LAMPIRAN A

PROGRAM CODE VISION AVR

```
/*****************************************************

This program was produced by the

CodeWizardAVR V2.05.0 Evaluation

Automatic Program Generator

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Project : Realisasi Alat Ukur pH dan Tds Air Berbasis Mikrokontroler ATMega 16

Version :

Date    : 3/12/2013

Author  : Freeware, for evaluation and non-commercial use only

Company : Jurusan Teknik Elektro Universitas Kristen Maranatha

Comments:

Chip type               : ATmega16

Program type            : Application

AVR Core Clock frequency: 16.000000 MHz

Memory model            : Small

External RAM size       : 0

Data Stack size         : 256

*****************************************************/
```

```
// Header Program
#include <mega16.h>
#include <delay.h>
#include <stdlib.h>
// Alphanumeric LCD Module functions
#include <alcd.h>
#define ADC_VREF_TYPE 0x40
//Inisisalisasi Variabel-variabel yang digunakan
char PH[8];
char TDS[8];
char suhu[8];
float ppm,kadar_ph,celcius, Total1,Total2,Total3,Rata1,Rata2,Rata3,suhu_tds;
unsigned int Baca0,Baca6,Baca7;
int i;
// Read the AD conversion result
unsigned int read_adc(unsigned char adc_input)
{
ADMUX=adc_input | (ADC_VREF_TYPE & 0xff);
// Delay needed for the stabilization of the ADC input voltage
delay_us(10);
// Start the AD conversion
ADCSRA|=0x40;
```

```
// Wait for the AD conversion to complete
while ((ADCSRA & 0x10)==0);
ADCSRA|=0x10;
return ADCW;
}
// Declare your global variables here
void main(void)
{
// Declare your local variables here
// Input/Output Ports initialization
// Port A initialization
// Func7=In Func6=In Func5=In Func4=In Func3=In Func2=In Func1=In Func0=In
// State7=T State6=T State5=T State4=T State3=T State2=T State1=T State0=T
PORTA=0x00;
DDRA=0x00;
// Port B initialization
// Func7=In Func6=In Func5=In Func4=In Func3=In Func2=In Func1=In Func0=In
// State7=T State6=T State5=T State4=T State3=T State2=T State1=T State0=T
PORTB=0x00;
DDRB=0x00;
// Port C initialization
// Func7=In Func6=In Func5=In Func4=In Func3=In Func2=In Func1=In Func0=In
```

```
// State7=T State6=T State5=T State4=T State3=T State2=T State1=T State0=T
PORTC=0x00;
DDRC=0x00;
// Port D initialization
// Func7=In Func6=In Func5=In Func4=In Func3=In Func2=In Func1=In Func0=In
// State7=T State6=T State5=T State4=T State3=T State2=T State1=T State0=T
PORTD=0x00;
DDRD=0x00;
// Timer/Counter 0 initialization
// Clock source: System Clock
// Clock value: Timer 0 Stopped
// Mode: Normal top=0xFF
// OC0 output: Disconnected
TCCR0=0x00;
TCNT0=0x00;
OCR0=0x00;
// Timer/Counter 1 initialization
// Clock source: System Clock
// Clock value: Timer1 Stopped
// Mode: Normal top=0xFFFF
// OC1A output: Discon.
// OC1B output: Discon.
```

```
// Noise Canceler: Off
// Input Capture on Falling Edge
// Timer1 Overflow Interrupt: Off
// Input Capture Interrupt: Off
// Compare A Match Interrupt: Off
// Compare B Match Interrupt: Off
TCCR1A=0x00;
TCCR1B=0x00;
TCNT1H=0x00;
TCNT1L=0x00;
ICR1H=0x00;
ICR1L=0x00;
OCR1AH=0x00;
OCR1AL=0x00;
OCR1BH=0x00;
OCR1BL=0x00;
// Timer/Counter 2 initialization
// Clock source: System Clock
// Clock value: Timer2 Stopped
// Mode: Normal top=0xFF
// OC2 output: Disconnected
ASSR=0x00;
```

```
TCCR2=0x00;

TCNT2=0x00;

OCR2=0x00;

// External Interrupt(s) initialization

// INT0: Off

// INT1: Off

// INT2: Off

MCUCR=0x00;

MCUCSR=0x00;

// Timer(s)/Counter(s) Interrupt(s) initialization

TIMSK=0x00;

// USART initialization

// USART disabled

UCSRB=0x00;

// Analog Comparator initialization

// Analog Comparator: Off

// Analog Comparator Input Capture by Timer/Counter 1: Off

ACSR=0x80;

SFIOR=0x00;

// ADC initialization

// ADC Clock frequency: 125.000 kHz

// ADC Voltage Reference: AVCC pin
```

```
// ADC Auto Trigger Source: ADC Stopped

ADMUX=ADC_VREF_TYPE & 0xff;

ADCSRA=0x87;

// SPI initialization

// SPI disabled

SPCR=0x00;

// TWI initialization

// TWI disabled

TWCR=0x00;

// Alphanumeric LCD initialization

// Connections specified in the

// Project|Configure|C Compiler|Libraries|Alphanumeric LCD menu:

// RS - PORTC Bit 0

// RD - PORTC Bit 1

// EN - PORTC Bit 2

// D4 - PORTC Bit 4

// D5 - PORTC Bit 5

// D6 - PORTC Bit 6

// D7 - PORTC Bit 7

// Characters/line: 16

lcd_init(16);

lcd_clear();
```

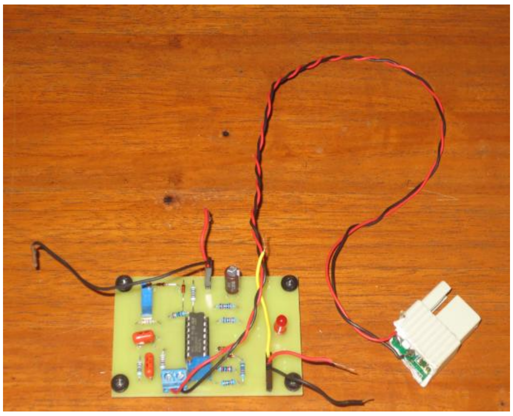
```
lcd_gotoxy(0,0);
lcd_putsf("++PH dan TDS++");
lcd_gotoxy(0,1);
lcd_putsf("BY SANDI");
delay_ms(1000);
//Inisialisasi Awal untuk program rata-rata
i=0;
Total1=0;
Total2=0;
Total3=0;
while (1)
    { i++;
    Baca0=read_adc(0);//Baca Adc (0)
    ppm=((float)Baca0*500/1024) ;//Rumus untuk Menghitung Nilai Tds
    Total1=Total1+ppm;//Menjumlahkan nilai ppm dan dimasukan ke variabel Total1
    Baca7=read_adc(7); //Baca Adc(7)
    kadar_ph=(-3.811*(float)Baca7*5/1024)+13.63;//Rumus Untuk Menghitung Nilai
                                                 pH
    Total2=Total2+kadar_ph ; //Menjumlahkan kadar_pH  dan dimasukan ke variabel
                             Total2
    Baca6=read_adc(6);  //Baca Adc(6)
    celcius=((float)Baca6*500/1024) ; //Rumus Untuk Menghitung Nilai Suhu
```

```
Total3=Total3+celcius; //Menjumlahkan celcius dan dimasukan ke variabel
                        Total3
delay_ms(200);
if(i==20)
{
Rata1=Total1/20;//rata-rata nilai Tds
Rata2=Total2/20; //rata-rata nilai pH
Rata3=Total3/20; //rata-rata nilai suhu
suhu_tds=((Rata1*((1+(0.0214*(Rata3-25)))))) ; //Rumus Menghitung koreksi
                                                  suhu terhadap tds
delay_ms(100);
lcd_clear();
lcd_gotoxy(0,0);
lcd_putsf("TDS= ");//menampilkan tulisan TDS pada baris 0 kolom 0
lcd_gotoxy(7,0);
lcd_putsf("ppm/");//menampilkan tulisan ppm/ pada baris 7  kolom 0
lcd_gotoxy(0,1);
lcd_putsf("PH=");//menampilkan tulisan PH pada baris 0 kolom 1
lcd_gotoxy(13,0);
lcd_putchar(0xdf);//menampilkan karakter derajat
lcd_putsf("C");  //menampilkan tulisan C
ftoa(suhu_tds,0,TDS);//mengubah tipe data float ke data array
```

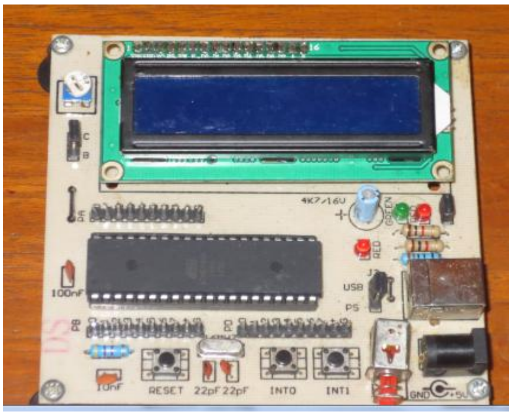
```
ftoa(Rata2,2,PH);//mengubah tipe data float ke data array dengan nilai ph 2 angka
                    dibelakang koma
ftoa(Rata3,0,suhu);//mengubah tipe data float ke data array
lcd_gotoxy(4,0);
lcd_puts(TDS);   //menampilkan nilai TDS  pada baris 4 kolom 0
lcd_gotoxy(3,1);
lcd_puts(PH); //menampilkan nilai pH  pada baris 3 kolom 1
lcd_gotoxy(11,0);
lcd_puts(suhu);//menampilkan nilai suhu pada pada baris 11 kolom 0
//Kembali ke inisialisasi awal untuk  program rata-rata
i=0;
Total1=0;
Total2=0 ;
Total3=0;
delay_ms(1000);
} ;
}


// Place your code here


}
```

LAMPIRAN B

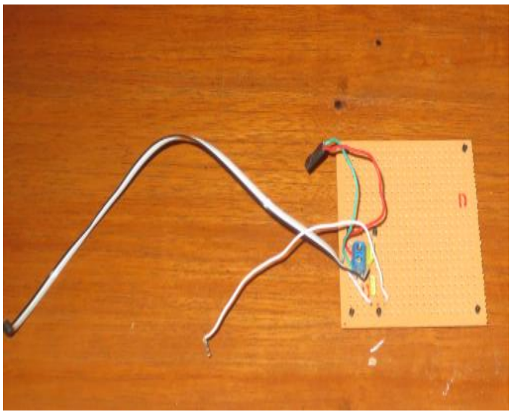
TAMPILAN REALISASI ALAT UKUR PH DAN TDS AIR BERBASIS MIKROKONTROLER ATMEGA16



SENSOR TDS

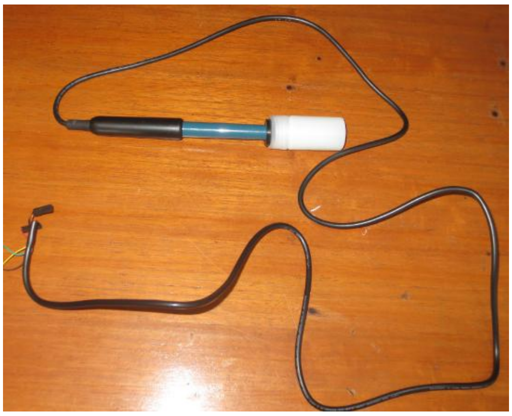


MINIMUM SISTEM

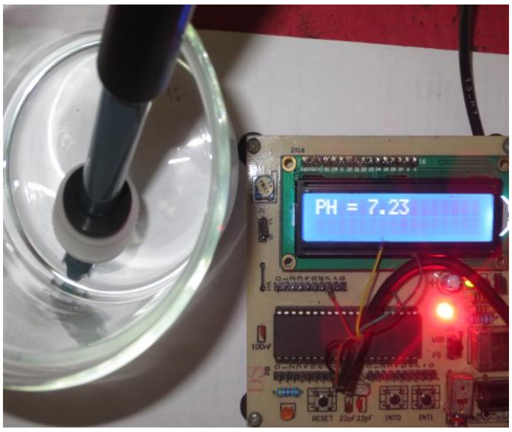


SENSOR TEMPERATURE

ALAT UKUR DIST3 HANNA INSTRUMENT



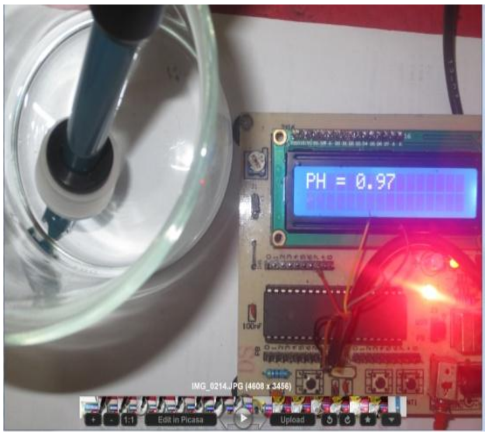
SENSOR PH VERNIER-BTA



PENGUKURAN PH AIR SAMPEL C

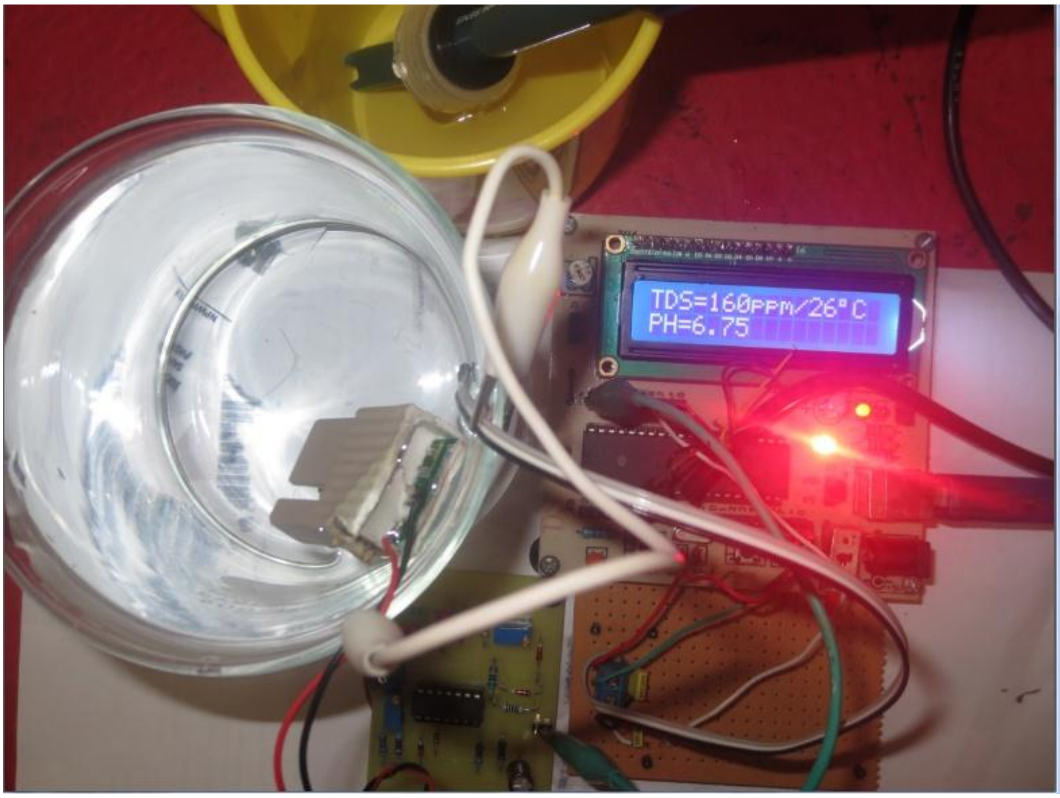
PENGUKURAN PH AIR CUKA

PENGUKURAN PH AIR SABUN



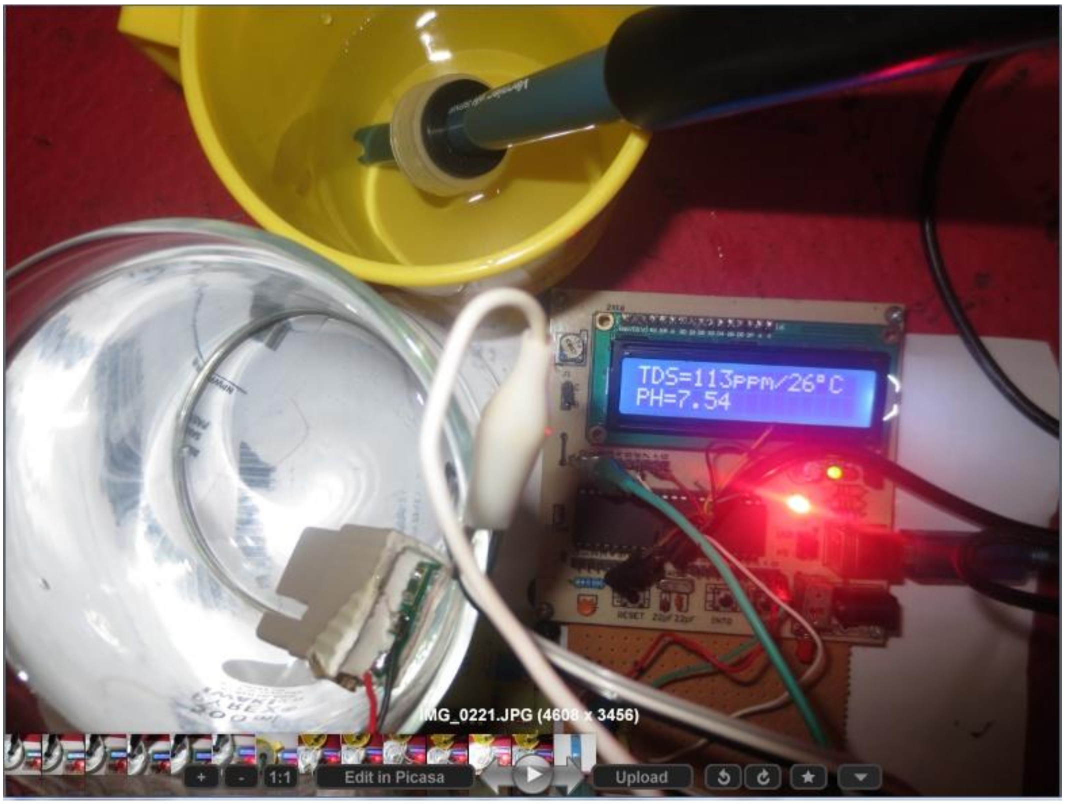
PENGUKURAN HCL

PENGUKURAN PH DAN TDS AIR SAMPEL C



PENGUKURAN PH DAN TDS SAMPEL D

PENGUKURAN PH DAN TDS AIR SAMPEL A



PENGUKURAN PH DAN TDS AIR SAMPEL B

LAMPIRAN C

LAPORAN HASIL PENGUKURAN TDS DI PT SUCOFINDO

Sertifikat No. 00628/BBBFAG
Tanggal: 12 April 2013

SUCOFINDO

LAPORAN HASIL ANALISA

PEMBERI ORDER	:	SANDI Pasteur - Bandung
JENIS SAMPLE	:	AIR LIMBAH
TANGGAL TERIMA SAMPLE	:	11 April 2013
TANGGAL ANALISA	:	11 – 12 April 2013
ANALISA / UJI	:	Total Dissolved Solid
KETERANGAN SAMPLE	:	Sampel dikirim oleh pelanggan dengan keterangan sbb - Kemasan : Botol plastik - Volume : 4 X 600 mL
IDENTITAS SAMPLE	:	" A, B, C & D "

Parameter	Satuan	Hasil				Metoda *)
		A	B	C	D	
Total Dissolved Solid	mg/l	64	108	156	154	2540 C

*) Standard methods 22nd edition 2012 APHA-AWWA-WEF

Bidang Pengujian, Konsultansi dan Jasa Lain

BDGOP2201300552

Tuti Gantini

1373822

LAMPIRAN D

DATASHEET SENSOR LM35,SENSOR PH VERNIER BTA, AND MICROCONTROLLER ATMEGA 16

National Semiconductor

December 1994

LM35/LM35A/LM35C/LM35CA/LM35D Precision Centigrade Temperature Sensors

General Description

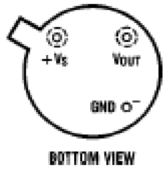
The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in ° Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±¼°C at room temperature and ±¾°C over a full −55 to +150°C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1°C in still air. The LM35 is rated to operate over a −55° to +150°C temperature range, while the LM35C is rated for a −40° to +110°C range (−10° with improved accuracy). The LM35 series is available packaged in hermetic TO-46 transistor packages, while the LM35C, LM35CA, and LM35D are also available in the plastic TO-92 transistor package. The LM35D is also available in an 8-lead surface mount small outline package and a plastic TO-202 package.

Features

- Calibrated directly in ° Celsius (Centigrade)
- Linear + 10.0 mV/°C scale factor
- 0.5°C accuracy guaranteeable (at +25°C)
- Rated for full −55° to +150°C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 µA current drain
- Low self-heating, 0.08°C in still air
- Nonlinearity only ±¼°C typical
- Low impedance output, 0.1 Ω for 1 mA load

Connection Diagrams

TO-46
Metal Can Package*

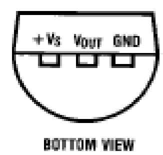


TL/H/5516–1

*Case is connected to negative pin (GND)

Order Number LM35H, LM35AH, LM35CH, LM35CAH or LM35DH
See NS Package Number H03H

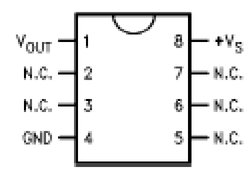
TO-92
Plastic Package



TL/H/5516–2

Order Number LM35CZ, LM35CAZ or LM35DZ
See NS Package Number Z03A

SO-8
Small Outline Molded Package



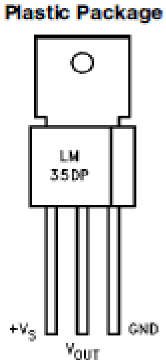
TL/H/5516–21

Top View

N.C. = No Connection

Order Number LM35DM
See NS Package Number M08A

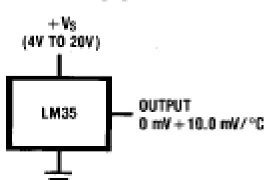
TO-202
Plastic Package



TL/H/5516–24

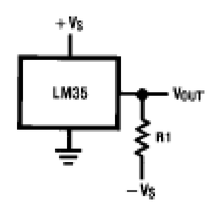
Order Number LM35DP
See NS Package Number P03A

Typical Applications



TL/H/5516–3

FIGURE 1. Basic Centigrade Temperature Sensor (+2°C to +150°C)



TL/H/5516–4

Choose $R_1 = -V_S/50\ \mu A$

$V_{OUT} = +1{,}500$ mV at +150°C
$= +250$ mV at +25°C
$= -550$ mV at −55°C

FIGURE 2. Full-Range Centigrade Temperature Sensor

TRI-STATE® is a registered trademark of National Semiconductor Corporation.

RRD-B30M75/Printed in U. S. A.

Absolute Maximum Ratings (Note 10)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	+35V to −0.2V
Output Voltage	+6V to −1.0V
Output Current	10 mA
Storage Temp., TO-46 Package,	−60°C to +180°C
TO-92 Package,	−60°C to +150°C
SO-8 Package,	−65°C to +150°C
TO-202 Package,	−65°C to +150°C
Lead Temp.:	
TO-46 Package, (Soldering, 10 seconds)	300°C
TO-92 Package, (Soldering, 10 seconds)	260°C
TO-202 Package, (Soldering, 10 seconds)	+230°C
SO Package (Note 12):	
Vapor Phase (60 seconds)	215°C
Infrared (15 seconds)	220°C
ESD Susceptibility (Note 11)	2500V
Specified Operating Temperature Range: T_{MIN} to T_{MAX} (Note 2)	
LM35, LM35A	−55°C to +150°C
LM35C, LM35CA	−40°C to +110°C
LM35D	0°C to +100°C

Electrical Characteristics (Note 1) **(Note 6)**

Parameter	Conditions	LM35A			LM35CA			Units (Max.)
		Typical	Tested Limit (Note 4)	Design Limit (Note 5)	Typical	Tested Limit (Note 4)	Design Limit (Note 5)	
Accuracy (Note 7)	$T_A=+25°C$ $T_A=-10°C$ $T_A=T_{MAX}$ $T_A=T_{MIN}$	±0.2 ±0.3 ±0.4 ±0.4	±0.5 ±1.0 ±1.0		±0.2 ±0.3 ±0.4 ±0.4	±0.5 ±1.0 	 ±1.0 ±1.5	°C °C °C °C
Nonlinearity (Note 8)	$T_{MIN} \le T_A \le T_{MAX}$	**±0.18**		**±0.35**	**±0.15**		**±0.3**	°C
Sensor Gain (Average Slope)	$T_{MIN} \le T_A \le T_{MAX}$	**+10.0**	**+9.9,** **+10.1**		**+10.0**		**+9.9,** **+10.1**	mV/°C
Load Regulation (Note 3) $0 \le I_L \le 1$ mA	$T_A=+25°C$ $T_{MIN} \le T_A \le T_{MAX}$	±0.4 **±0.5**	±1.0	 **±3.0**	±0.4 **±0.5**	±1.0	 **±3.0**	mV/mA mV/mA
Line Regulation (Note 3)	$T_A=+25°C$ $4V \le V_S \le 30V$	±0.01 **±0.02**	±0.05	 **±0.1**	±0.01 **±0.02**	±0.05	 **±0.1**	mV/V mV/V
Quiescent Current (Note 9)	$V_S=+5V$, +25°C $V_S=+5V$ $V_S=+30V$, +25°C $V_S=+30V$	56 **105** 56.2 **105.5**	67 68 	 **131** **133**	56 **91** 56.2 **91.5**	67 68 	 **114** **116**	μA μA μA μA
Change of Quiescent Current (Note 3)	$4V \le V_S \le 30V$, +25°C $4V \le V_S \le 30V$	0.2 **0.5**	1.0	 **2.0**	0.2 **0.5**	1.0	 **2.0**	μA μA
Temperature Coefficient of Quiescent Current		**+0.39**		**+0.5**	**+0.39**		**+0.5**	μA/°C
Minimum Temperature for Rated Accuracy	In circuit of *Figure 1*, $I_L=0$	+1.5		+2.0	+1.5		+2.0	°C
Long Term Stability	$T_J=T_{MAX}$, for 1000 hours	±0.08			±0.08			°C

Note 1: Unless otherwise noted, these specifications apply: $-55°C \le T_J \le +150°C$ for the LM35 and LM35A; $-40° \le T_J \le +110°C$ for the LM35C and LM35CA; and $0° \le T_J \le +100°C$ for the LM35D. $V_S=+5Vdc$ and $I_{LOAD}=50$ μA, in the circuit of *Figure 2*. These specifications also apply from +2°C to T_{MAX} in the circuit of *Figure 1*. Specifications in **boldface** apply over the full rated temperature range.

Note 2: Thermal resistance of the TO-46 package is 400°C/W, junction to ambient, and 24°C/W junction to case. Thermal resistance of the TO-92 package is 180°C/W junction to ambient. Thermal resistance of the small outline molded package is 220°C/W junction to ambient. Thermal resistance of the TO-202 package is 85°C/W junction to ambient. For additional thermal resistance information see table in the Applications section.

Electrical Characteristics (Note 1) **(Note 6)** (Continued)

Parameter	Conditions	LM35			LM35C, LM35D			Units (Max.)
		Typical	Tested Limit (Note 4)	Design Limit (Note 5)	Typical	Tested Limit (Note 4)	Design Limit (Note 5)	
Accuracy, LM35, LM35C (Note 7)	$T_A = +25°C$	±0.4	±1.0		±0.4	±1.0		°C
	$T_A = -10°C$	±0.5			±0.5		±1.5	°C
	$T_A = T_{MAX}$	±0.8	±1.5		±0.8		±1.5	°C
	$T_A = T_{MIN}$	±0.8		±1.5	±0.8		±2.0	°C
Accuracy, LM35D (Note 7)	$T_A = +25°C$				±0.6	±1.5		°C
	$T_A = T_{MAX}$				±0.9		±2.0	°C
	$T_A = T_{MIN}$				±0.9		±2.0	°C
Nonlinearity (Note 8)	$T_{MIN} \leq T_A \leq T_{MAX}$	**±0.3**		**±0.5**	**±0.2**		**±0.5**	°C
Sensor Gain (Average Slope)	$T_{MIN} \leq T_A \leq T_{MAX}$	**+10.0**	**+9.8, +10.2**		**+10.0**		**+9.8, +10.2**	mV/°C
Load Regulation (Note 3) $0 \leq I_L \leq 1$ mA	$T_A = +25°C$	±0.4	±2.0		±0.4	±2.0		mV/mA
	$T_{MIN} \leq T_A \leq T_{MAX}$	**±0.5**		**±5.0**	**±0.5**		**±5.0**	mV/mA
Line Regulation (Note 3)	$T_A = +25°C$	±0.01	±0.1		±0.01	±0.1		mV/V
	$4V \leq V_S \leq 30V$	**±0.02**		**±0.2**	**±0.02**		**±0.2**	mV/V
Quiescent Current (Note 9)	$V_S = +5V$, +25°C	56	80		56	80		µA
	$V_S = +5V$	**105**		**158**	**91**		**138**	µA
	$V_S = +30V$, +25°C	56.2	82		56.2	82		µA
	$V_S = +30V$	**105.5**		**161**	**91.5**		**141**	µA
Change of Quiescent Current (Note 3)	$4V \leq V_S \leq 30V$, +25°C	0.2	2.0		0.2	2.0		µA
	$4V \leq V_S \leq 30V$	**0.5**		**3.0**	**0.5**		**3.0**	µA
Temperature Coefficient of Quiescent Current		**+0.39**		**+0.7**	**+0.39**		**+0.7**	µA/°C
Minimum Temperature for Rated Accuracy	In circuit of *Figure 1*, $I_L = 0$	+1.5		+2.0	+1.5		+2.0	°C
Long Term Stability	$T_J = T_{MAX}$, for 1000 hours	±0.08			±0.08			°C

Note 3: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output due to heating effects can be computed by multiplying the internal dissipation by the thermal resistance.

Note 4: Tested Limits are guaranteed and 100% tested in production.

Note 5: Design Limits are guaranteed (but not 100% production tested) over the indicated temperature and supply voltage ranges. These limits are not used to calculate outgoing quality levels.

Note 6: Specifications in **boldface** apply over the full rated temperature range.

Note 7: Accuracy is defined as the error between the output voltage and 10mv/°C times the device's case temperature, at specified conditions of voltage, current, and temperature (expressed in °C).

Note 8: Nonlinearity is defined as the deviation of the output-voltage-versus-temperature curve from the best-fit straight line, over the device's rated temperature range.

Note 9: Quiescent current is defined in the circuit of *Figure 1*.

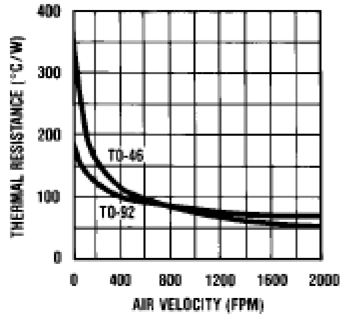
Note 10: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions. See Note 1.

Note 11: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

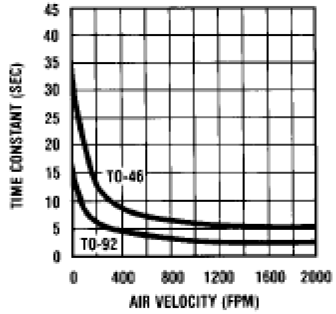
Note 12: See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" or the section titled "Surface Mount" found in a current National Semiconductor Linear Data Book for other methods of soldering surface mount devices.

Typical Performance Characteristics

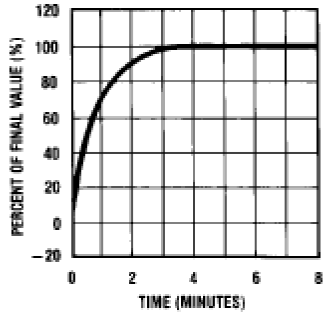
Thermal Resistance Junction to Air



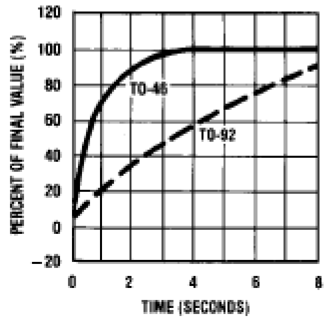
Thermal Time Constant



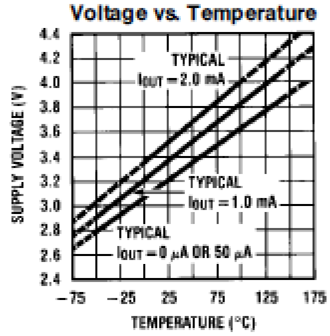
Thermal Response in Still Air



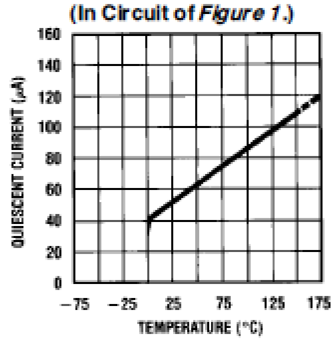
Thermal Response in Stirred Oil Bath



Minimum Supply Voltage vs. Temperature

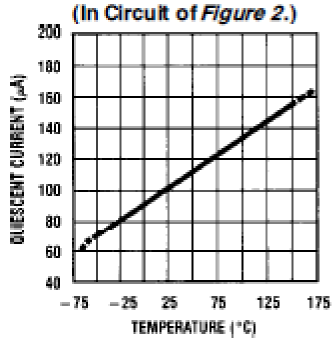


Quiescent Current vs. Temperature (In Circuit of *Figure 1*.)

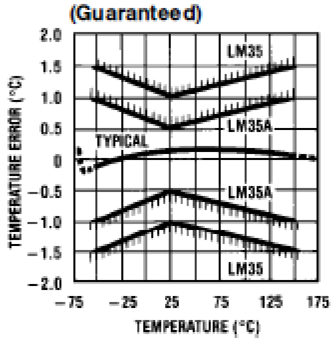


TL/H/5516–17

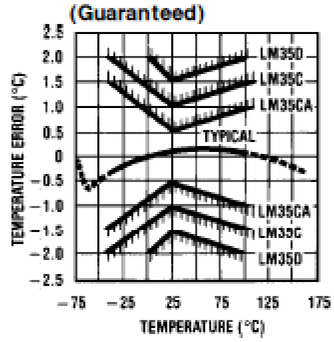
Quiescent Current vs. Temperature (In Circuit of *Figure 2*.)



Accuracy vs. Temperature (Guaranteed)

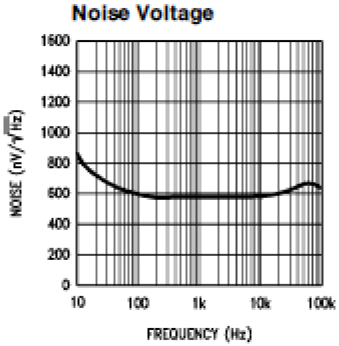


Accuracy vs. Temperature (Guaranteed)

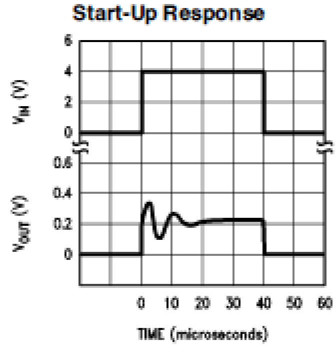


TL/H/5516–18

Noise Voltage



Start-Up Response



TL/H/5516–22

Applications

The LM35 can be applied easily in the same way as other integrated-circuit temperature sensors. It can be glued or cemented to a surface and its temperature will be within about 0.01°C of the surface temperature.

This presumes that the ambient air temperature is almost the same as the surface temperature; if the air temperature were much higher or lower than the surface temperature, the actual temperature of the LM35 die would be at an intermediate temperature between the surface temperature and the air temperature. This is expecially true for the TO-92 plastic package, where the copper leads are the principal thermal path to carry heat into the device, so its temperature might be closer to the air temperature than to the surface temperature.

To minimize this problem, be sure that the wiring to the LM35, as it leaves the device, is held at the same temperature as the surface of interest. The easiest way to do this is to cover up these wires with a bead of epoxy which will insure that the leads and wires are all at the same temperature as the surface, and that the LM35 die's temperature will not be affected by the air temperature.

The TO-46 metal package can also be soldered to a metal surface or pipe without damage. Of course, in that case the V− terminal of the circuit will be grounded to that metal. Alternatively, the LM35 can be mounted inside a sealed-end metal tube, and can then be dipped into a bath or screwed into a threaded hole in a tank. As with any IC, the LM35 and accompanying wiring and circuits must be kept insulated and dry, to avoid leakage and corrosion. This is especially true if the circuit may operate at cold temperatures where condensation can occur. Printed-circuit coatings and varnishes such as Humiseal and epoxy paints or dips are often used to insure that moisture cannot corrode the LM35 or its connections.

These devices are sometimes soldered to a small light-weight heat fin, to decrease the thermal time constant and speed up the response in slowly-moving air. On the other hand, a small thermal mass may be added to the sensor, to give the steadiest reading despite small deviations in the air temperature.

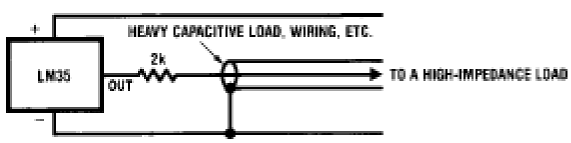
Temperature Rise of LM35 Due To Self-heating (Thermal Resistance)

	TO-46, no heat sink	TO-46, small heat fin*	TO-92, no heat sink	TO-92, small heat fin**	SO-8 no heat sink	SO-8 small heat fin**	TO-202 no heat sink	TO-202*** small heat fin
Still air	400°C/W	100°C/W	180°C/W	140°C/W	220°C/W	110°C/W	85°C/W	60°C/W
Moving air	100°C/W	40°C/W	90°C/W	70°C/W	105°C/W	90°C/W	25°C/W	40°C/W
Still oil	100°C/W	40°C/W	90°C/W	70°C/W				
Stirred oil	50°C/W	30°C/W	45°C/W	40°C/W				
(Clamped to metal, Infinite heat sink)	(24°C/W)				(55°C/W)			(23°C/W)

* Wakefield type 201, or 1" disc of 0.020" sheet brass, soldered to case, or similar.

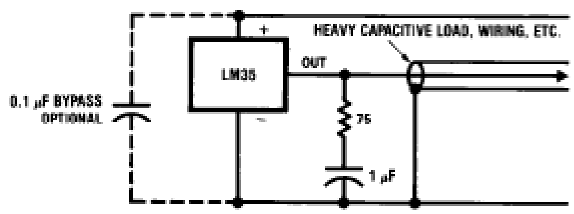
** TO-92 and SO-8 packages glued and leads soldered to 1" square of 1/16" printed circuit board with 2 oz. foil or similar.

Typical Applications (Continued)



TL/H/5516–19

FIGURE 3. LM35 with Decoupling from Capacitive Load



TL/H/5516–20

FIGURE 4. LM35 with R-C Damper

CAPACITIVE LOADS

Like most micropower circuits, the LM35 has a limited ability to drive heavy capacitive loads. The LM35 by itself is able to drive 50 pf without special precautions. If heavier loads are anticipated, it is easy to isolate or decouple the load with a resistor; see *Figure 3*. Or you can improve the tolerance of capacitance with a series R-C damper from output to ground; see *Figure 4*.

When the LM35 is applied with a 200Ω load resistor as shown in *Figure 5, 6,* or *8,* it is relatively immune to wiring capacitance because the capacitance forms a bypass from ground to input, not on the output. However, as with any linear circuit connected to wires in a hostile environment, its performance can be affected adversely by intense electromagnetic sources such as relays, radio transmitters, motors with arcing brushes, SCR transients, etc, as its wiring can act as a receiving antenna and its internal junctions can act as rectifiers. For best results in such cases, a bypass capacitor from V_{IN} to ground and a series R-C damper such as 75Ω in series with 0.2 or 1 μF from output to ground are often useful. These are shown in *Figures 13, 14,* and *16.*

Typical Applications (Continued)

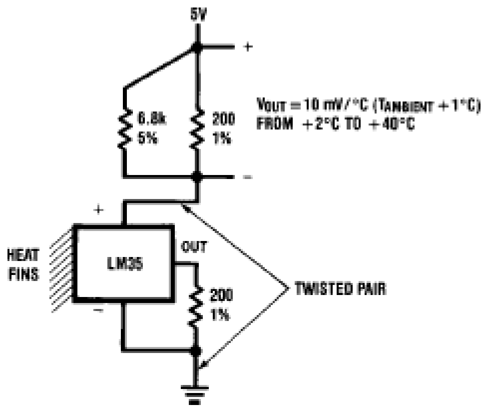


FIGURE 5. Two-Wire Remote Temperature Sensor (Grounded Sensor)

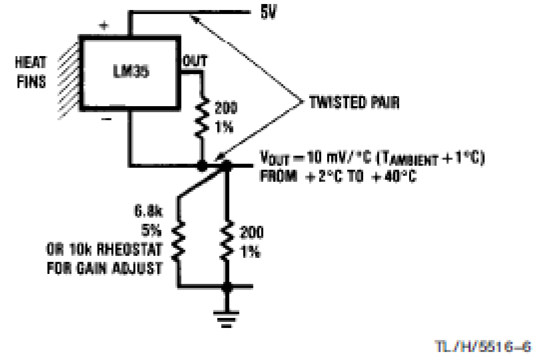


FIGURE 6. Two-Wire Remote Temperature Sensor (Output Referred to Ground)

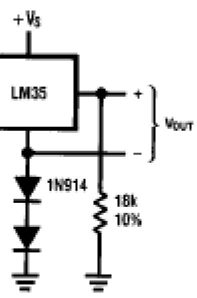


FIGURE 7. Temperature Sensor, Single Supply, −55° to +150°C

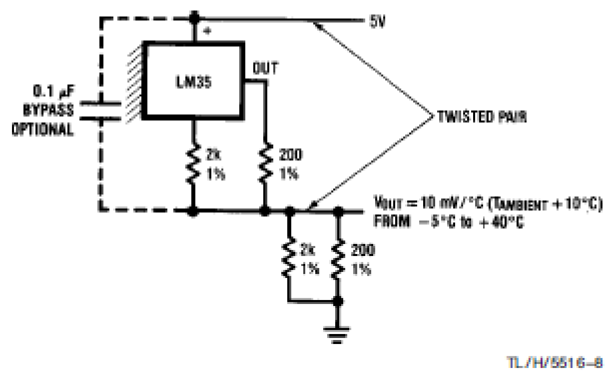


FIGURE 8. Two-Wire Remote Temperature Sensor (Output Referred to Ground)

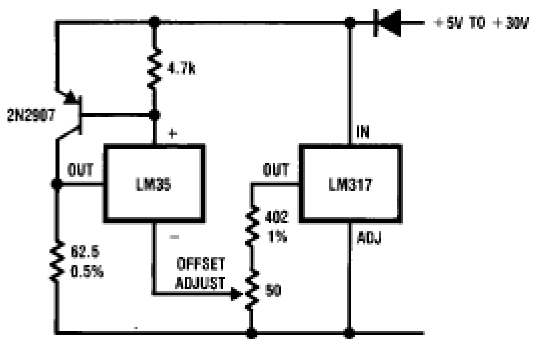


FIGURE 9. 4-To-20 mA Current Source (0°C to +100°C)

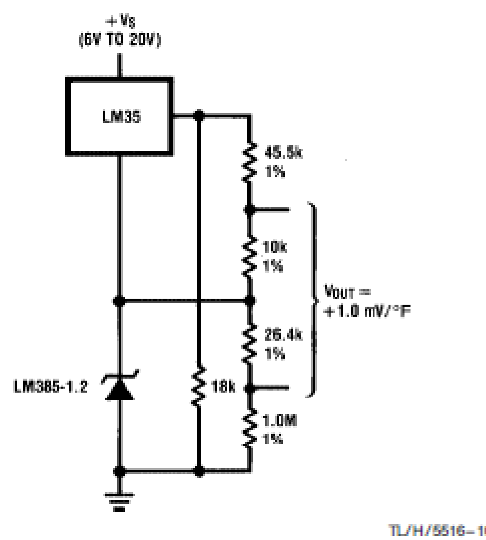


FIGURE 10. Fahrenheit Thermometer

Typical Applications (Continued)

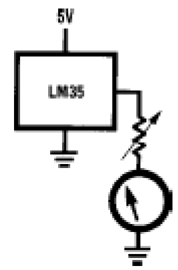


FIGURE 11. Centigrade Thermometer (Analog Meter)

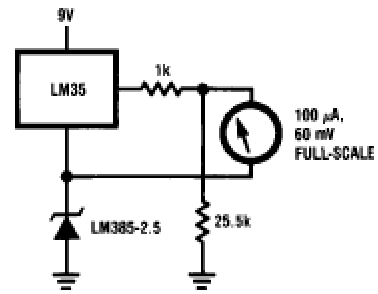


FIGURE 12. Expanded Scale Thermometer (50° to 80° Fahrenheit, for Example Shown)

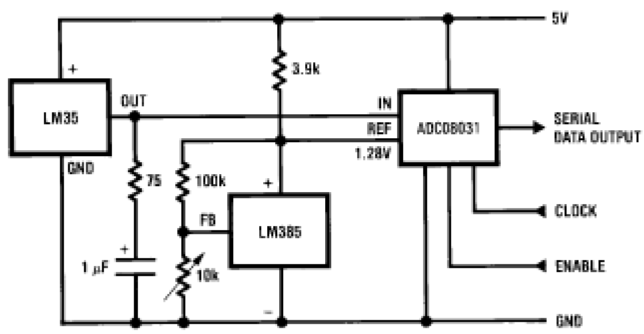


FIGURE 13. Temperature To Digital Converter (Serial Output) (+128°C Full Scale)

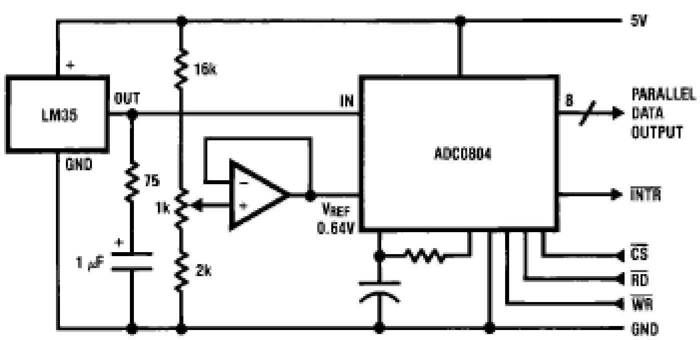
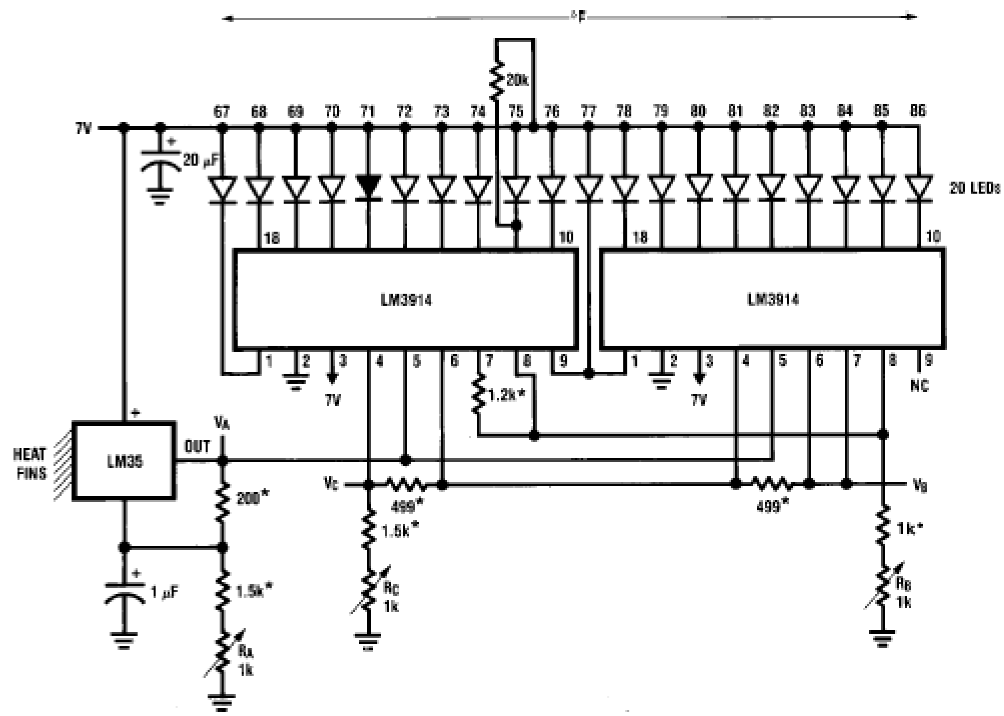


FIGURE 14. Temperature To Digital Converter (Parallel TRI-STATE® Outputs for Standard Data Bus to μP Interface) (128°C Full Scale)

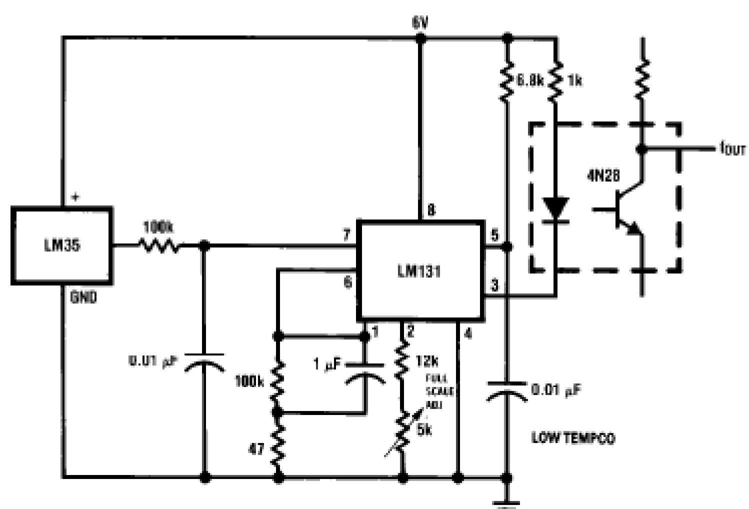
Typical Applications (Continued)



TL/H/5516–16

* = 1% or 2% film resistor
-Trim R_B for $V_B = 3.075V$
-Trim R_C for $V_C = 1.955V$
-Trim R_A for $V_A = 0.075V + 100mV/°C \times T_{ambient}$
-Example, $V_A = 2.275V$ at 22°C

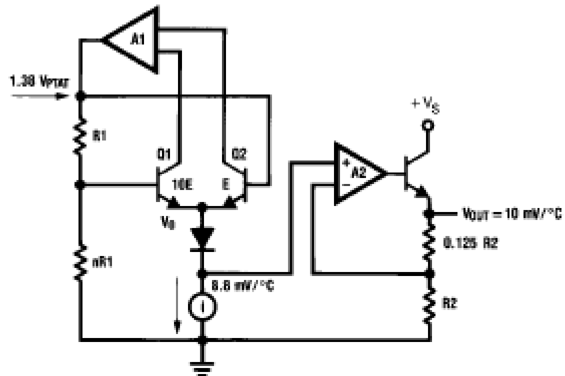
FIGURE 15. Bar-Graph Temperature Display (Dot Mode)



TL/H/5516–15

FIGURE 16. LM35 With Voltage-To-Frequency Converter And Isolated Output (2°C to +150°C; 20 Hz to 1500 Hz)

Block Diagram



TL/H/5516–23

pH Sensor

(Order Code PH-BTA)

Our pH Sensor can be used for any lab or demonstration that can be done with a traditional pH meter. This sensor offers the additional advantages of automated data collection, graphing, and data analysis. Typical activities using our pH sensor include studies of household acids and bases, acid-base titrations, monitoring pH change during chemical reactions or in an aquarium as a result of photosynthesis, investigations of acid rain and buffering, and investigations of water quality in streams and lakes.

Collecting Data with the pH Sensor

This sensor can be used with the following interfaces to collect data:

- Vernier LabQuest® as a standalone device or with a computer
- Vernier LabQuest® Mini with a computer
- Vernier LabPro® with a computer, TI graphing calculator, or Palm® handheld
- Vernier Go!®Link
- Vernier EasyLink®
- Vernier SensorDAQ®
- CBL 2™

Here is the general procedure to follow when using the pH Sensor:

1. Connect the pH Sensor to the interface.
2. Start the data-collection software[1].
3. The software will identify the pH Sensor and load a default data-collection setup. You are now ready to collect data.

Important: Do not fully submerge the sensor. The handle is not waterproof.

Data-Collection Software

This sensor can be used with an interface and the following data-collection software.

- **Logger *Pro* 3** This computer program is used with LabQuest, LabQuest Mini, LabPro, or Go!Link.
- **Logger *Pro* 2** This computer program is used with ULI or Serial Box Interface.
- **Logger Lite** This computer program is used with LabQuest, LabQuest Mini, LabPro, or Go!Link.
- **LabQuest App** This program is used when LabQuest is used as a standalone device.
- **EasyData App** This calculator application for the TI-83 Plus and TI-84 Plus can be used with CBL 2, LabPro, and Vernier EasyLink. We recommend version 2.0 or newer, which can be downloaded from the Vernier web site, www.vernier.com/easy/easydata.html, and then transferred to the calculator. See the Vernier web site, www.vernier.com/calc/software/index.html for more information on the App and Program Transfer Guidebook.
- **DataMate program** Use DataMate with LabPro or CBL 2 and TI-73, TI-83, TI-84, TI-86, TI-89, and Voyage 200 calculators. See the LabPro and CBL 2 Guidebooks for instructions on transferring DataMate to the calculator.
- **Data Pro** This program is used with LabPro and a Palm handheld.
- **LabVIEW** National Instruments LabVIEW™ software is a graphical programming language sold by National Instruments. It is used with SensorDAQ and can be used with a number of other Vernier interfaces. See www.vernier.com/labview for more information.

[1] If you are using Logger *Pro* 2 with either a ULI or SBI, the sensor will not auto-ID. Open an experiment file for the pH Sensor in the Probes & Sensors folder.

pH Electrode Specifications

Type:	Sealed, gel-filled, epoxy body, Ag/AgCl
Response time:	90% of final reading in 1 second
Temperature range:	5 to 80°C
12 mm OD	
Range:	pH 0–14
13-bit Resolution (SensorDAQ):	0.0025 pH units
12-bit Resolution (LabQuest, LabQuest Mini, Go!Link, LabPro, ULI, SBI):	0.005 pH units
10-bit Resolution (CBL 2):	0.02 pH units
Isopotential pH:	pH 7 (point at which temperature has no effect)
Output:	59.2 mV/pH at 25°C
Stored Calibration Values[2]:	
Intercept (k_0):	13.720
Slope (k_1):	–3.838

NOTE: This product is to be used for educational purposes only. It is not appropriate for industrial, medical, research, or commercial applications.

How the pH Sensor Works

The pH Amplifier inside the handle is a circuit which allows a standard combination pH electrode (such as the Vernier 7120B) to be monitored by a lab interface. The cable from the pH Amplifier ends in a BTA plug.

The pH Sensor will produce a voltage of 1.75 volts in a pH 7 buffer. The voltage will increase by about 0.25 volts for every pH number decrease. The voltage will decrease by about 0.25 volts/pH number as the pH increases.

The Vernier gel-filled pH Sensor is designed to make measurements in the pH range of 0 to 14. A polycarbonate body that extends below the glass sensing bulb of the

[2] These are average calibration values. Actual values may vary because sensors are individually calibrated by Vernier before shipping.

electrode makes this probe ideal for the demands of a middle school, high school, or university level science class or for making measurements in the environment. The gel-filled reference half cell is sealed—it never needs to be refilled.

This sensor is equipped with circuitry that supports auto-ID. When used with LabQuest, LabQuest Mini, LabPro, Go! Link, SensorDAQ, EasyLink, or CBL 2, the data-collection software identifies the sensor and uses pre-defined parameters to configure an experiment appropriate to the recognized sensor.

Preparing for Use

To prepare the electrode to make pH measurements, follow this procedure:

- Remove the storage bottle from the electrode by first unscrewing the lid, then removing the bottle and lid. Thoroughly rinse the lower section of the probe, especially the region of the bulb, using distilled or deionized water.
- When the probe is not being stored in the storage bottle, it can be stored for short periods of time (up to 24 hours) in pH-4 or pH-7 buffer solution. It should never be stored in distilled water.
- Connect the pH Sensor to your lab interface, load or perform a calibration (as described in the next section), and you are ready to make pH measurements. **Note:** Do not completely submerge the sensor. The handle is not waterproof.

When you are finished making measurements, rinse the tip of the electrode with distilled water. Slide the cap onto the electrode body, then screw the cap onto the storage bottle. Note: When the level of storage solution left in the bottle gets low, you can replenish it with small amounts of tap water the first few times you use the probe (but not indefinitely!). A better solution is to prepare a quantity of pH-4 buffer/KCl storage solution (see the section on Maintenance and Storage) and use it to replace lost solution.

Do I Need to Calibrate the pH Sensor?

We feel that you should not have to perform a new calibration when using the pH Sensor for most experiments in the classroom. We have set the sensor to match our stored calibration before shipping it. You can simply use the appropriate calibration file that is stored in your data-collection program from Vernier in any of these ways:

1. If you ordered the PH-BTA version of the sensor, and you are using it with a LabQuest, LabQuest Mini, LabPro or CBL 2 interface, then a calibration (in pH) is automatically loaded when the pH Sensor is connected. **Note:** Each pH Sensor (PH-BTA version) is calibrated at Vernier. This custom calibration is then stored on the sensor. This means that when you first use it, you will see pH readings that are accurate to +/- 0.10 pH units, without calibration! With time, you may see some minor loss of the initial custom calibration accuracy, but for most purposes (see below), it should not be necessary to calibrate the pH Sensor.
2. If you are using Logger *Pro* software (version 2.0 or newer) on a Macintosh or Windows computer, open an experiment file for the pH Sensor, and its stored calibration will be loaded at the same time. **Note:** If you have an earlier version of Logger *Pro*, a free upgrade is available from our web site.
3. Any version of the DataMate or EasyData program (with LabPro or CBL 2) has stored calibrations for this sensor.
4. Any version of Data Pro has stored calibrations for this sensor.

If you are performing a chemistry experiment, or doing water quality testing that requires a very accurate calibration, you can calibrate the Vernier pH Electrode following this procedure:

- Use the 2-point calibration option of the Vernier data-collection program. Rinse the tip of the electrode in distilled water. Place the electrode into one of the buffer solutions (e.g., pH 4). When the voltage reading displayed on the computer or calculator screen stabilizes, enter a pH value, "4".
- For the next calibration point, rinse the electrode and place it into a second buffer solution (e.g., pH 7). When the displayed voltage stabilizes, enter a pH value, "7".
- Rinse the electrode with distilled water and place it in the sample.

pH Buffer Solutions

In order to do a calibration of the pH Sensor, or to confirm that a saved pH calibration is accurate, you need to have a supply of pH buffer solutions that cover the range of pH values you will be measuring. We recommend buffer solutions of pH 4, 7, and 10.

- Vernier sells a pH buffer kit (order code PHB). The kit has 12 tablets: four tablets each of buffer pH 4, 7, and 10. Each tablet is added to 100 mL of distilled or deionized water to prepare respective pH buffer solutions.
- Flinn Scientific (www.flinnsci.com, Tel: 800-452-1261) sells a wide variety of buffer tablets and prepared buffer solutions.
- You can prepare your own buffer solutions using the following recipes:

pH 4.00	Add 2.0 mL of 0.1 M HCl to 1000 mL of 0.1 M potassium hydrogen phthalate.
pH 7.00	Add 582 mL of 0.1 M NaOH to 1000 mL of 0.1 M potassium dihydrogen phosphate.
pH 10.00	Add 214 mL of 0.1 M NaOH to 1000 mL of 0.05 M sodium bicarbonate.

Maintenance and Storage

Short-term storage (up to 24 hours): Place the electrode in pH-4 or pH-7 buffer solution.

Long-term storage (more than 24 hours): Store the electrode in a buffer pH-4/KCl storage solution in the storage bottle. The pH Electrode is shipped in this solution. Vernier sells 500 mL bottles of replacement pH Storage Solution (order code PH-SS), or you can prepare additional storage solution by adding 10 g of solid potassium chloride (KCl) to 100 mL of buffer pH-4 solution. Flinn Scientific (800- 452-1261) sells a Buffer Solution Preservative (order code B0175) that can be added to this storage solution. By storing the electrode in this solution, the reference portion of the electrode is kept moist. Keeping the reference junction moist adds to electrode longevity and retains electrode response time when the unit is placed back into service. If the electrode is inadvertently stored dry (we don't recommend this!), immerse the unit in soaking solution for a minimum of eight hours prior to service.

When testing a pH Sensor, it is best to place it into a known buffer solution. This allows you to see if the sensor is reading correctly (e.g., in a buffer pH 7, is the sensor reading close to pH 7). Do not place your sensor into distilled water to check for readings—distilled water can have a pH reading anywhere between 5.5 and 7.0, due to variable amounts of carbon dioxide dissolved from the atmosphere. Furthermore, due to a lack of ions, the pH values reported with the sensor in distilled water will be erratic.

If your pH Sensor is reading slightly off of the known buffer pH (e.g., reads 6.7 in a buffer 7), you may simply need to calibrate the sensor. You can calibrate the sensor in two buffer solutions for two calibration points. If you do not remember or know how to perform a calibration, refer to the booklet that came with the pH sensor.

If your readings are off by several pH values, the pH readings do not change when moved from one buffer solution to another different buffer, or the sensor's response seems slow, the problem may be more serious. Sometimes a method called "shocking" is used to revive pH electrodes. To shock your pH Sensor, perform the following:

1. Let the pH Electrode soak for 4-8 hours in an HCl solution between 0.1 and 1.0 M.
2. Rinse off the electrode and let it sit in some buffer pH 7 for an hour or so.
3. Rinse the electrode and give it another try.

Mold growth in the buffer/KCl storage solution can be prevented by adding a commercial growth inhibitor. This mold will not harm the electrode and can easily be removed using a light detergent solution.

This sensor is designed to be used in aqueous solutions. The polycarbonate body of the sensor can be damaged by many organic solvents. In addition, do not use the sensor in solutions containing: perchlorates, silver ions, sulfide ions, biological samples with high concentrations of proteins, or Tris buffered solutions.[3] Do not use it in hydrofluoric acid or in acid or base solutions with a concentration greater than 1.0 molar. The electrode may be used to measure the pH of sodium hydroxide solutions with a concentration near 1.0 molar, but should not be left in this concentration of sodium hydroxide for periods longer than 5 minutes. Using or storing the electrode at very high temperatures or very low temperatures (near 0°C) can damage it beyond repair.

[3] Vernier now offers Tris-Compatible Flat pH Sensor which features a double junction electrode, so it can be used with proteins, sulfides, and Tris buffers. Order code FPH-BTA.

Features

- High-performance, Low-power AVR® 8-bit Microcontroller
- Advanced RISC Architecture
  - 131 Powerful Instructions – Most Single-clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 16 MIPS Throughput at 16 MHz
  - On-chip 2-cycle Multiplier
- High Endurance Non-volatile Memory segments
  - 16K Bytes of In-System Self-programmable Flash program memory
  - 512 Bytes EEPROM
  - 1K Byte Internal SRAM
  - Write/Erase Cycles: 10,000 Flash/100,000 EEPROM
  - Data retention: 20 years at 85°C/100 years at 25°C[1]
  - Optional Boot Code Section with Independent Lock Bits
    In-System Programming by On-chip Boot Program
    True Read-While-Write Operation
  - Programming Lock for Software Security
- JTAG (IEEE std. 1149.1 Compliant) Interface
  - Boundary-scan Capabilities According to the JTAG Standard
  - Extensive On-chip Debug Support
  - Programming of Flash, EEPROM, Fuses, and Lock Bits through the JTAG Interface
- Peripheral Features
  - Two 8-bit Timer/Counters with Separate Prescalers and Compare Modes
  - One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode
  - Real Time Counter with Separate Oscillator
  - Four PWM Channels
  - 8-channel, 10-bit ADC
    8 Single-ended Channels
    7 Differential Channels in TQFP Package Only
    2 Differential Channels with Programmable Gain at 1x, 10x, or 200x
  - Byte-oriented Two-wire Serial Interface
  - Programmable Serial USART
  - Master/Slave SPI Serial Interface
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal Calibrated RC Oscillator
  - External and Internal Interrupt Sources
  - Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby and Extended Standby
- I/O and Packages
  - 32 Programmable I/O Lines
  - 40-pin PDIP, 44-lead TQFP, and 44-pad QFN/MLF
- Operating Voltages
  - 2.7 - 5.5V for ATmega16L
  - 4.5 - 5.5V for ATmega16
- Speed Grades
  - 0 - 8 MHz for ATmega16L
  - 0 - 16 MHz for ATmega16
- Power Consumption @ 1 MHz, 3V, and 25°C for ATmega16L
  - Active: 1.1 mA
  - Idle Mode: 0.35 mA
  - Power-down Mode: < 1 µA

8-bit AVR® Microcontroller with 16K Bytes In-System Programmable Flash

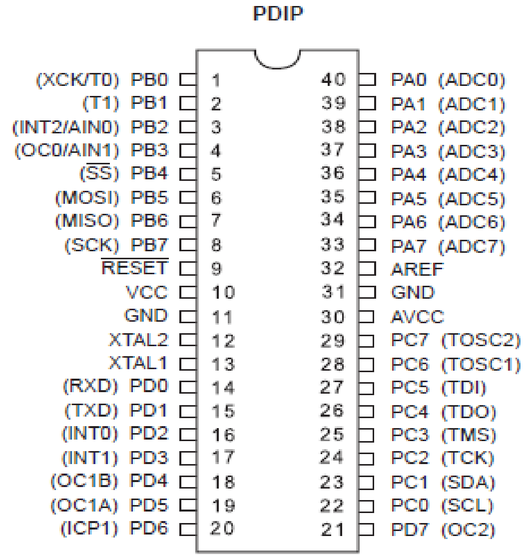
ATmega16
ATmega16L

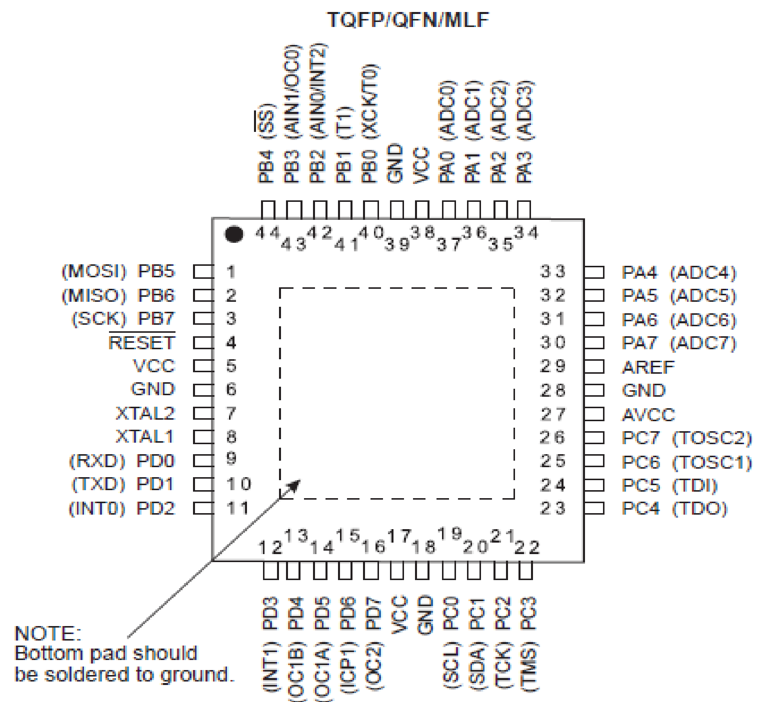
Summary

Note: Not recommended for new designs.

Pin Configurations

Figure 1. Pinout ATmega16





Disclaimer

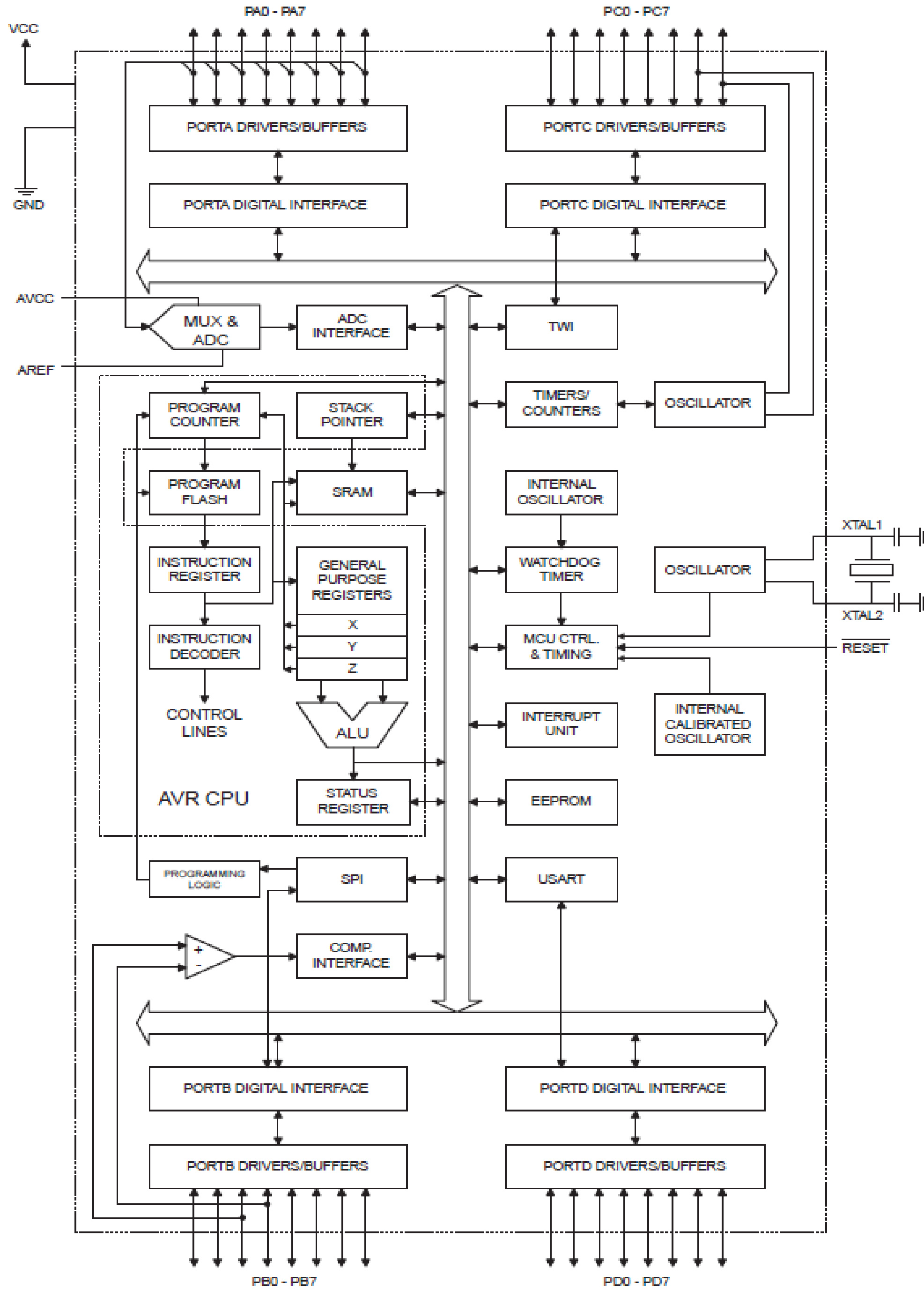
Typical values contained in this datasheet are based on simulations and characterization of other AVR microcontrollers manufactured on the same process technology. Min and Max values will be available after the device is characterized.

Overview

The ATmega16 is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega16 achieves throughputs approaching 1 MIPS per MHz allowing the system designer to optimize power consumption versus processing speed.

Block Diagram

Figure 2. Block Diagram



The AVR core combines a rich instruction set with 32 general purpose working registers. All the 32 registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in one single instruction executed in one clock cycle. The resulting architecture is more code efficient while achieving throughputs up to ten times faster than conventional CISC microcontrollers.

The ATmega16 provides the following features: 16K bytes of In-System Programmable Flash Program memory with Read-While-Write capabilities, 512 bytes EEPROM, 1K byte SRAM, 32 general purpose I/O lines, 32 general purpose working registers, a JTAG interface for Boundary-scan, On-chip Debugging support and programming, three flexible Timer/Counters with compare modes, Internal and External Interrupts, a serial programmable USART, a byte oriented Two-wire Serial Interface, an 8-channel, 10-bit ADC with optional differential input stage with programmable gain (TQFP package only), a programmable Watchdog Timer with Internal Oscillator, an SPI serial port, and six software selectable power saving modes. The Idle mode stops the CPU while allowing the USART, Two-wire interface, A/D Converter, SRAM, Timer/Counters, SPI port, and interrupt system to continue functioning. The Power-down mode saves the register contents but freezes the Oscillator, disabling all other chip functions until the next External Interrupt or Hardware Reset. In Power-save mode, the Asynchronous Timer continues to run, allowing the user to maintain a timer base while the rest of the device is sleeping. The ADC Noise Reduction mode stops the CPU and all I/O modules except Asynchronous Timer and ADC, to minimize switching noise during ADC conversions. In Standby mode, the crystal/resonator Oscillator is running while the rest of the device is sleeping. This allows very fast start-up combined with low-power consumption. In Extended Standby mode, both the main Oscillator and the Asynchronous Timer continue to run.

The device is manufactured using Atmel's high density nonvolatile memory technology. The On-chip ISP Flash allows the program memory to be reprogrammed in-system through an SPI serial interface, by a conventional nonvolatile memory programmer, or by an On-chip Boot program running on the AVR core. The boot program can use any interface to download the application program in the Application Flash memory. Software in the Boot Flash section will continue to run while the Application Flash section is updated, providing true Read-While-Write operation. By combining an 8-bit RISC CPU with In-System Self-Programmable Flash on a monolithic chip, the Atmel ATmega16 is a powerful microcontroller that provides a highly-flexible and cost-effective solution to many embedded control applications.

The ATmega16 AVR is supported with a full suite of program and system development tools including: C compilers, macro assemblers, program debugger/simulators, in-circuit emulators, and evaluation kits.

Pin Descriptions

VCC Digital supply voltage.

GND Ground.

Port A (PA7..PA0) Port A serves as the analog inputs to the A/D Converter.

Port A also serves as an 8-bit bi-directional I/O port, if the A/D Converter is not used. Port pins can provide internal pull-up resistors (selected for each bit). The Port A output buffers have symmetrical drive characteristics with both high sink and source capability. When pins PA0 to PA7 are used as inputs and are externally pulled low, they will source current if the internal pull-up resistors are activated. The Port A pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Port B (PB7..PB0)

Port B is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port B output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port B pins that are externally pulled low will source current if the pull-up resistors are activated. The Port B pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Port B also serves the functions of various special features of the ATmega16 as listed on page 58.

Port C (PC7..PC0)

Port C is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port C output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port C pins that are externally pulled low will source current if the pull-up resistors are activated. The Port C pins are tri-stated when a reset condition becomes active, even if the clock is not running. If the JTAG interface is enabled, the pull-up resistors on pins PC5(TDI), PC3(TMS) and PC2(TCK) will be activated even if a reset occurs.

Port C also serves the functions of the JTAG interface and other special features of the ATmega16 as listed on page 61.

Port D (PD7..PD0)

Port D is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port D output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port D pins that are externally pulled low will source current if the pull-up resistors are activated. The Port D pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Port D also serves the functions of various special features of the ATmega16 as listed on page 63.

$\overline{\text{RESET}}$

Reset Input. A low level on this pin for longer than the minimum pulse length will generate a reset, even if the clock is not running. The minimum pulse length is given in Table 15 on page 38. Shorter pulses are not guaranteed to generate a reset.

XTAL1

Input to the inverting Oscillator amplifier and input to the internal clock operating circuit.

XTAL2

Output from the inverting Oscillator amplifier.

AVCC

AVCC is the supply voltage pin for Port A and the A/D Converter. It should be externally connected to V_{CC}, even if the ADC is not used. If the ADC is used, it should be connected to V_{CC} through a low-pass filter.

AREF

AREF is the analog reference pin for the A/D Converter.

Resources

A comprehensive set of development tools, application notes and datasheets are available for download on http://www.atmel.com/avr.

Data Retention

Reliability Qualification results show that the projected data retention failure rate is much less than 1 PPM over 20 years at 85°C or 100 years at 25°C.

Register Summary

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Page
$3F ($5F)	SREG	I	T	H	S	V	N	Z	C	9
$3E ($5E)	SPH	–	–	–	–	–	SP10	SP9	SP8	12
$3D ($5D)	SPL	SP7	SP6	SP5	SP4	SP3	SP2	SP1	SP0	12
$3C ($5C)	OCR0	Timer/Counter0 Output Compare Register								85
$3B ($5B)	GICR	INT1	INT0	INT2	–	–	–	IVSEL	IVCE	48, 69
$3A ($5A)	GIFR	INTF1	INTF0	INTF2	–	–	–	–	–	70
$39 ($59)	TIMSK	OCIE2	TOIE2	TICIE1	OCIE1A	OCIE1B	TOIE1	OCIE0	TOIE0	85, 115, 133
$38 ($58)	TIFR	OCF2	TOV2	ICF1	OCF1A	OCF1B	TOV1	OCF0	TOV0	86, 115, 133
$37 ($57)	SPMCR	SPMIE	RWWSB	–	RWWSRE	BLBSET	PGWRT	PGERS	SPMEN	250
$36 ($56)	TWCR	TWINT	TWEA	TWSTA	TWSTO	TWWC	TWEN	–	TWIE	180
$35 ($55)	MCUCR	SM2	SE	SM1	SM0	ISC11	ISC10	ISC01	ISC00	32, 68
$34 ($54)	MCUCSR	JTD	ISC2	–	JTRF	WDRF	BORF	EXTRF	PORF	41, 69, 231
$33 ($53)	TCCR0	FOC0	WGM00	COM01	COM00	WGM01	CS02	CS01	CS00	83
$32 ($52)	TCNT0	Timer/Counter0 (8 Bits)								85
$31[(1)] ($51)[(1)]	OSCCAL	Oscillator Calibration Register								30
	OCDR	On-Chip Debug Register								227
$30 ($50)	SFIOR	ADTS2	ADTS1	ADTS0	–	ACME	PUD	PSR2	PSR10	57,88,134,201,221
$2F ($4F)	TCCR1A	COM1A1	COM1A0	COM1B1	COM1B0	FOC1A	FOC1B	WGM11	WGM10	110
$2E ($4E)	TCCR1B	ICNC1	ICES1	–	WGM13	WGM12	CS12	CS11	CS10	113
$2D ($4D)	TCNT1H	Timer/Counter1 – Counter Register High Byte								114
$2C ($4C)	TCNT1L	Timer/Counter1 – Counter Register Low Byte								114
$2B ($4B)	OCR1AH	Timer/Counter1 – Output Compare Register A High Byte								114
$2A ($4A)	OCR1AL	Timer/Counter1 – Output Compare Register A Low Byte								114
$29 ($49)	OCR1BH	Timer/Counter1 – Output Compare Register B High Byte								114
$28 ($48)	OCR1BL	Timer/Counter1 – Output Compare Register B Low Byte								114
$27 ($47)	ICR1H	Timer/Counter1 – Input Capture Register High Byte								114
$26 ($46)	ICR1L	Timer/Counter1 – Input Capture Register Low Byte								114
$25 ($45)	TCCR2	FOC2	WGM20	COM21	COM20	WGM21	CS22	CS21	CS20	128
$24 ($44)	TCNT2	Timer/Counter2 (8 Bits)								130
$23 ($43)	OCR2	Timer/Counter2 Output Compare Register								130
$22 ($42)	ASSR	–	–	–	–	AS2	TCN2UB	OCR2UB	TCR2UB	131
$21 ($41)	WDTCR	–	–	–	WDTOE	WDE	WDP2	WDP1	WDP0	43
$20[(2)] ($40)[(2)]	UBRRH	URSEL	–	–	–	UBRR[11:8]				167
	UCSRC	URSEL	UMSEL	UPM1	UPM0	USBS	UCSZ1	UCSZ0	UCPOL	166
$1F ($3F)	EEARH	–	–	–	–	–	–	–	EEAR8	19
$1E ($3E)	EEARL	EEPROM Address Register Low Byte								19
$1D ($3D)	EEDR	EEPROM Data Register								19
$1C ($3C)	EECR	–	–	–	–	EERIE	EEMWE	EEWE	EERE	19
$1B ($3B)	PORTA	PORTA7	PORTA6	PORTA5	PORTA4	PORTA3	PORTA2	PORTA1	PORTA0	66
$1A ($3A)	DDRA	DDA7	DDA6	DDA5	DDA4	DDA3	DDA2	DDA1	DDA0	66
$19 ($39)	PINA	PINA7	PINA6	PINA5	PINA4	PINA3	PINA2	PINA1	PINA0	66
$18 ($38)	PORTB	PORTB7	PORTB6	PORTB5	PORTB4	PORTB3	PORTB2	PORTB1	PORTB0	66
$17 ($37)	DDRB	DDB7	DDB6	DDB5	DDB4	DDB3	DDB2	DDB1	DDB0	66
$16 ($36)	PINB	PINB7	PINB6	PINB5	PINB4	PINB3	PINB2	PINB1	PINB0	66
$15 ($35)	PORTC	PORTC7	PORTC6	PORTC5	PORTC4	PORTC3	PORTC2	PORTC1	PORTC0	67
$14 ($34)	DDRC	DDC7	DDC6	DDC5	DDC4	DDC3	DDC2	DDC1	DDC0	67
$13 ($33)	PINC	PINC7	PINC6	PINC5	PINC4	PINC3	PINC2	PINC1	PINC0	67
$12 ($32)	PORTD	PORTD7	PORTD6	PORTD5	PORTD4	PORTD3	PORTD2	PORTD1	PORTD0	67
$11 ($31)	DDRD	DDD7	DDD6	DDD5	DDD4	DDD3	DDD2	DDD1	DDD0	67
$10 ($30)	PIND	PIND7	PIND6	PIND5	PIND4	PIND3	PIND2	PIND1	PIND0	67
$0F ($2F)	SPDR	SPI Data Register								142
$0E ($2E)	SPSR	SPIF	WCOL	–	–	–	–	–	SPI2X	142
$0D ($2D)	SPCR	SPIE	SPE	DORD	MSTR	CPOL	CPHA	SPR1	SPR0	140
$0C ($2C)	UDR	USART I/O Data Register								163
$0B ($2B)	UCSRA	RXC	TXC	UDRE	FE	DOR	PE	U2X	MPCM	164
$0A ($2A)	UCSRB	RXCIE	TXCIE	UDRIE	RXEN	TXEN	UCSZ2	RXB8	TXB8	165
$09 ($29)	UBRRL	USART Baud Rate Register Low Byte								167
$08 ($28)	ACSR	ACD	ACBG	ACO	ACI	ACIE	ACIC	ACIS1	ACIS0	202
$07 ($27)	ADMUX	REFS1	REFS0	ADLAR	MUX4	MUX3	MUX2	MUX1	MUX0	217
$06 ($26)	ADCSRA	ADEN	ADSC	ADATE	ADIF	ADIE	ADPS2	ADPS1	ADPS0	219
$05 ($25)	ADCH	ADC Data Register High Byte								220
$04 ($24)	ADCL	ADC Data Register Low Byte								220
$03 ($23)	TWDR	Two-wire Serial Interface Data Register								182
$02 ($22)	TWAR	TWA6	TWA5	TWA4	TWA3	TWA2	TWA1	TWA0	TWGCE	182

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Page
$01 ($21)	TWSR	TWS7	TWS6	TWS5	TWS4	TWS3	–	TWPS1	TWPS0	181
$00 ($20)	TWBR	Two-wire Serial Interface Bit Rate Register								180

Notes: 1. When the OCDEN Fuse is unprogrammed, the OSCCAL Register is always accessed on this address. Refer to the debugger specific documentation for details on how to use the OCDR Register.

2. Refer to the USART description for details on how to access UBRRH and UCSRC.

3. For compatibility with future devices, reserved bits should be written to zero if accessed. Reserved I/O memory addresses should never be written.

4. Some of the Status Flags are cleared by writing a logical one to them. Note that the CBI and SBI instructions will operate on all bits in the I/O Register, writing a one back into any flag read as set, thus clearing the flag. The CBI and SBI instructions work with registers $00 to $1F only.