after test current pulses are cut off then the device has gone to latch up. Current pulse is turned on for 10 ms and off for 20 ms.

RECOMMENDED OPERATION CONDITIONS

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Supply Voltage	V_{CC}		2.0	2.35	3.6	V
Operating Temperature	T_A		-20	+25	+60	°C

The device performance may deteriorate in the long run if the Recommended Operation Conditions limits are continuously exceeded.

ELECTRICAL CHARACTERISTICS

T_A = -20°C to +60°C, Typ T_A = 25°C, VDD = 2.35 V, R_{sensor} = 4.5kΩ unless otherwise noted

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Average ADC Current during Conversion Time (see Conversion Time at bottom)	I_{CONV}	Max value at VDD = 3.6 V		30	50	µA
Average ADC Current in Pressure and Temperature Measurement during Conversion Period (no sensor current included)	I_{ADC}	1 conversion/s (conversion period 1 s), XENMCLKDIV=1, R_{sensor} = 4.5 kΩ, Max value at VDD = 3.6 V OSR=512 OSR=256 OSR=128 OSR=64		 0.5 0.25 0.13 0.07	 0.9 0.5 0.3 0.2	µA
Average Supply Current in Pressure Measurement during Conversion Period (including sensor bridge current)	I_{SAVG_P}	1 conversion/s (conversion period 1 s), XENMCLKDIV=1, R_{sensor} = 4.5 kΩ, Max value at VDD = 3.6 V OSR=512 OSR=256 OSR=128 OSR=64		 1.6 0.8 0.5 0.3	 2.5 1.3 0.7 0.4	µA
Average Supply Current in Temperature Measurement (including sensor bridge current)	I_{SAVG_T}	1 conversion/s (conversion period 1 s), XENMCLKDIV=1, R_{sensor} = 4.5 kΩ, Max value at VDD = 3.6 V OSR=512 OSR=256 OSR=128 OSR=64		 0.9 0.5 0.3 0.2	 1.5 0.8 0.4 0.3	µA
Peak Supply Current During Pressure Measurement	I_{SC}	VDD = 2.35 V, R_{sensor} = 4.5 kΩ		0.52		mA
Peak Supply Current During Temperature Measurement	I_{SC}	VDD = 2.35 V, R_{sensor} = 4.5 kΩ		0.19		mA
Standby Current	I_{SS}	VDD = 2.35 V		0.1	0.5	µA
Conversion Time	t_{CONV}	MCLK = 32768 Hz, XENMCLKDIV=1 OSR=512 OSR=256 OSR=128 OSR=64		 16.1 8.3 4.4 2.5		ms

Note: XENMCLKDIV refer to the I^2C serial interface control bits, see table 1 on page 5.

ELECTRICAL CHARACTERISTICS

T_A = -20°C to +60°C, Typ T_A = 25°C, VDD = 2.35 V, R_{sensor} = 4.5kΩ unless otherwise noted

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Resolution				16		Bit
		ISR = 325 mV ISR = 98 mV		4.9 1.5		µV
Accuracy		ISRLIN = 282 mV, OSR = 512 ISRLIN = 85 mV, OSR = 512		17 5.1		µV
Integral Nonlinearity	INL			4		LSB
Differential Nonlinearity	DNL			3		LSB
ENOB (Effective Number of Bits)		ISRLIN = 282 mV OSR=512 OSR=256 OSR=128 OSR=64		 14 13 12 10		Bit
External Clock Signal	MCLK		30000	32768	35000	Hz
Delay Between End of Conversion and ADC Result Read-Out	t_{DEL}	MCLK = 32768 Hz	0.1			ms
Duty Cycle of MCLK	DUTYC	Master Clock Division Enabled XENMCLKDIV=0	60/40	50/50	40/60	%
Serial Data Clock	SCL				400	kHz
Input Signal Conversion Range	ISR	ISCR = 1 ISCR = 0		325 98		mV
Linear Input Signal Conversion Range	ISRLIN	ISCR = 1 ISCR = 0		282 85		mV
Output Code Values			0		65152	
Temperature Measurement Resistors	R_1 R_2 R_3 R_4		-15%	7710 17000 3073 17000	+15%	Ω
Temperature Measurement Resistors Temp Coefficient	TC_R		TBD	-280	TBD	ppm / °C

Note: ISCR refer to the I²C serial interface control bits, see table 1 on page 5.
TBD = To Be Defined

MAS6501 CONTROL REGISTER

Table 1. MAS6501 control register bit description

Bit Number	Bit Name	Description	Value	Function
7-6	OSRS(1:0)	Over Sampling Ratio (OSR) selection	11 01 10 00	OSR = 512 OSR = 256 OSR = 128 OSR = 64
5	SCO	Start Conversion	0 1	No Conversion Start Conversion
4	PTS	Pressure/Temperature Selection	1 0	Pressure configuration Temperature configuration
3	ISCR	Input Signal Conversion Range	1 0	325 mV (282 mV linear range) 98 mV (85 mV linear range)
2	XENMCLKDIV	Enable Master Clock Division	0 1	MCLK division enabled MCLK division disabled
1	XOSENABLE	Enable offset	0 1	Offset enabled Offset disabled
0	OSSELECT	Offset value selection	1 0	+123 mV +33 mV

MAS6501 has one control register for configuring the measurement setup. See table 1 for control register bit definitions. Control register values are set via I2C bus.

First two OSRS bits of the control register define four selectable over sampling ratios. The higher OSR the better ADC accuracy but the longer conversion time.

The SCO bit controls the A/D conversion. When SCO = 0, no A/D conversion takes place. When SCO = 1, the A/D converter turns on and the analog data is being converted. Then MCLK must be clocked at least until EOC pin goes high indicating that conversion has been accomplished.

PTS bit selects between pressure and temperature measurement. In temperature measurement the sensor is connected in bridge configuration together with four integrated resistors (see figure 3 on page 8 and resistors R1, R2, R3 and R4).

ISCR selects between two A/D conversion ranges.

The XENMCLKDIV bit controls the internal clock frequency of MAS6501, fCLK(INT). When the bit is low, the MCLK division is enabled and the internal clock frequency fCLK(INT) = fMCLK/2, where fMCLK is the master clock frequency. When the XENMCLKDIV bit is high, the MCLK division is disabled and fCLK(INT) = fMCLK.

In the XENMCLKDIV = 1 mode the duty cycle should be as close to 50 % as possible. In this mode, the conversion time is made half (see page 3 conversion time values with XENMCLKDIV = 1) compared to clock speed division mode XENMCLKDIV = 0 whereas the resolution remains unchanged. In XENMCLKDIV = 0 mode the conversion time and also current consumption are doubled but then the external master clock signal MCLK does not need to have close to 50% duty cycle.

XOSENABLE can be used to enable input signal range offset option. At 1 value no offset is applied but at 0 value an offset value which is determined with OSSELECT bit is used.

OSSELECT selects between two offset values. No offset is applied if offset is disabled (XOSENABLE=1).

I²C SERIAL INTERFACE CONTROL

Serial Interface

MAS6501 has two wire serial I2C bus type interface comprising of serial clock (SCL) and serial data (SDA) pins. I2C bus is used to write configuration data to sensor interface IC and read the measurement result when A/D conversion has been finished.

Digital interface includes also master clock (MCLK), end of conversion (EOC) and master reset (XCLR) pins.

MLCK signal is needed to be clocked during conversion period. It can be stopped after EOC goes high which indicates that A/D conversion has been accomplished. MCLK signal can also be running all the time.

XCLR is used to reset the A/D converter. Reset initializes internal registers and counters. After connecting supply voltage to MAS6501 and before starting operating the device via I2C bus it is required to reset the device with XCLR reset pin if supply voltage rise time has been longer than 400 ns. If the supply voltage rise time is shorter than this the external reset with XCLR pin is unnecessary since the device is automatically reset by power on reset (POR) circuitry.

Device and Register Addresses

I2C bus standard makes it possible to connect several I2C bus devices into same bus. The devices are distinguished from each other by unique device address codes. MAS6501 device address is shown in table 2. The LSB bit of the device address defines whether the bus is configured to Read (1) or Write (0) operation.

Table 2. MAS6501 device address

A7	A6	A5	A4	A3	A2	A1	W/R
1	1	1	0	1	1	1	0/1

MAS6501 contains three 8-bit registers which are presented in table 3. Control register is used to configure the device to proper measurement setup. Control register bits are described in table 1 (page 5). Two other 8-bit registers are used to store the 16-bit A/D conversion result.

Table 3. MAS6501 internal register addresses

A7	A6	A5	A4	A3	A2	A1	A0	Register Description
1	1	1	1	1	1	0	1	MSB A/D Conversion Result Register
1	1	1	1	1	1	1	0	LSB A/D Conversion Result Register
1	1	1	1	1	1	1	1	Control register

I^2C SERIAL INTERFACE CONTROL...

I2C Bus Protocol Definitions

Two wire I2C bus protocol has special bus signal conditions. Figure 2 shows start (S), stop (P) and binary data conditions. At start condition the SCL is high and SDA has falling edge. At stop condition the SCL is also high but SDA has rising edge. Data must be held stable in SDA pin when SCL is high. Data can change value at SDA pin only when SCL is low.

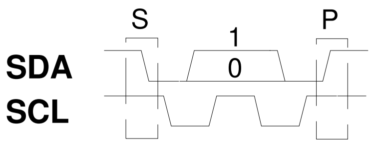


Figure 2. I2C protocol definitions

I2C contains also acknowledge (A) and not acknowledge (N) commands. At acknowledge the master device sends 0 bit to SDA bus (pulls down SDA) for one SCL clock cycle. At not acknowledge (N) the slave device sends 0 bit to SDA (pulls down SDA) for one SCL clock cycle.

Abbreviations:
A= Acknowledge by Slave
N = Not Acknowledge by Master
S = Start
P = Stop

Conversion Starting – Write Sequence

Conversion is started by first writing measurement configuration bits into the control register. Write sequence is illustrated in Table 4. To start conversion the control register SCO bit has to be set high (SCO=1, see control register bit description in table 1).

Table 4. MAS6501 I2C bus write sequence bits

S	AW	A	AC	A	DC	A	P

Abbreviations:
AW = Device Write Address (%1110 1110)
AR = Device Read Address (%1110 1111)
AC = Control Register Address (%1111 1111)
Ax = MSB (x=M, %1111 1101) or LSB (x=L, %1111 1110) ADC Result Register Address
DC = Control Register Data
Dx = MSB (x=M) or LSB (x=L) A/D Result Register Data

Each I2C bus operation like write starts with start command (see figure 2). After start the MAS6501 device address with write bit (AW, see table 2) is sent and ended to acknowledge (A). After this control register address (AC, see table 3) is sent and ended to acknowledge (A). Next control register data (DC, see table 1) is written and ended to acknowledge (A). Finally the I2C bus operation is ended with stop command (see figure 2).

A/D Conversion

A/D conversion is progressed by running MCLK signal until EOC goes high indicating that conversion is done and data is ready for reading.

I²C SERIAL INTERFACE CONTROL...

Conversion Result – Read Sequence

Table 5 presents general control sequence for single register data read.

Table 5. MAS6501 I2C bus single register (address Ax) read sequence bits

S	AW	A	Ax	A	S	AR	A	Dx	N	P

Table 6 presents control sequence for reading the 16-bit A/D conversion result from both MSB and LSB data registers. LSB register data (DL) can be read right after MSB register data (DM) read since in case the read sequence is continued (not ended to stop condition P) the register address is automatically incremented to point to next register address (in this case to point to the LSB data register).

Table 6. MAS6501 I2C bus MSB (first) and LSB (second) A/D conversion result read sequence

S	AW	A	AM	A	S	AR	A	DM	N	DL	N	P

Accuracy Improvement – Averaging

Averaging technique can be used to remove conversion error caused by noise and thus improve measurement accuracy. By accomplishing several A/D conversions and taking average of the samples it is possible to average out noise. Theoretically noise is reduced by factor $\sqrt{N}$ where N is number of averaged samples. A/D converter nonlinearities cannot be removed by averaging.

APPLICATION INFORMATION

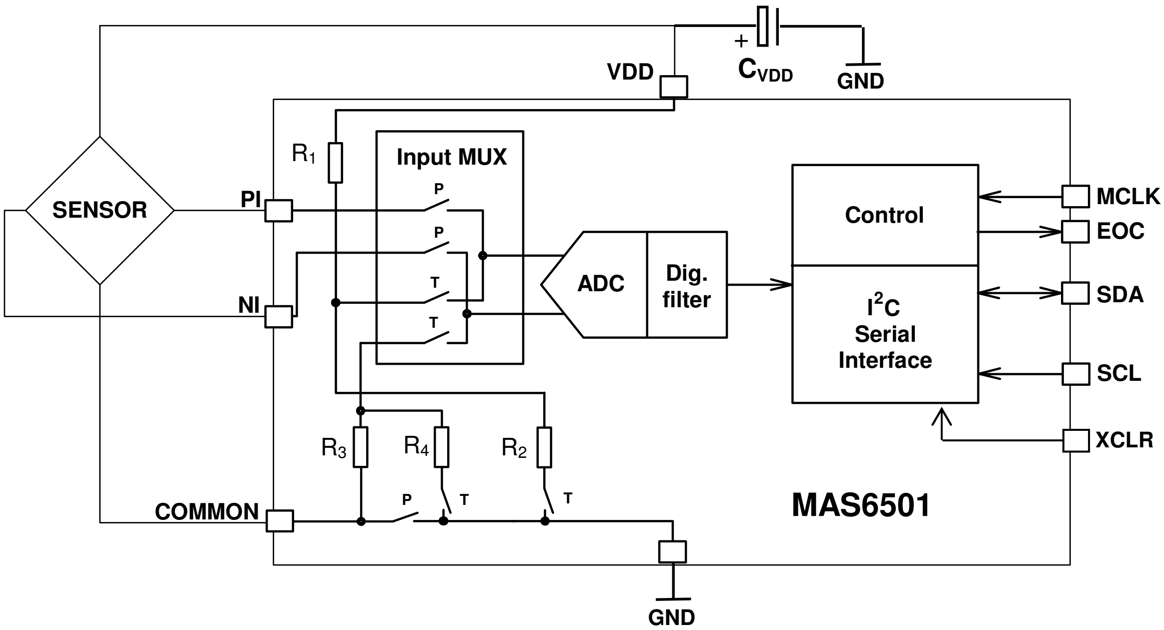


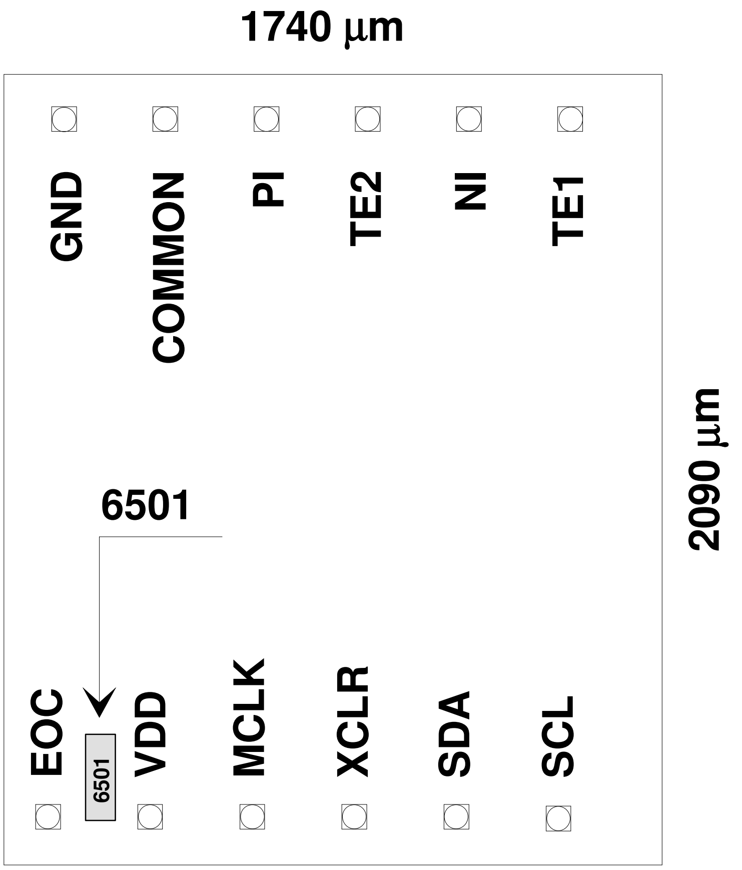
Figure 3. Resistive sensor connection circuit

Together with a resistive pressure sensor, MAS6501 can be used in pressure measurement applications. Control can be performed with a micro-controller through the I^2C serial interface.

The sensor is connected between the power supply voltage (VDD) and MAS6501 signal ground (COMMON) which can be internally (switch inside of MAS6501) connected to ground (GND). Sensor output is read as a differential signal through PI (positive input) and NI (negative input) to the ΔΣ converter in MAS6501.
In the pressure measurement mode, the switches marked “P” are closed and the sensor output is fed through to the ADC. In the temperature measurement mode, the switches marked “T” are closed and the voltage at the ADC input is determined by the internal resistor array and the temperature-dependent resistance of the sensor. In this configuration the sensor bridge is connected as part of single four resistor bridge circuit where other four resistors (R1, R2, R3, R4) are inside the IC.

To guarantee conversion accuracy a supply voltage decoupling capacitor of 4.7 µF or more should be placed between VDD and GND of MAS6501 (see C_{VDD} in figure 3).

MAS6501 PAD LAYOUT



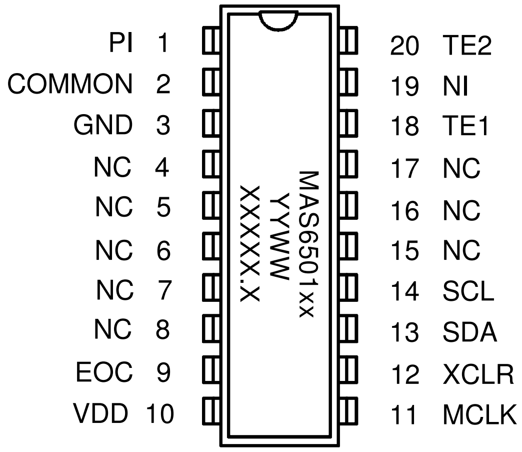
Die dimensions 1740 µm x 2090 µm; round PAD ∅ 80 µm

Note: Because the substrate of the die is internally connected to GND, the die has to be placed over a GND plate on PCB or left floating. Please make sure that GND is the first pad to be bonded. Pick-and-place and all component assembly are recommended to be performed in ESD protected area.
Note: Coordinates are pad center points where origin has been located in the center of the silicon die.

Pad Identification	Name	X-coordinate	Y-coordinate
End of Conversion	EOC	-713 µm	-839 µm
Power Supply	VDD	-450 µm	-839 µm
Master Clock	MCLK	-200 µm	-839 µm
Clear I2C, Stop Conversion	XCLR	-18 µm	-839 µm
Serial Bus Data Input/Output	SDA	318 µm	-839 µm
Serial Bus Clock	SCL	726 µm	-839 µm
Supply Ground	GND	-713 µm	839 µm
Sensor Ground	COMMON	-450 µm	839 µm
ADC Positive Input	PI	-200 µm	839 µm
Test Pin 2	TE2	-18 µm	839 µm
ADC Negative Input	NI	318 µm	839 µm
Test Pin 1	TE1	726 µm	839 µm

Note: Test pins TE1 and TE2 must be left floating.

SAMPLES IN SBDIL 20 PACKAGE



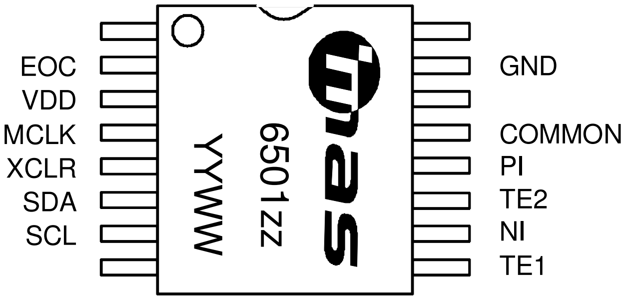
Top Marking Definitions:
YYWW = Year Week
XXXXX.X = Lot Number
xx = Sample Version

PIN DESCRIPTION

Pin Name	Pin	Type	Function	Notes
PI	1	AI	ADC Positive Input	
COMMON	2	AI	Sensor Ground	
GND	3	G	Supply Ground	
	4	NC		
	5	NC		
	6	NC		
	7	NC		
	8	NC		
EOC	9	DO	End of Conversion	
VDD	10	P	Power Supply	
MCLK	11	DI	Master Clock	
XCLR	12	DI	Clear I2C, Stop Conversion	
SDA	13	DI/O	Serial Bus Data Input/Output	
SCL	14	DI	Serial Bus Clock	
	15	NC		
	16	NC		
	17	NC		
TE1	18	DI/O	Test Pin 1	Pin must be left floating
NI	19	AI	ADC Negative Input	
TE2	20	DI	Test Pin 2	Pin must be left floating

A = Analog, D = Digital, P = Power, G = Ground, I = Input, O = Output, NC = Not Connected

PIN CONFIGURATION & TOP MARKING FOR PLASTIC TSSOP-16 PACKAGE



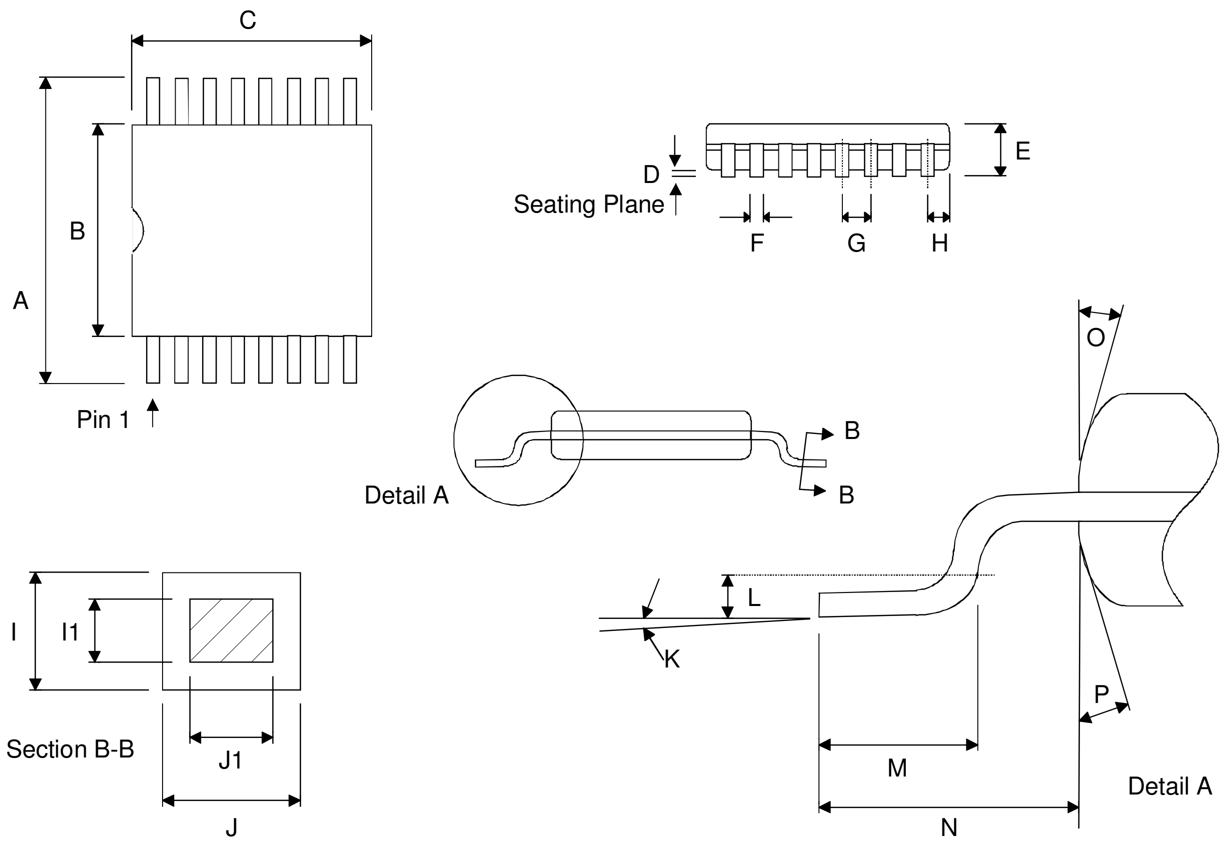
Top Marking Definitions:
zz = Version
YYWW = Year Week

PIN DESCRIPTION

Pin Name	Pin	Type	Function	Note
	1	NC		
EOC	2	DO	End of Conversion	
VDD	3	P	Power Supply	
MCLK	4	DI	Master Clock	
XCLR	5	DI	Clear I2C, Stop Conversion	
SDA	6	DI/O	Serial Bus Data Input/Output	
SCL	7	DI	Serial Bus Clock	
	8	NC		
TE1	9	DI/O	Test Pin 1	Pin must be left floating
NI	10	AI	ADC Negative Input	
TE2	11	DI	Test Pin 2	Pin must be left floating
PI	12	AI	ADC Positive Input	
COMMON	13	AI	Sensor Ground	
	14	NC		
GND	15	G	Supply Ground	
	16	NC		

A = Analog, D = Digital, P = Power, G = Ground, I = Input, O = Output, NC = Not Connected

PACKAGE (TSSOP-16) OUTLINES



Dimension	Min	Max	Unit
A	6.40 BSC		mm
B	4.30	4.50	mm
C	5.00 BSC		mm
D	0.05	0.15	mm
E		1.10	mm
F	0.19	0.30	mm
G	0.65 BSC		mm
H	0.18	0.28	mm
I	0.09	0.20	mm
I1	0.09	0.16	mm
J	0.19	0.30	mm
J1	0.19	0.25	mm
K	0°	8°	
L	0.24	0.26	mm
M (The length of a terminal for soldering to a substrate)	0.50	0.75	mm
N	1.00 REF		mm
O	12°		
P	12°		

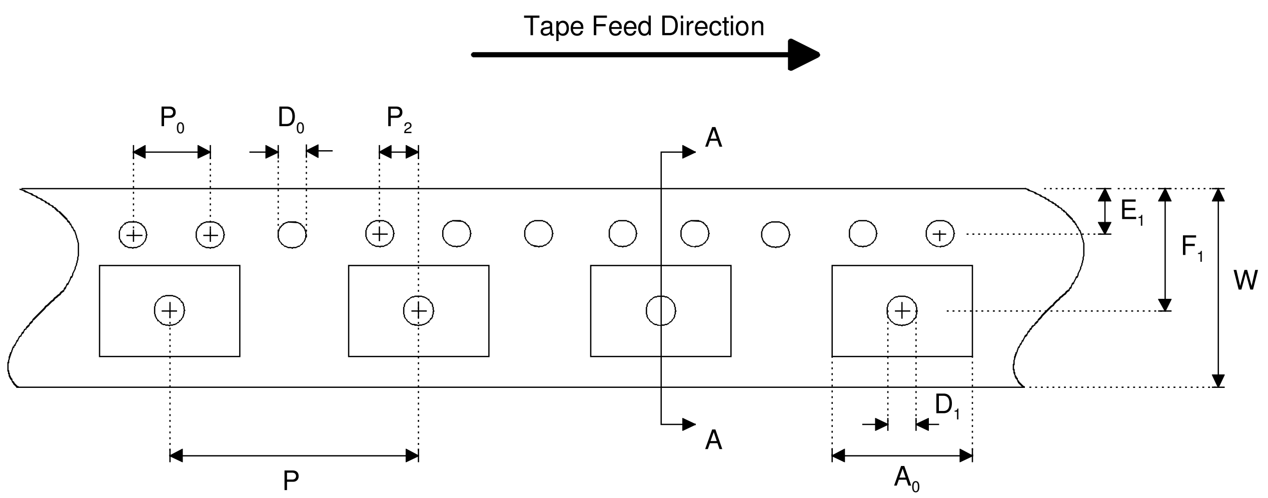
Dimensions do not include mold flash, protrusions, or gate burrs.
All dimensions are in accordance with JEDEC standard MO-153.

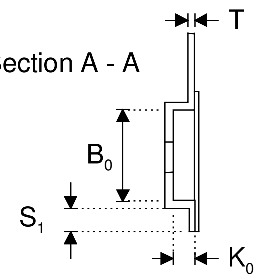
SOLDERING INFORMATION

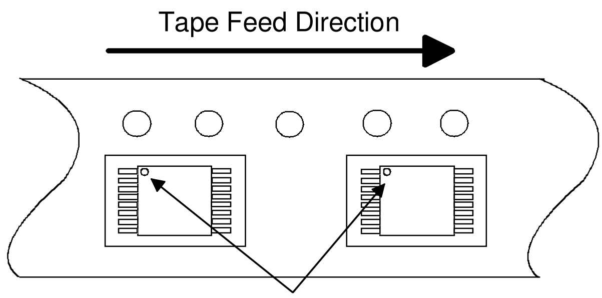
◆ **For Pb-Free, RoHS Compliant TSSOP-16**

Resistance to Soldering Heat	According to RSH test IEC 68-2-58/20
Maximum Temperature	260°C
Maximum Number of Reflow Cycles	3
Reflow profile	Thermal profile parameters stated in IPC/JEDEC J-STD-020 should not be exceeded. http://www.jedec.org
Seating Plane Co-planarity	max 0.08 mm
Lead Finish	Solder plate 7.62 - 25.4 µm, material Matte Tin

EMBOSSED TAPE SPECIFICATIONS

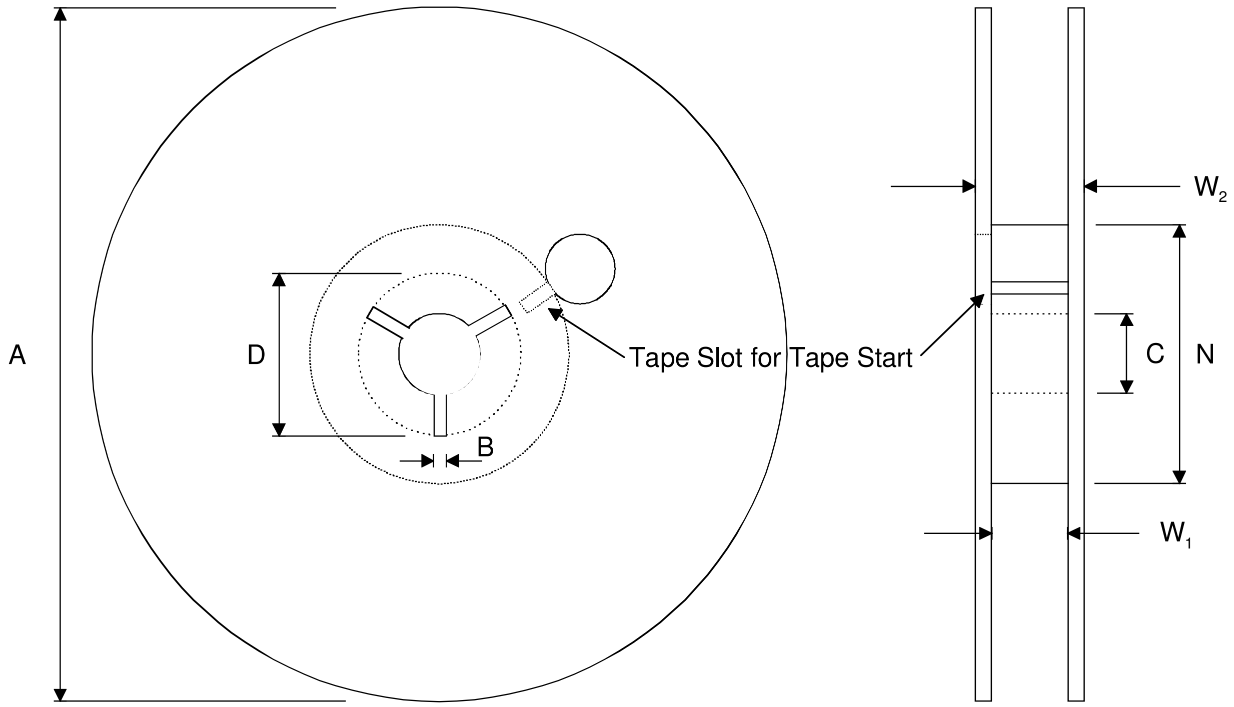






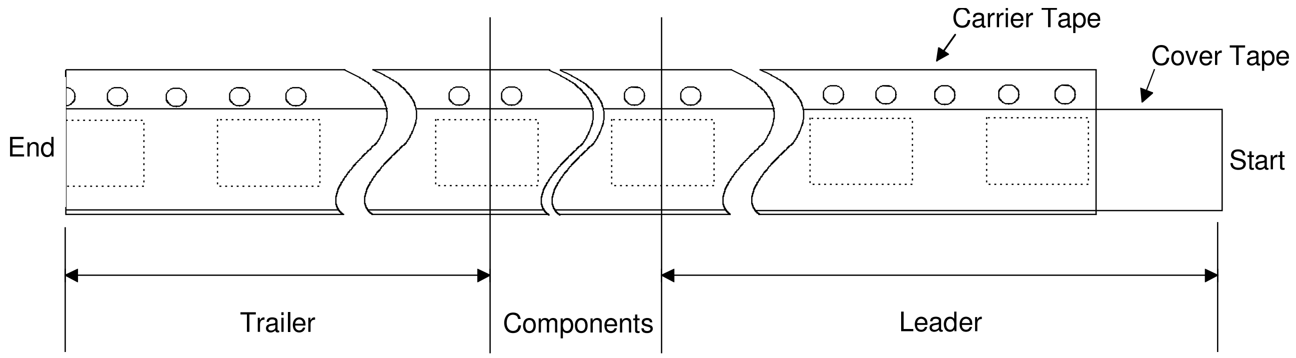
Dimension	Min	Max	Unit
A_0	6.50	6.70	mm
B_0	5.20	5.40	mm
D_0	1.50 +0.10 / -0.00		mm
D_1	1.50		mm
E_1	1.65	1.85	mm
F_1	7.20	7.30	mm
K_0	1.20	1.40	mm
P	11.90	12.10	mm
P_0	4.0		mm
P_2	1.95	2.05	mm
S_1	0.6		mm
T	0.25	0.35	mm
W	11.70	12.30	mm

REEL SPECIFICATIONS



2000 Components on Each Reel

Reel Material: Conductive, Plastic Antistatic or Static Dissipative
Carrier Tape Material: Conductive
Cover Tape Material: Static Dissipative



Dimension	Min	Max	Unit
A		330	mm
B	1.5		mm
C	12.80	13.50	mm
D	20.2		mm
N	50		mm
W_1 (measured at hub)	12.4	14.4	mm
W_2 (measured at hub)		18.4	mm
Trailer	160		mm
Leader	390, of which minimum 160 mm of empty carrier tape sealed with cover tape		mm
Weight		1500	g

ORDERING INFORMATION

Product Code	Product	Description
MAS6501BA1WA300	16-Bit A/D-Converter	EWS-tested wafer, Thickness 400 µm.
MAS6501BA1ST206	16-Bit A/D-Converter	TSSOP-16, Pb-free, RoHS compliant, Tape & Reel

Contact Micro Analog Systems Oy for other wafer thickness options.

LOCAL DISTRIBUTOR

MICRO ANALOG SYSTEMS OY CONTACTS

Micro Analog Systems Oy Kamreerintie 2, P.O. Box 51 FIN-02771 Espoo, FINLAND	Tel. +358 9 80 521 Fax +358 9 805 3213 http://www.mas-oy.com