DISEÑO Y CONSTRUCCIÓN DE UN PROTOTIPO PARA MEDICIÓN Y DETECCIÓN DE HUMEDAD RELATIVA

KAROL ARMANDO GÓMEZ RÍOS

LUIS ENYERLOOK FAJARDO ARIZA

UNIVERSIDAD INDUSTRIAL DE SANTANDER

FACULTAD DE INGENIERÍAS FÍSICO-MECÁNICAS

ESCUELA DE INGENIERÍAS ELÉCTRICA, ELECTRÓNICA Y TELECOMUNICACIONES

BUCARAMANGA

2007

DISEÑO Y CONSTRUCCIÓN DE UN PROTOTIPO PARA MEDICIÓN Y DETECCIÓN DE HUMEDAD RELATIVA

KAROL ARMANDO GÓMEZ RÍOS

LUIS ENYERLOOK FAJARDO ARIZA

Proyecto de grado para optar por el título de Ingeniero Electrónico

Director

JOSE ALEJANDRO AMAYA PALACIO

INGENIERO ELECTRICISTA

UNIVERSIDAD INDUSTRIAL DE SANTANDER

FACULTAD DE INGENIERÍAS FÍSICO-MECÁNICAS

ESCUELA DE INGENIERÍAS ELÉCTRICA, ELECTRÓNICA Y TELECOMUNICACIONES

BUCARAMANGA

2007

A Dios quien me dio fuerzas para no desfallecer durante este proceso de aprendizaje.

A mi Madre Maria Helena, Mi padre Eliseo y Mis hermanos David Daniel, Juan Andres y Natalia por su incondicional apoyo para alcanzar mis metas.

A mi Tía Doris, Mi tío Jose Alberto Y mis primos Cesar y Rocío quienes me ayudaron y me brindaron un hogar durante mi permanencia en Bucaramanga.

A mis demás familiares quienes siempre estuvieron a mi lado apoyándome y colaborándome para llegar ser lo que soy.

A mi novia Olga Milena y su familia quienes me han brindado fuerzas para seguir adelante con mis planes.

A mis amigos y compañeros con quienes he compartido tantos momentos de alegría y quienes me han brindado su colaboración y apoyo para culminar esta fase de mi vida.

Karol Armando Gómez Ríos

A mi Mami por su comprensión, paciencia, apoyo incondicional y todo el amor que siempre me ha brindado, además de la fortaleza que siempre me dio para no desfallecer.

A Dios por darme la fuerza necesaria para seguir adelante.

A mi Papi quien ha sido mi ejemplo para ser una mejor persona.

A Yeimy y su familia quienes me han hecho sentir parte de su familia.

A Angie amiga leal y sincera quien siempre me apoyo y aconsejo en todo.

A mi familia, en especial a mis hermanos Yohana, Bleydi, Harvey y mi cuñado Calderon quienes siempre estuvieron dándome fortaleza para culminar con mi proceso.

A mis amigos y todas las personas que siempre han estado ahí de una u otra manera brindándome todo su apoyo y colaboración.

Inyer

AGRADECIMIENTOS

Los Autores de este proyecto damos nuestro especial agradecimiento a nuestros profesores por todas las enseñanzas impartidas durante nuestra formación profesional, a nuestro director de proyecto José Alejandro Amaya Palacio por su apoyo y colaboración en todo momento.

A nuestros amigos y compañeros quienes estuvieron con nosotros durante este largo proceso de aprendizaje.

A nuestros familiares quienes nos apoyaron y confiaron en nosotros para que culmináramos satisfactoriamente este proyecto.

A los grupos GIC y CIC quienes nos brindaron su colaboración para la feliz culminación de este proyecto.

Los autores

TABLA DE CONTENIDO

Pág.

LISTA DE TABLAS

LISTA DE FIGURAS

Pág.

LISTA DE ANEXOS

RESUMEN

TITULO: DISEÑO Y CONSTRUCCIÓN DE UN PROTOTIPO PARA MEDICIÓN Y DETECCIÓN DE HUMEDAD RELATIVA*

AUTOR: GÓMEZ RÍOS, Karol Armando, y, FAJARDO ARIZA, Luis Enyerlook**

PALABRAS CLAVES: Diseño, sensor, prototipo, medición, detección, humedad relativa.

DESCRIPCIÓN:

Este proyecto surge de la idea de estudiar la variable de humedad relativa, la cual tiene gran importancia en la industria y en el confort del ser humano entre otros, además es una variable que en la carrera de ingeniería electrónica no se ha estudiado, debido a que no se le ha dado la importancia necesaria. Este prototipo busca ser una guía en el estudio de la humedad relativa para esta carrera.

Para su medición y detección se hace el diseño de un prototipo, en el cual se emplea un sensor digital que tiene como función tomar la señal de humedad del ambiente, procesarla y enviarla por medio de su interfaz serial al microcontrolador, quien es el encargado de transformar estos valores binarios a números decimales, los cuales se visualizan después en una pantalla LCD e igualmente en el computador.

Para comprobar la precisión del prototipo se contrastaron los valores obtenidos con los arrojados al hacer las mismas pruebas con un termo-higrómetro el cual esta certificado para calibración de equipos de laboratorio. Los datos obtenidos al realizar esta comparación muestran la semejanza que existe entre estos valores, de lo cual se puede concluir un funcionamiento correcto, logrando con esto obtener un prototipo que se puede emplear para el inicio del estudio de esta variable en la carrera.

---

* Trabajo de Grado

** Facultad de Ingenierías Físico-mecánicas. Ingeniería Electrónica. José Alejando Amaya Palacio

ABSTRACT

TITLE: DESIGN AND CONSTRUCTION OF A PROTOTYPE FOR MEASUREMENT AND DETECTION OF RELATIVE HUMIDITY *

AUTHORS: GOMEZ RIOS, Karol Armando, and, FAJARDO ARIZA, Luis Enyerlook**

KEY WORDS: Design, sensor, prototype, measurement, detection, relative humidity.

DESCRIPTION:

This project arises from the idea to study the relative humidity variable, which has great importance in the industry and the comfort of the human being among others; in addition it is a variable that in the race of electronic engineering has not studied, because the necessary importance has not occurred him. This prototype looks for to be a guide in the study of the relative humidity for this race.

For his measurement and detection does design of prototype, in which sensor uses digital which it must like function take the signal from humidity of the atmosphere, process it and send it by means of his serial interface to the microcontroller, who is the one in charge to transform these binary values to numbers decimal, which visualize later in a screen LCD and also in the computer.

In order to verify the precision of the prototype the values obtained with thrown when doing the same tests with a thermos-hygrometer were resisted which this certificate for calibration of laboratory equipment. The data collected when making this comparison show the similarity that exists between these values, of which a correct operation can be concluded, managing with this to obtain a prototype that can be used for the beginning of the study of this variable in the race.

---

* Graduation Work

** Faculty of Physical-Mechanical Engineering. Electronics Engineering. Jose Alejando Amaya Palacio

INTRODUCCIÓN

La ingeniería electrónica es una carrera, la cual en sus inicios ofreció un valiosísimo aporte en la evolución de la tecnología y del mundo como lo conocemos en la actualidad. Se fundamenta teórica y prácticamente en utilizar el ingenio y la creatividad de sus profesionales para observar, describir, explicar y predecir procesos relacionados con el control automático y las comunicaciones en sus múltiples y variadas aplicaciones en pro de optimizar procesos y calidad de vida de las personas.

En este mundo cambiante con avances de toda índole, las exigencias del mercado y la industria deben ir de la mano con la investigación para optimizar procesos y aprovechar la materia prima.

La Universidad Industrial de Santander forma profesionales con proyección y altos estándares de calidad en pro de generar competencias aptas para el ritmo en el que avanza el mundo y la tecnología.

Fruto de esto y como respuesta a una necesidad, a la implementación y enriquecimiento de la carrera nace el proyecto titulado “Diseño y construcción de un prototipo para medición y detección de humedad relativa” que busca que la Escuela de Ingenierías Eléctrica Electrónica y Telecomunicaciones cuente con el diseño de un nuevo sistema para la medición y detección de una nueva e importante variable, humedad relativa, la cual no es tomada con la importancia necesaria, además de abordar fundamentadamente la medición de esta nueva variable para ser medida en el curso de Instrumentación Electrónica.

Este proyecto se fundamenta bajo la no reconocida importancia de la humedad relativa la cual impacta directamente en la comodidad del ser humano y puede generar daños en equipos electrónicos, busca generar un prototipo, capaz de adquirir, detectar niveles predeterminados y visualizar medidas de humedad relativa con la exactitud requerida en procesos relacionados a la cámara de niebla (corrosión), procesos de campo, textiles, entre otros lo cual manifiesta la gran importancia y utilidad.

El desarrollo de este proyecto fué un proceso enriquecedor que arrojó nuevos conocimientos a la carrera, en el cual se unió esfuerzo y disciplina para el desarrollo del prototipo que hoy es una realidad.

1. FUNDAMENTACIÓN TEÓRICA

1.1 HUMEDAD

Es la cantidad de vapor de agua en el aire. A una temperatura dada el aire puede alcanzar un máximo nivel de humedad, es la humedad de saturación (cuando caen gotas de agua).

La cantidad de humedad existente en relación con la humedad de saturación expresada en porcentaje es la humedad relativa.

1.1.1 Humedad absoluta. La humedad absoluta es la cantidad de vapor de agua presente en el aire, se expresa en gramos de agua por kilogramos de aire seco (g/kg), gramos de agua por unidad de volumen (g/m^3) o como presión de vapor (Pa o kPa o mm Hg). A mayor temperatura, mayor cantidad de vapor de agua permite acumular el aire.

1.1.2 Humedad de saturación. Es la cantidad máxima de vapor de agua que puede contener un metro cúbico de aire en unas condiciones determinadas de presión y temperatura.

1.1.3 Humedad relativa. Al contenido de agua en el aire se le conoce como humedad relativa y se define como el porcentaje de saturación del aire con vapor de agua, es decir, es la relación entre la cantidad de vapor de agua que contiene un metro cúbico de aire en unas condiciones determinadas de temperatura y presión y la que tendría si estuviera saturado a la misma temperatura y presión. La humedad relativa de una muestra de aire depende de la temperatura y de la presión a la que se encuentre.

Una humedad relativa del 100% significa un ambiente en el que no cabe más agua. El cuerpo humano no puede transpirar y la sensación de calor puede llegar a ser asfixiante, corresponde a un ambiente húmedo. Una humedad del 0% corresponde a un ambiente seco, se transpira con facilidad.

Algunos factores de riesgo relacionados con la Humedad relativa son:

- **Electricidad estática.** El aire seco puede provocar electricidad estática en un ambiente. La electricidad estática puede ser disminuida mediante la elevación de la humedad relativa del aire. Las máquinas de un parque de atracciones desprenden electricidad estática como resultado de la fricción. Cuando hay mayor cantidad de máquinas que están activas durante un gran periodo de tiempo, más fricción tendrá lugar y el riesgo de la electricidad estática aumenta, esto principalmente les ocurre a los elementos secos de las máquinas. En las salas de ordenadores, hay también un riesgo de electricidad estática. La mayor parte de la electricidad estática es provocada a una humedad relativa de entre un 30-35%.

- **Efectos sobre la salud.** A medida que la temperatura aumenta, la humedad relativa disminuye. El aire seco puede tener efectos sobre la salud, tales como sequedad de nariz y garganta. Esto provoca una mayor susceptibilidad a los patógenos tales como virus. Cuando hace frío, una humedad del aire más elevada hace a la gente pensar que está más templado. Esto hace que los calefactores estén encendidos con menos frecuencia.

Según estadísticas de comportamiento el clima para el crecimiento de las bacterias es peor cuando la humedad relativa se encuentra entre el 40 y el 60%. Los virus pueden sobrevivir menos a una humedad relativa de entre un 47 y un 70%. Para las personas, la humedad relativa es más agradable entre el 45 y el 55%.

Una humedad relativa elevada puede provocar constricción.

Como medir humedad relativa

- **Método del bulbo seco/bulbo húmedo.** La forma mas utilizada en la medición de humedad relativa es la del método del bulbo seco/bulbo húmedo que se rige por la norma ASTM e337-02[1] Standard Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures) que es la siguiente:

La temperatura de bulbo seco se corresponde con la temperatura ambiental tal y como se mide normalmente. Es decir en un lugar sombrío y al abrigo de corrientes de aire y con un termómetro de mercurio o alcohol. El bulbo del termómetro se mantiene directamente al aire.

Para medir la temperatura de bulbo húmedo se usa el mismo tipo de termómetro pero se realiza la siguiente operación. Se llena en un pequeño vaso con agua. Se introduce en el agua una sustancia porosa como una buena cantidad de algodón y un trozo de tela natural pero siempre de forma que parte esté sumergida en el agua y otra parte quede fuera del agua. El bulbo del termómetro se colocará rodeado de la tela o el algodón que sobresalga del agua.

---

[1] La norma a la cual se hace referencia se encuentra en el anexo A.

Cuando se rodea el bulbo del termómetro con el algodón o tela lo estamos rodeando de una sustancia que esta humedecida. El aire circulante en la atmósfera 'choca' con el algodón humedecido y evapora parte del agua. Al evaporar el agua debe absorber el calor latente y lo hace robando calor al bulbo del termómetro. Entonces la temperatura del termómetro desciende.

La temperatura del termómetro desciende continuamente hasta que el aire de los alrededores se satura, es decir, no admite más agua. Entonces la temperatura permanece en un valor fijo que se denomina temperatura del bulbo húmedo.

- **Temperatura de punto de rocío.** Otra forma de medición de la humedad relativa es la basada en la temperatura de punto de rocío, la cual se puede realizar de la siguiente forma:

Primero se toma un recipiente metálico (una lata) y se añade agua a temperatura ambiente (agua expuesta al ambiente durante al menos una hora), luego se mide la temperatura del agua y se anota.

Después se añaden pequeños pedazos de hielo y se remueven con suavidad con el termómetro. Debe observase con atención la lata hasta que aparezcan gotas diminutas en el exterior de la lata (se notará porque la lata se empaña). Se anota esta temperatura que se llamará 'punto de rocío[2]'.

Luego de esto empleando la siguientes formulas se halla el valor de humedad relativa.

---

[2] El punto de rocío o temperatura de rocío es la temperatura a la que empieza a condensar el vapor de agua contenido en el aire, produciendo rocío, neblina o, en caso de que la temperatura sea lo suficientemente baja, escarcha.

$$RH = \left(\frac{Pv}{Pvs} \right) * 100$$

$$Pv = 6{,}112 * Exp\left[\frac{17{,}7 * Td}{Td + 243{,}5} \right]$$

$$Pvs = 6{,}11 * Exp\left[\frac{17{,}27 * T}{237{,}3 + T} \right]$$

Donde:

RH = Humedad relativa

Pv = Presión de vapor en Hpa

Pvs = Presión de vapor de saturación para T en Hpa

Td = Temperatura de punto de rocío en grados Celsius

T = Temperatura ambiente en grados Celsius.

2. DISEÑO DEL PROTOTIPO

Para el diseño del **PROTOTIPO PARA MEDICIÓN Y DETECCIÓN DE HUMEDAD RELATIVA** se deben tener en cuenta las aplicaciones que tendrá y las posibilidades de que en próximos trabajos se pueda realizar un control sobre esta variable tan importante en la industria.

PLANTEAMIENTO DEL PROBLEMA

La humedad relativa juega un papel importante en todos los procesos industriales. La medición de la humedad es un proceso verdaderamente analítico en el cual el sensor debe estar en contacto con el ambiente de proceso a diferencia de los sensores de presión y temperatura que invariablemente se encuentran aislados del proceso por protecciones conductoras del calor o diafragmas respectivamente. Esto tiene, por supuesto, implicaciones en la contaminación y degradación del sensor en niveles variables dependiendo de la naturaleza del ambiente.

La humedad relativa es una nueva variable a estudiar en la Universidad Industrial de Santander por lo cual se busca entregar un dispositivo capaz de medir y detectar con la mayor precisión posible esta variable.

3. ARQUITECTURA DEL PROTOTIPO

En este capítulo se hará referencia a la forma como se encuentra organizado el prototipo desde el momento que se hace el sensado de la variable (humedad relativa) hasta la visualización en la pantalla LCD y el PC.

Las siguientes son las etapas que conforman el desarrollo de este prototipo:

- **ETAPA DE SENSADO:** a través de esta se obtiene la variable estudiada por medio del **SHT75.**

- **ETAPA DE ADQUISICIÓN DE DATOS:** es la encargada de obtener los datos del sensor y procesarlos para su posterior visualización.

- **ETAPA DE VISUALIZACIÓN:** es la encargada de mostrar en la pantalla LCD los datos correspondientes a la humedad relativa.

- **ETAPA DE COMUNICACIÓN:** Esta permite la transferencia de los datos desde el microcontrolador hasta el computador.

3.1 ETAPA DE SENSADO.

SENSORES

Los sensores también conocidos como transductores, son dispositivos que reconocen señales de entrada de magnitudes físicas reales (mecánicas, eléctricas, térmicas, químicas, radiantes, etc.) procedentes de algún proceso o medio externo, convirtiendo esa información en señales de tipo eléctrico, que sirven para supervisar y controlar una determinada operación o proceso.

Los sensores se clasifican según el tipo de señal que manejan en su salida, o la forma en que presentan la magnitud sensada, en:

- **Análogos:** la señal de salida que proporcionan es un valor de tensión o corriente que corresponde a un rango determinado por las características propias del sensor.

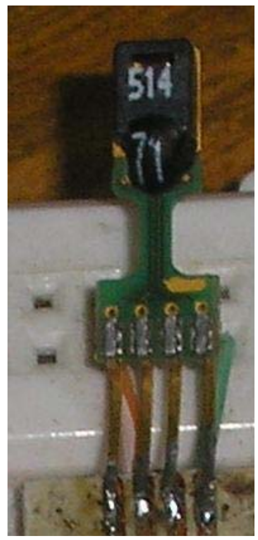
- **Digitales:** estos proporcionan una señal codificada en pulsos o código digital (binario, BCD, etc.).

- **Dos estados:** (cerrado-abierto, on-off). Son aquellos que únicamente poseen dos estados, los cuales están separados por un valor de la magnitud sensada.

Esta etapa permite obtener la señal proveniente del medio ambiente a través del sensor de humedad relativa **SHT75** el cual tiene la función de digitalizar la señal análoga correspondiente a la variable estudiada para luego transferir los datos al microcontrolador.
Este sensor fué elegido debido a sus características favorables para el prototipo, entre las principales se encuentran el bajo consumo de energía tanto en reposo como en funcionamiento, precisión, rango y comunicación serial.

3.1.1 Sensor de humedad y temperatura SHT75. El SHT75 (Ver Figura 1) es un sensor de humedad relativa y temperatura encapsulado en una pastilla que posee una salida digital calibrada. Esta pastilla contiene un polímero capacitivo para medir la humedad y un sensor de temperatura de bandgap[3], ambos son acoplados a un convertidor análogo-digital de 14 bit y a un circuito de interfaz serial de manera uniforme sobre la misma pastilla.

Figura 1. Foto sensor SHT75



Fuente: Autores del Proyecto

Parámetros. Entre los parámetros más importantes para este sensor de humedad y temperatura están:

- Voltaje de alimentación: 2,4 a 5,5 V

[3] El sensor de temperatura de bandgap de silicio es una forma sumamente común de sensor de temperatura usada en equipo electrónico. Su ventaja principal es que puede ser incluido en un circuito integrado de silicio con un bajo costo. El principio del sensor es que el voltaje delantero de un diodo de silicio es dependiente de la temperatura de acuerdo con la siguiente formula: $V_{BE} = V_{G0}(1 - T / T_0) + V_{BE0}(T / T_0) + (nKT / q)\ln(T_0 / T) + (KT / q)\ln(IC / IC_0)$ donde T: Temperatura en grados Kelvins, V_{GO}: voltaje de bandgap en cero absoluto, V_{BEO}: voltaje de bandgap a temperatura T_0 y corriente IC_0, K: constante de Boltzmann, q: carga del electrón, n: constante dependiente del dispositivo

- Consumo en medición: 550 µA
- Consumo en reposo : 0,3 µA
- Rango de temperatura: -40ºC a 123,8ºC
- Exactitud (temperatura): ± 0,3ºC a 25ºC
- Rango de humedad : 0 a 100%
- Exactitud (Humedad): ± 1,8%
- Comunicación serial de dos líneas
- Generación automática de CRC

Funcionamiento

- **Pines de alimentación.** El SHT75 requiere un voltaje de alimentación entre 2,4 y 5,5 voltios. Después de encendido necesita de 11 milisegundos (ms) para llegar a su estado de "Sueño" antes de esto no se debe enviar ningún dato. Los pines de alimentación (VDD y GND) pueden ser desacoplados por un capacitor de 100 nF.

- **Interfaz serial.** La interfaz serial del SHT75 es optimizada para la lectura del sensor y consumo de energía. No es compatible con interfaz I^2C.

- **Entrada serial de reloj (SCK).** El SCK es usado para sincronizar la comunicación entre el microcontrolador y el SHT75, pero debido a que la interfaz cuenta con lógica completamente estática no existe frecuencia de SCK mínima.
- **Datos seriales.** El pin de datos es del tipo de tres estados, es utilizado para transmitir datos dentro y fuera del dispositivo. Los datos cambian

después del flanco de bajada y es están disponibles en el siguiente flanco de subida del SCK. Durante la transmisión de datos la línea de datos debe permanecer estable mientras el SCK esta en alto. Para evitar conflictos entre los datos el microcontrolador debe manejar únicamente datos bajos. Externamente se requiere una resistencia de pull-up[4] para llevar la señal al estado alto.

- **Transmisión de comando de operación.** Para iniciar la transmisión se debe enviar la secuencia que se muestra en la figura 2.

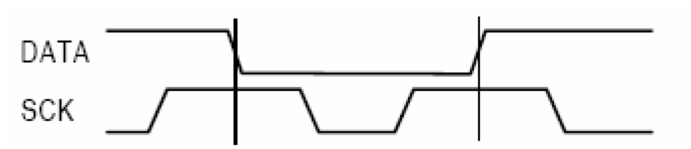
Esta secuencia consiste en el siguiente procedimiento:

⇒ Se coloca la línea de SCK el alto y posteriormente el pin de datos (DATA) en bajo.

⇒ Se produce un pulso en el SCK[5]

⇒ La línea de datos se coloca nuevamente en estado alto mientras el SCK permanece en el mismo estado.

Figura 2. Inicio de Transmisión



Fuente: Hoja de Datos del Fabricante

[4] Un resistencia de Pull-up es una resistencia eléctrica que se conecta entre el pin de entrada de señales binarias de algún dispositivo electrónico, y el polo opuesto al polo de la señal que se está enviando al dispositivo. Este tipo de conexión se utiliza para obtener señales claramente polarizadas a la entrada de un circuito. Al estar abierto el interruptor, la resistencia conecta a tierra el circuito, estableciendo 0 Voltios en la línea de entrada digital, sin embargo, al cerrarse el interruptor, la señal de la línea, será la tensión de entrada, ya que esta resistencia, en paralelo con la resistencia de entrada del dispositivo, la hace despreciable. Por tanto, la línea solo tendrá dos estados definidos, 0 V y +Vi, evitándose estados indefinidos.

[5] Cambio de estado pasando de alto a bajo y posteriormente de bajo a alto.

Posteriormente se envía un comando cuyos tres primero bits son “000” y los siguientes cinco dependerán de la acción que se quiera realizar, para el caso de medición de humedad el comando correspondiente que debe enviar el microcontrolador es “00000101”. Al recibir el comando el SHT75 indica la recepción correcta de este, forzando la línea de datos ha estado bajo luego del flanco de bajada del octavo pulso del SCK. La línea de datos es liberada luego del noveno pulso del SCK.

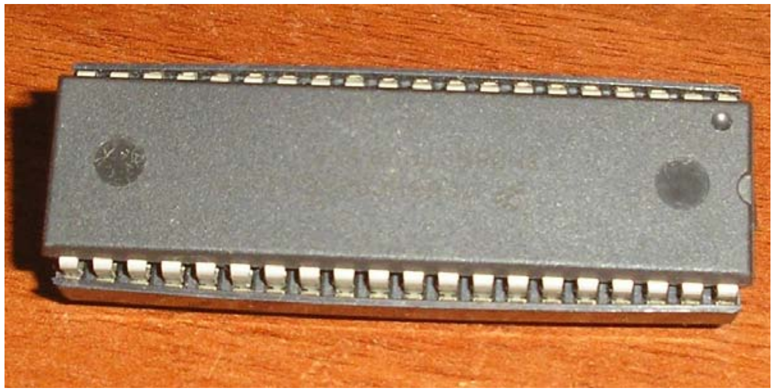
- **Secuencia de medición.** Luego de enviar un comando de medición el microcontrolador debe esperar a que esta se complete. Esto toma de 11 a 210 ms dependiendo de la resolución con la que se realice (8 ó 14 bits).

3.2 ETAPA DE ADQUISICIÓN DE DATOS

La función principal de esta etapa es la de recibir los datos que envía el sensor y procesarlos para una posterior visualización en la pantalla LCD, para esto se utiliza el microcontrolador **MC68HC908GP32** de Motorola el cual se eligió por sus características y su práctica implementación debido a que se puede encontrar la tarjeta de desarrollo necesaria para su programación en la Escuela de Ingeniería Eléctrica, Electrónica y Telecomunicaciones de la Universidad Industrial de Santander.

3.2.1 Microcontrolador. El microcontrolador utilizado para la implementación del medidor de humedad es el MC68HC908GP32 (Ver Figura 3), es un microcontrolador de la familia HC08 de MOTOROLA.

Figura 3. Foto microcontrolador MC68HC908GP32



Fuente: Autores del Proyecto

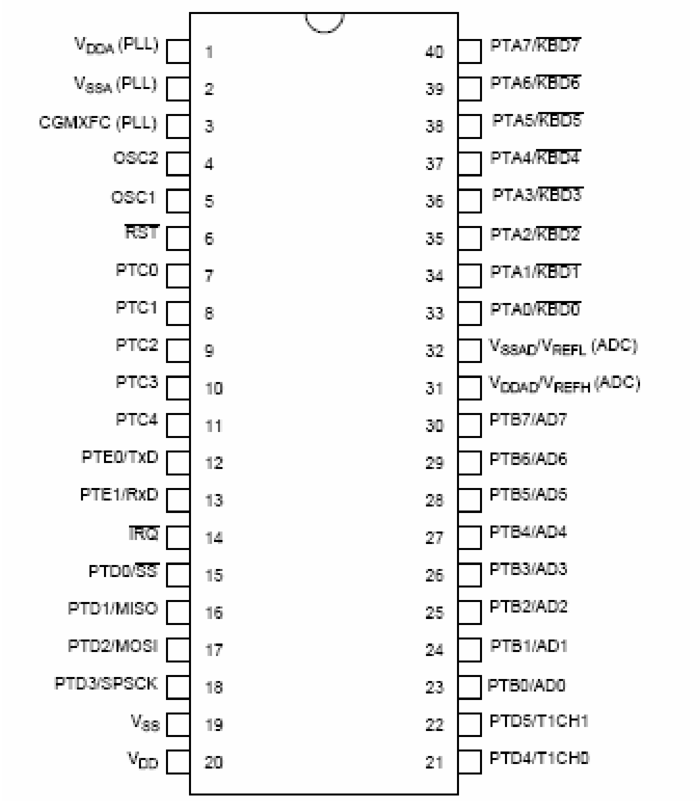
Características

- Procesador de 8 bits optimizado para lenguaje C.
- 32 kBytes de memoria flash EEPROM.
- 512 Bytes de RAM.
- Modos de bajo consumo.
- Oscilador de 32 kHz con PLL incluido.
- Protección de bajo voltaje interno.
- 8 canales de conversión análoga-digital (ADC).
- Puertos seriales SCI (Serial Comunication Interface), SPI (Serial Peripheral Interface), master slave.
- 2 timers de 16 bits.

- Salidas de comparación y entradas de captura.
- Protecciones: COP, Clock Monitor, Illegal Address reset, Illegal Opcode.
- Chip de 40 pines.
- Voltaje de operación de 2,5 a 5,5 V.

Diagrama de pines

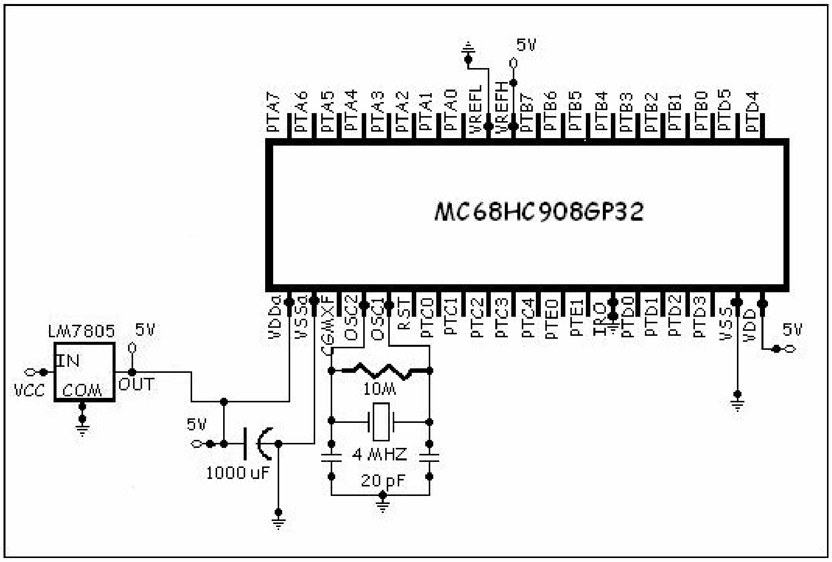
Figura 4. Diagrama de pines del MC68HC908GP32



Fuente: Hoja de Datos del Fabricante

Conexión. La Figura 5 muestra la forma como esta conectado el microcontrolador en el prototipo:

Figura 5. Conexión de alimentación del MC68HC908GP32



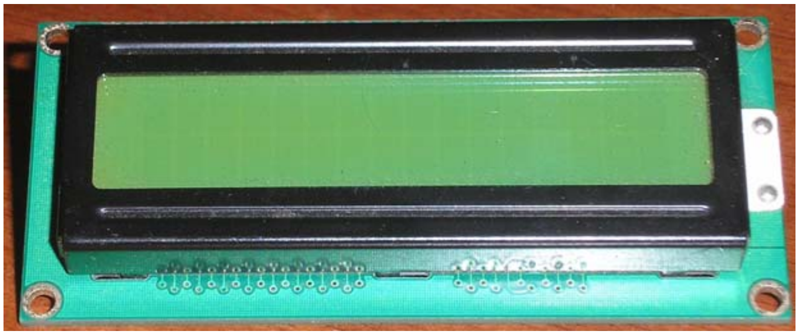
Fuente: Autores del Proyecto

3.3 ETAPA DE VISUALIZACIÓN

En esta etapa se hace la implementación de una pantalla LCD (ver Figura 6) la cual permite la visualización los valores de la variable estudiada (humedad relativa), los cuales son enviados desde el microcontrolador y se muestran en forma decimal.

3.3.1. Pantalla LCD. Para este prototipo es muy importante poder observar en el sitio de trabajo el valor de humedad relativa que el sensor esta detectando en el momento para que al tener la necesidad de hacer un control de humedad se realice inmediatamente durante el proceso.

Figura 6. Foto pantalla LCD



Fuente: Autores del Proyecto

Características

- Bajo consumo de corriente.
- Fácil conexión al microcontrolador.
- No requiere de multiplexado para visualizar varios caracteres.
- Muestra caracteres alfanuméricos y ASCII.

Los módulos LCD se pueden encontrar en diferentes presentaciones como son: 2 líneas por 16 caracteres, 2 líneas por 20 caracteres, 4 líneas por 20 caracteres, etc.

Para el caso del prototipo de medición y detección de humedad relativa se usará el módulo de 2 líneas por 16 caracteres (2 x 16), que además de las características ya mencionadas, es de bajo costo, se consigue fácilmente en el comercio y su tamaño es suficiente para las necesidades del prototipo.

Pines de conexión. El módulo LCD 2 x 16 tiene 14 pines los cuales están distribuidos como se muestra en la tabla 1:

Tabla 1. Pines de conexión de la pantalla LCD

PIN	SIMBOLO	NOMBRE Y FUNCION
1	Vss	Tierra, 0 V
2	Vdd	Alimentación, +5 V
3	Vo	Ajuste de Voltaje de Contraste
4	RS	Selección Dato/Control
5	R/W	Lectura/Escritura en LCD
6	E	Habilitación
7	D0	D0 BIT menos significativo
8	D1	D1
9	D2	D2
10	D3	D3
11	D4	D4
12	D5	D5
13	D6	D6
14	D7	D7 BIT mas significativo

Fuente: Autores del Proyecto

Instrucciones de control. Para el modulo LCD los pines de control E, Rs y R/W deben presentar un estado determinado dependiendo la operación que se desee realizar. Este módulo responde a un conjunto especial de instrucciones (Ver Tabla 2) que son enviadas por el microcontrolador. En la siguiente tabla se pueden observar las instrucciones del módulo:

Tabla 2. Instrucciones de control pantalla LCD

	CODIGO										DESCRIPCION
INSTRUCIONES	RS	R/W	D7	D6	D5	D4	D3	D2	D1	D0	
Borrado de Pantalla	0	0	0	0	0	0	0	0	0	1	Limpia el display y direcciona 00 a DD RAM
Cursor a casa	0	0	0	0	0	0	0	0	1	*	Direcciona 00 a DD RAM sin cambiar los datos en RAM
Selección de modo	0	0	0	0	0	0	0	1	I/D	S	Configura corrimiento del cursor y desplazamiento del display
Control On/Off de pantalla	0	0	0	0	0	0	1	D	C	B	Configura parpadeo del display, cursor y carácter
Corrimiento de cursor o de pantalla	0	0	0	0	0	1	S/C	R/L	*	*	Mueve el cursor y el display sin cambiar los datos en la RAM
Selección de Función	0	0	0	0	1	DL	N	F	*		Configura Bus de datos (DL) líneas (N) y puntos matriz (F)
Selección dirección CG RAM	0	0	0	1	Dirección para generar en RAM						Dirección para la generación de caracteres en CG RAM
Selección dirección DD RAM	0	0	1	Dirección de RAM							Direcciona para escribir un carácter en DD RAM
Leer bandera de ocupado	0	1	BF	AC							Lectura bandera Busy FLAG para saber el funcionamiento
Escribir dato a CG o DD RAM	1	0	Escritura del dato								escribe el dato o carácter en DD RAM o en CG RAM
Leer dato desde CG o DD RAM	1	1	Lectura del dato								lee el dato o carácter desde DD RAM o CG RAM

En la tabla 3 se puede encontrar el significado de cada una de las abreviaturas utilizadas en la tabla de instrucciones de modulo.

Tabla 3. Significado de abreviaciones de la tabla de instrucciones de la pantalla LCD

I/D	=	1	Incrementa
		0	Decrementa
S	=	1	Desplaza el mensaje en la pantalla
		0	Mensaje fijo en la pantalla
D	=	1	Encender (activar) la pantalla
		0	Apagar la pantalla
C	=	1	Activar el cursor
		0	Desactivar el cursor
B	=	1	Parpadea carácter señalado por el cursor
		0	No parpadea el carácter
S/C	=	1	Desplaza la pantalla
		0	Mueve el cursor
R/L	=	1	Desplazamiento a la derecha
		0	Desplazamiento a la izquierda
DL	=	1	Datos de 8 bits
		0	Datos de 4 bits
BF	=	1	Durante operación interna del modulo
		0	Finalizada la operación interna
N	=	1	Dos líneas de pantalla
		0	Una línea de pantalla
F	=	1	Matriz de 5 x 10 puntos
		0	Matriz de 5 x 7 puntos

Fuente: Autores del Proyecto

3.4 ETAPA DE COMUNICACIÓN

Esta etapa permite la conexión entre el microcontrolador y el PC mediante el puerto serial por medio del circuito integrado **MAX232**. La visualización en el PC se realiza por medio de una interfaz grafica creada en LabVIEW.

3.4.1 Puerto serie (RS-232). Un puerto serie es una interfaz de comunicaciones entre ordenadores y periféricos en donde la información es transmitida bit a bit enviando un solo bit a la vez (en contraste con el puerto paralelo que envía varios bits a la vez).

El puerto serie por excelencia es el RS-232 que utiliza cableado simple desde 3 hilos hasta 25 y que conecta ordenadores o microcontroladores a todo tipo de periféricos, desde terminales a impresoras y módems pasando por ratones.

La interfaz entre el RS-232 y el microprocesador generalmente se realiza mediante el integrado 82C50.

El RS-232 original tenía un conector tipo D de 25 pines, sin embargo la mayoría de dichos pines no se utilizaban, por lo que IBM incorporó desde su PS/2 un conector más pequeño de solamente 9 pines que es el que actualmente se utiliza.

En Europa la norma RS-422 de origen alemán es también un estándar muy usado en el ámbito industrial.

Uno de los defectos de los puertos serie iniciales era su lentitud en comparación con los puertos paralelos, sin embargo, con el paso del tiempo, están apareciendo multitud de puertos serie con una alta velocidad que los hace muy interesantes ya que tienen la ventaja de un menor cableado y solucionan el problema de la velocidad con un mayor apantallamiento[6]; son más baratos ya que usan la técnica del par trenzado; por ello, el puerto RS-232 e incluso multitud de puertos paralelos están siendo reemplazados por nuevos puertos serie como el USB, el Firewire o el Serial ATA.

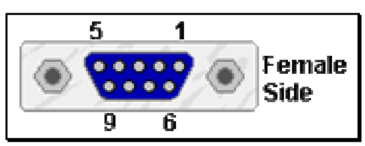
En la tabla 4 se encuentran identificados los pines de conexión para el conector serial DB9 según el estándar RS-232, y en la figura 7 se observa el conector DB9.

Tabla 4. Pines de conexión para el conector DB-9 según Estándar RS-232

Pin	Señal
1	Data Carrier Detec (DCD)
2	Receieve Data Line RD
3	Transmite Data Line (TD)
4	Data Terminal Ready (DTR)
5	Signal Ground (GND)
6	Data Set Ready (DSR)
7	Request To Send (RTS)
8	Clear To Send (CTS)
9	Ring Indicator (RI)

Fuente: Autores del Proyecto

Figura 7. Conector DB9



Fuente: http://www.hw-server.com/rs232

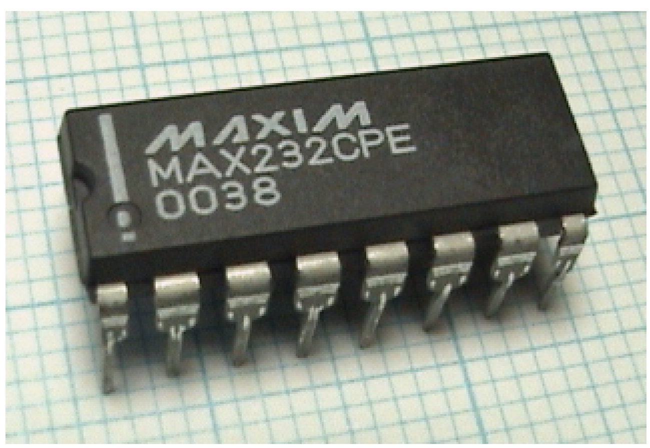
[6] Apantallamiento es la protección que se logra mediante la colocación de un elemento que impide o atenúa en gran medida el paso de campos hasta la unidad que se desea proteger.

Para este prototipo se utilizan solos los pines 2, 3, 5 del conector DB9 para la comunicación con el PC, y se utiliza una taza de transferencia de 7812,5 Baudios.

3.4.2 MAX232. Se utilizó el MAX232 (Ver Figura 8) ya que es un integrado que cumple las funciones de cambiar los niveles de tención que salen del microcontrolador para que puedan ser recibidas por el PC, mediante un programa de visualización que en este caso es LabVIEW.

En las figuras 9 y 10 se encuentran los diagramas de pines y de conexión respectivamente para el MAX232, las cuales son suministrados en el data sheet del fabricante.

Figura 8. Foto del MAX232



Fuente: http://homepage2.nifty.com/salvia/mirror/elecmake/parts/ic/MAX232.jpg

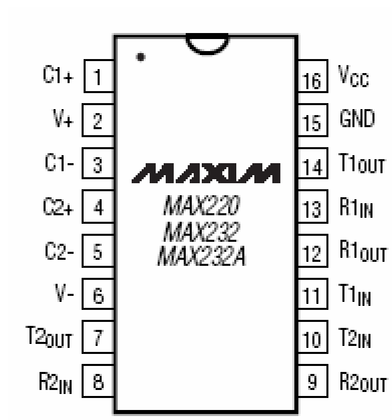
Características

Las principales características del MAX232[7] son:

- Voltaje de alimentación (V_{CC}) 0,3 – 6,0 V
- T_{IN} -0,3V (V_{CC} – 0,3 V)
- R_{IN} ± 30V
- T_{OUT} ±15 V.
- R_{OUT} -0,3V (V_{CC} + 0,3 V)
- Corriente de la Fuente de V_{CC} 4 mA.

Diagrama de pines

Figura 9. Diagrama de pines del MAX232

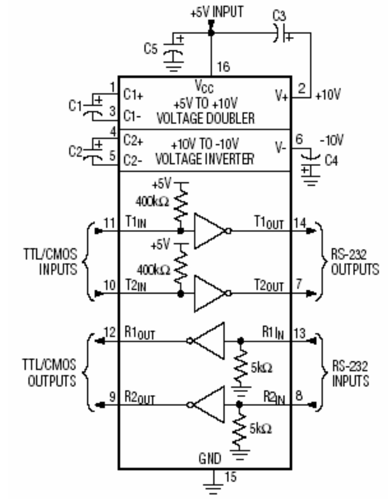


Fuente: Hoja de Datos del Fabricante

[7] El fabricante proporciona la hoja de datos.

Conexión

Figura 10. Diagrama de conexión del MAX232



Fuente: Hoja de Datos del Fabricante

3.4.3 LabVIEW. LabVIEW es una herramienta gráfica de programación, esto significa que los programas no se escriben, sino que se dibujan**.**

Un programa se divide en Panel Frontal y Diagrama de bloques. El Panel frontal es el interfaz con el usuario, en él se definen los controles e indicadores que se muestran en pantalla. El diagrama de bloques es el programa propiamente dicho, donde se define su funcionalidad, aquí se colocan iconos que realizan una determinada función y se interconectan.

Es usado principalmente para tareas como:

- Adquisición de datos
- Control de instrumentos
- Automatización industrial o PAC (Controlador de Automatización Programable)
- Diseño de control: prototipaje rápido y hardware-en-el-bucle (HIL)

Su principal característica es la facilidad de uso, además presenta facilidades para el manejo de:

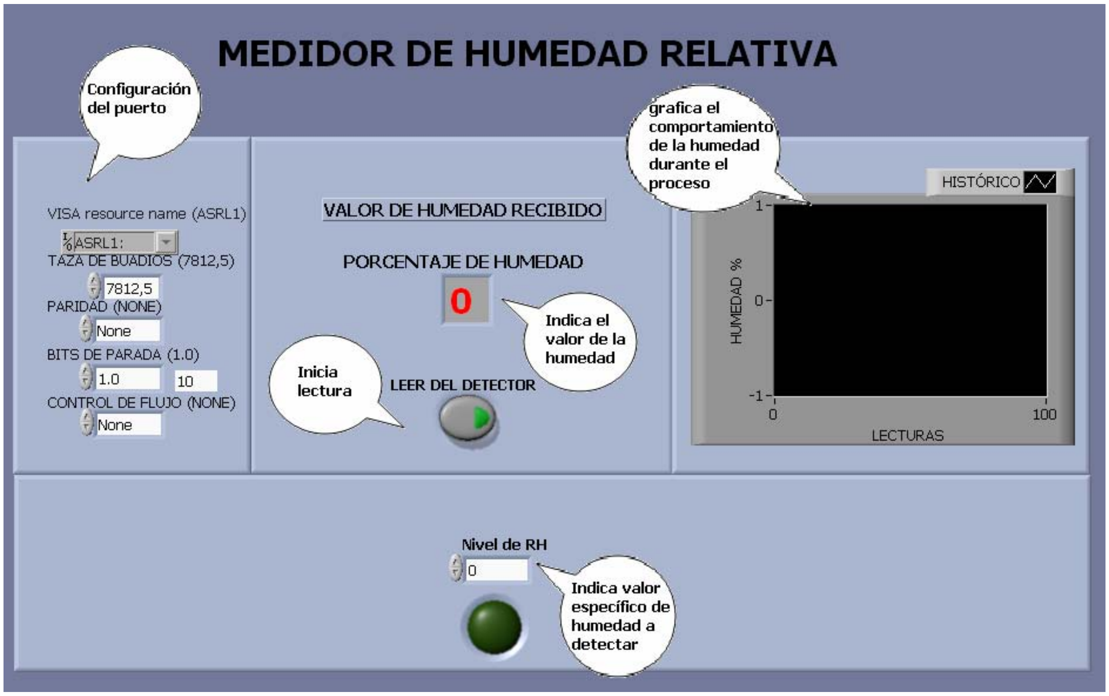
- Interfaces de comunicaciones como:
    - Puerto serie
    - Puerto paralelo
    - GPIB
    - TCP/IP, UDP, DataSocket
    - Irda
    - Bluetooth
    - USB
- Herramientas para el procesado digital de señales.
- Visualización y manejo de gráficas con datos dinámicos.
- Adquisición y tratamiento de imágenes.
- Control de movimiento.
- Tiempo Real estrictamente hablando.
- Programación de FPGAs.
- Sincronización.

En este prototipo se utilizará LabVIEW para adquirir los datos provenientes del microcontrolador, para visualizarlos en el PC.

La figura 11 muestra la interfaz grafica creada para la visualización de los datos recibidos del prototipo y se indica el uso ó función de cada cuadro en la interfaz.

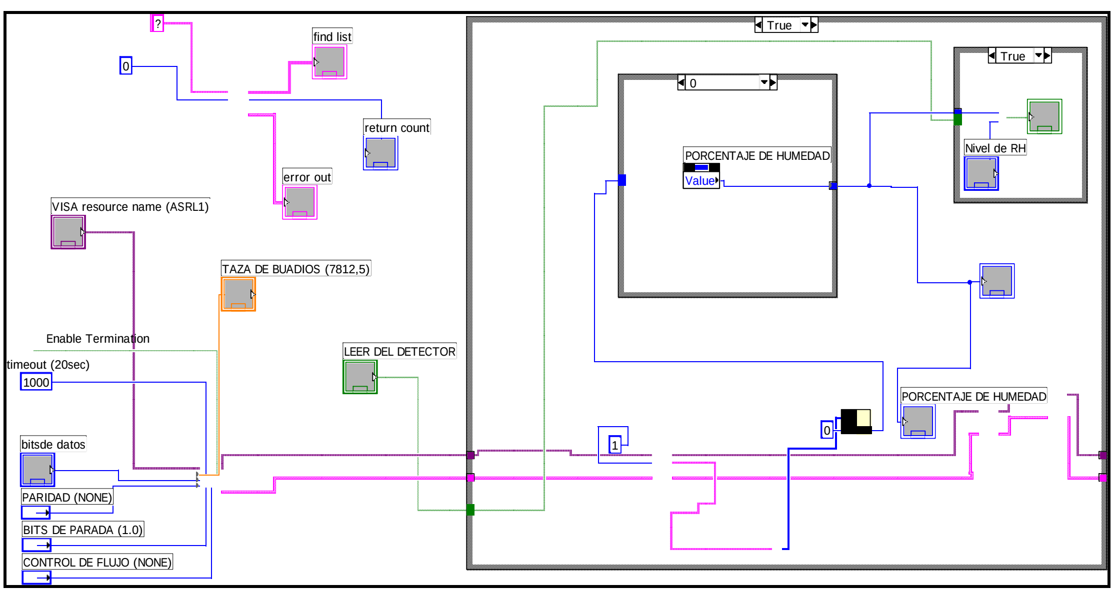
En la figura 12 podemos encontrar el diagrama de bloques correspondiente a la interfaz gráfica creada en LabVIEW 7.1 para la visualización de los datos que se reciben del prototipo.

Figura 11. Interfaz gráfica para visualizar los datos recibidos del prototipo



Fuente: Autores del proyecto

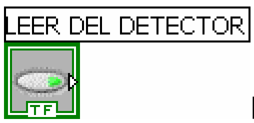
Figura 12. Diagrama de bloques de la interfaz gráfica



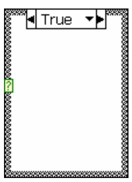
Fuente: Autores del proyecto

Los siguientes fueron los bloques utilizados para la realización de la interfaz gráfica:

Inicializa el puerto serial especificado por visa resourse name y permite la configuración de la tasa de transferencia, bits de parada, bits de paridad y control de flujo.



Este icono permite que se inicie la lectura del puerto serie por parte de la interfaz grafica.



Estructura caso es utilizada para el proceso de visualización de los datos e indicador de niveles específicos de humedad relativa.

4. PRUEBAS REALIZADAS

Para este prototipo se hicieron pruebas de comparación con el termo-higrómetro Traceable® Pocket Hygrometer / Dew Point Thermometer de la empresa Control Company (Ver Figura 13, el cual se encuentra en la sede de Guatiguará en el laboratorio de recubrimientos CIC (Corporación para la Investigación de Corrosión), este termo-higrómetro tiene certificación de calidad ISO 9001 y Acreditación para calibración de laboratorio ISO 17025.

El termo-higrómetro utilizado para hacer las pruebas al prototipo corresponde al modelo 4392CC y número serial 72051792 de control company y en la corporación para la Investigación de la corrosión tiene número de inventario ECREC029-4.

Figura 13. Fotos del Termo-Higrómetro

Fuente: Autores del Proyecto

Los resultados obtenidos en las pruebas son los que aparecen en la tabla 5:

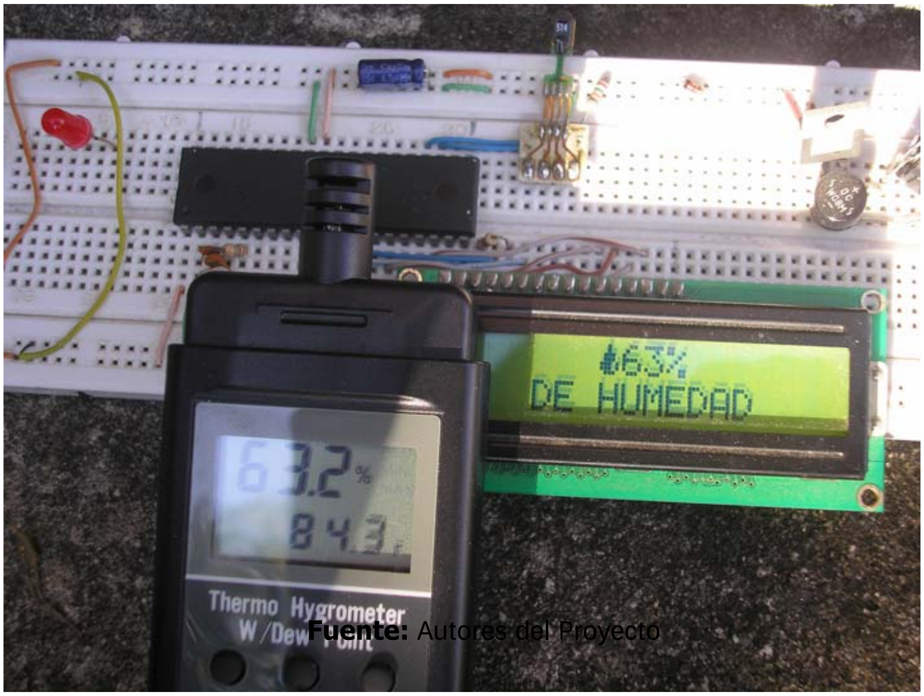
Tabla 5. Datos de la prueba de humedad

HUMEDAD PROTOTIPO	HUMEDAD HIGRÓMETRO
49,00	49,10
55,00	55,10
55,00	54,10
56,00	56,50
58,00	58,50
60,00	59,90
60,00	59,30
51,00	51,20
43,00	42,00
45,00	43,00
44,00	44,70
59,00	59,30
60,00	61,00
66,00	66,30
64,00	63,30
62,00	62,20
61,00	61,10
63,00	63,20
61,00	60,90
50,00	50,70

Fuente: Autores del Proyecto

Estas mediciones se tomaron de tal forma que el prototipo y el termo-higrómetro estuvieran lo más cerca posible para tener lecturas mas acertadas como se muestra en la figura 14

Figura 14. Forma como se tomaron los datos de humedad



Fuente: Autores del Proyecto

Fuente: Autores del Proyecto

Algunas de estas mediciones se presentan en las fotos que se encuentran en el **anexo D**.

Al realizar los cálculos del error absoluto que corresponde a:

$$Ea = |RHh - RHp|$$

Donde:

Ea = Error absoluto

RHh = Humedad medida con el Termo-higrómetro

RHp = Humedad medida con el prototipo

Para el cálculo del porcentaje de error se utiliza la siguiente formula:

$$\%E = \frac{Ea}{RHh} * 100$$

Donde %E es el porcentaje de error.

Los resultados de calcular el Ea y %E aparecen en la tabla 6:

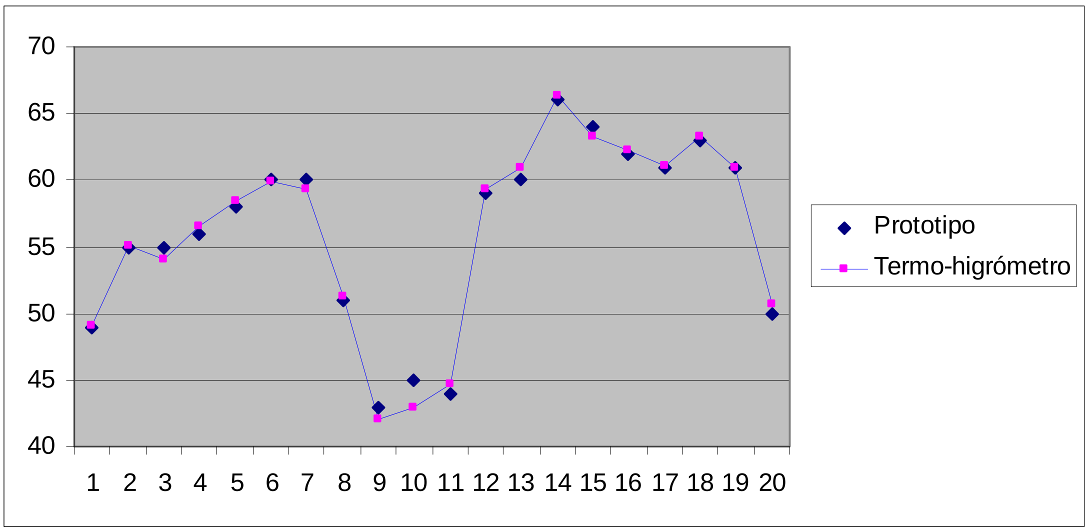
Tabla 6. Error absoluto y porcentaje de error

HUMEDAD PROTOTIPO	HUMEDAD HIGRÓMETRO	ERROR ABSOLUTO	% DE ERROR
49,00	49,10	0,1	0,20
55,00	55,10	0,1	0,18
55,00	54,10	0,9	1,66
56,00	56,50	0,5	0,88
58,00	58,50	0,5	0,85
60,00	59,90	0,1	0,17
60,00	59,30	0,7	1,18
51,00	51,20	0,2	0,39
43,00	42,00	1	2,38
45,00	43,00	2	4,65
44,00	44,70	0,7	1,57
59,00	59,30	0,3	0,51
60,00	61,00	1	1,64
66,00	66,30	0,3	0,45
64,00	63,30	0,7	1,11
62,00	62,20	0,2	0,32
61,00	61,10	0,1	0,16
63,00	63,20	0,2	0,32
61,00	60,90	0,1	0,16
50,70	50,00	0,7	1,40

Fuente: Autores del Proyecto

En la figura 15 se contrastan gráficamente los valores obtenidos en las mediciones del prototipo y el termo-higrómetro.

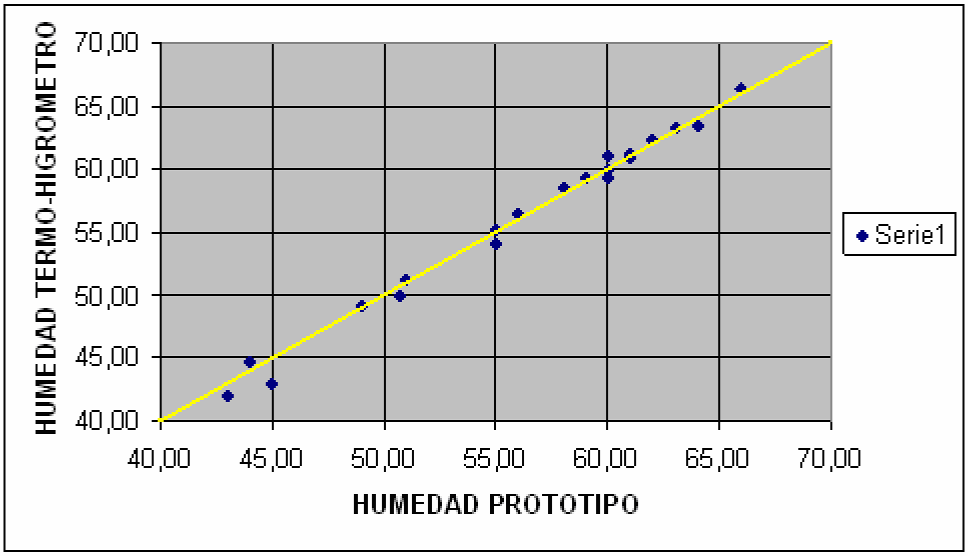
Figura 15. Contraste de los datos medidos



Fuente: Autores del Proyecto

En La Figura 16 se puede observar la tendencia a la linealidad que tienen los valores medidos con el prototipo con respecto al termo-higrómetro de calibración de la Corporación para la Investigación de Corrosión (CIC.) que esta en la sede de la Universidad ubicada en Guatiguará.

Figura 16. Tendencia de los datos medidos con el prototipo contra datos del Termo-Higrómetro



Fuente: Autores del Proyecto

Se realiza el análisis de correlación de los datos medidos con el prototipo contra los datos que proporciona el termo-higrómetro por medio de las siguientes formulas:

$$r = \frac{Sxy}{Sx * Sy}$$

$$Sxy = \sum_{i=1}^{n} \sum_{j=1}^{k} \frac{\left(Xi - \overline{X}\right) * \left(Yj - \overline{Y}\right) * nij}{n}$$

$$Sx = \sqrt{\frac{\sum_{i=1}^{n} \left(Xi - \overline{X}\right)^2}{n}}$$

$$Sy = \sqrt{\frac{\sum_{i=1}^{n}\left(Yi - \overline{Y}\right)^2}{n}}$$

Donde:

r = Correlación

Sxy = Covarianza

Sx = desviación típica de x

Sy = desviación típica de y

X = datos de humedad dados por el prototipo

Y = datos de humedad dados por el termo-higrómetro

Al realizar este análisis de correlación con la calculadora Hewlett Packard 48G+ se obtienen los siguientes resultados:

Sxy = 48.6632

SX = 6,52934552

Sy = 7,52919807

r = 0,995745636

Esto indica que existe una relación directa entre los datos tomados del prototipo y los datos correspondientes a las lecturas con el termo-higrómetro.

CONCLUSIONES, OBSERVACIONES Y RECOMENDACIONES

CONCLUSIONES

Se encontró que una de las normas que rige la medición de la humedad relativa es la ASTM E337-02 la cual esta basa en la medición de la temperatura de bulbo húmedo y bulbo seco.

Se seleccionó el sensor SHT75 debido a las características que presenta como la precisión y su alta velocidad de respuesta, además de ser un sensor que no se ha trabajado en la carrera de ingeniería electrónica.

Se realizó la selección del microcontrolador teniendo en cuenta, sus características tales como su rapidez de respuesta y su comunicación, además que en la Escuela contamos con la tarjeta de desarrollo para este microcontrolador.

Se implementó el hardware necesario para la medición y visualización de la humedad relativa así como un algoritmo para la adquisición y visualización tanto en la pantalla LCD como en el computador.

Se implemento la interfaz de comunicación entre el computador y el microcontrolador a través del integrado MAX232, el cual se encarga de cambiar los niveles de voltaje provenientes del microcontrolador para que se puedan recibir los datos en el computador sin ningún inconveniente.

Se implemento una interfaz grafica en LabVIEW la cual nos permite la visualización continua de la humedad relativa en el computador e indicación de niveles específicos por medio de una alarma.

Se contrasto el funcionamiento del prototipo con un termo-higrómetro calibrado que se encuentra en la sede de Guatiguará, obteniendo resultados similares entre los datos medidos.

OBSERVACIONES

El sensor empleado esta diseñado para espacios cerrados, debido a que en el aire libre por su sensibilidad y rapidez de respuesta presenta variaciones en sus lecturas a causa de corrientes de aire lo cual hace que su respuesta no se estabilice rápidamente.

El hardware empleado para la realización del prototipo se hizo teniendo en cuenta las bases adquiridas en la universidad.

Debido a las restricciones en manejo de software dentro de la Universidad Industrial de Santander, se seleccionó el software LabVIEW 7.1 para la visualización de los datos provenientes del microcontrolador en el computador ya que la universidad posee las licencias necesarias para su utilización.

RECOMENDACIONES

Se sugiere que para la implementación del sensor en espacios al aire libre se encapsule para mejorar su estabilidad.

Se sugiere que en la materia de instrumentación electrónica se comience a trabajar esta nueva variable ya que puede afectar los implementos electrónicos y es una variable muy importante en la industria.

BIBLIOGRAFÍA

℘ MOTOROLA. Technical data – MC68HC908GP32, rev 2.1 12/2.003.

℘ NATIONAL INSTRUMENTS. LabVIEW Express 7.0. User Manual [Online]. Disponible desde: Http://www.ni.com.

℘ MAXIM. Technical data MAX232. Disponible desde: Http://www.datasheetcatalog.com.

℘ DOEBELLIN O., Ernest. Measurement systems application and design. USA. 2004. Department of mechanical engineering. The Ohio State University.

℘ POLENTA, Héctor. Instrumentación de procesos industriales. Tomo II. Barcelona, España. 2006.

℘ BALLCELS, Joseph y ROMERAL, José Luis. Autómatas programables México D.F. Alfa Omega grupo editor, 1998:

℘ SENSIRION. The Sensor Company, Technical data, SHT75, Disponible desde: Http://www.sensirion.com.

℘ DE LA ESPRIELLA, Gabriel, GONZÁLEZ, Nelson Gabriel. Sistema de control de humedad por computador diseño y construcción, Trabajo de grado 1992, Escuela de Ingeniería Mecánica. Universidad Industrial de Santander.

℘ MONROY JÁCOME, Diego Fernando, ZABALA VARGAS, Sergio Andrés. Repotenciación y actualización de un potenciostato galvanostato princeton modelo 363 para el laboratorio de corrosión de la escuela de ingeniería metalúrgica y ciencia de materiales. Trabajo de grado 2005, Escuela de Ingeniería Eléctrica, Electrónica y Telecomunicaciones. Universidad Industrial de Santander.

℘ CANCHILA MERCADO, Ardanys, ROMERO CONTRERAS, Daiana. Desarrollo de un sistema de administración y control de equipos médicos del laboratorio clínico del Hospital Universitario de Santander. Trabajo de grado 2006, Escuela de Ingeniería Eléctrica, Electrónica y Telecomunicaciones. Universidad Industrial de Santander.

Anexo A. Norma ASTM E337-02

Designation: E 337 – 02

Standard Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)[1]

This standard is issued under the fixed designation E 337; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 *General:*

1.1.1 This test method covers the determination of the humidity of atmospheric air by means of wet- and dry-bulb temperature readings.

1.1.2 This test method is applicable for meteorological measurements at the earth's surface, for the purpose of the testing of materials, and for the determination of the relative humidity of most standard atmospheres and test atmospheres.

1.1.3 This test method is also applicable when the temperature of the wet bulb only is required. In this case, the instrument comprises a wet-bulb thermometer only.

1.1.4 Relative humidity (RH) does not denote a unit. Uncertainties in the relative humidity are expressed in the form $RH \pm rh$ %, which means that the relative humidity is expected to lie in the range $(RH - rh)$ % to $(RH + rh)$ %, where RH is the observed relative humidity. All uncertainties are at the 95 % confidence level.

1.2 *Method A—Psychrometer Ventilated by Aspiration:*

1.2.1 This method incorporates the psychrometer ventilated by aspiration. The aspirated psychrometer is more accurate than the sling (whirling) psychrometer (see Method B), and it offers advantages in regard to the space which it requires, the possibility of using alternative types of thermometers (for example, electrical), easier shielding of thermometer bulbs from extraneous radiation, accidental breakage, and convenience.

1.2.2 This method is applicable within the ambient temperature range 5 to 80°C, wet-bulb temperatures not lower than 1°C, and restricted to ambient pressures not differing from standard atmospheric pressure by more than 30 %.

1.3 *Method B—Psychrometer Ventilated by Whirling (Sling Psychrometer):*

1.3.1 This method incorporates the psychrometer ventilated by whirling (sling psychrometer).

1.3.2 This method is applicable within the ambient temperature range 5 to 50°C, wet-bulb temperatures not lower than 1°C and restricted to ambient pressures not differing from standard atmospheric pressure by more than 30 %.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* (For more specific safety precautionary statements, see 8.1 and 15.1.)

2. Referenced Documents

2.1 *ASTM Standards:*

D 861 Practice for Use of the Tex System to Designate Linear Density of Fibers, Yarn Intermediates, and Yarns[2]

D 1193 Specification for Reagent Water[3]

D 1356 Terminology Relating to Sampling and Analysis of Atmospheres[4]

D 1357 Practice for Planning the Sampling of the Ambient Atmosphere[4]

D 3631 Test Methods for Measuring Surface Atmospheric Pressure[4]

D 4230 Test Method of Measuring Humidity with Cooled-Surface Condensation (Dew-Point) Hygrometer[4]

E 1 Specification for ASTM Thermometers[5]

E 380 Practice for Use of the International System of Units (SI) (the Modernized Metric System)[6]

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of humidity terms used in this test method, refer to Terminology D 4023.

3.1.2 For definitions of other terms in this test method, refer to Terminology D 1356.

3.2 *Definitions of Terms Specific to This Standard:*

[1] This test method is under the jurisdiction of ASTM Committee D22 on Sampling and Analysis of Atmospheres and is the direct responsibility of Subcommittee D22.11 on Meteorology.

Current edition approved October 10, 2002. Published December 2002. Originally published as E 337 – 31 T. Last previous edition E 337 –84(96)ε1.

[2] *Annual Book of ASTM Standards*, Vol 07.01.

[3] *Annual Book of ASTM Standards*, Vol 11.01.

[4] *Annual Book of ASTM Standards*, Vol 11.03.

[5] *Annual Book of ASTM Standards*, Vol 14.03.

[6] *Annual Book of ASTM Standards*, Vol 14.02. (Excerpts in all other volumes.)

3.2.1 *Method A—Aspirated Psychrometer*:

3.2.1.1 *aspiration*—The wet and dry bulbs (and the psychrometer) are described as aspirated because there is provision for the forced ventilation by drawing air over the bulbs by suction. The flow may be either transverse or parallel to the axes of the bulbs.

3.2.1.2 *thermometer*—for purposes of this standard, and except where a specific type is indicated, the term thermometer means any temperature-measuring device.

3.2.1.3 *wet-bulb covering and wick*—the wet bulb is provided with a water-retaining covering of a woven-cotton material. A cotton wick which connects the covering to a water reservoir may be provided so that water is fed to the covering continuously by capillarity.

3.2.2 *Method B—Sling Psychrometer*:

3.2.2.1 *ventilation*—the wet and dry bulbs (and the psychrometer) are described as ventilated because there is provision for a flow of the air over the bulbs. The flow is transverse to the axes of the bulbs.

3.2.2.2 *wet-bulb covering*—the wet bulb is provided with a water-retaining covering of a woven-cotton material.

4. Summary of Methods

4.1 *General*:

4.1.1 The wet-bulb temperature depression, the dry-bulb temperature, and the ambient pressure provide the basis for deriving the relative humidity.

4.2 *Method A—Aspirated Psychrometer:*

4.2.1 Establish the airflow (see 7.4) and maintain it until a minimum wet-bulb temperature is attained. (With mercury-in-glass thermometers, about 2-min ventilation time is usually necessary.)

4.2.2 Read the thermometers with the necessary precision, obtaining the dry-bulb temperature with an overall uncertainty of ±0.2°C or better, and the temperature depression with an overall uncertainty of ±0.2°C or better for an uncertainty in the relative humidity of ±3 % RH. For an uncertainty in the relative humidity of ±2 % RH, obtain the dry-bulb temperature with an overall uncertainty of ±0.2°C or better and the temperature depression with an overall uncertainty of ±0.1°C or better. (Also see Section 12.)

4.3 *Method B—Sling Psychrometer:*

4.3.1 Holding the instrument well away from the body, and for outdoor measurements to windward and in the shade, whirl it at such a rate as to achieve the specified airspeed at the wet and dry bulbs, see 14.4.

4.3.2 Read the thermometers with the necessary precision, obtaining the dry-bulb temperature with an overall uncertainty of ±0.6°C or better, and the temperature depression with an overall uncertainty of ±0.3°C or better for an uncertainty in the relative humidity of ±5 % RH, also see Section 19.

5. Significance and Use

5.1 The object of this test method is to provide guidelines for the construction of a psychrometer and the techniques required for accurately measuring the humidity in the atmosphere. Only the essential features of the psychrometer are specified.

METHOD A—PSYCHROMETER VENTILATED BY ASPIRATION

6. Interferences

6.1 When an aspirated psychrometer is used for measurements in a small enclosed space and steadily rising wet- and dry-bulb temperatures are observed, consider whether heat and moisture liberated by the instrument itself are affecting the conditions.

6.2 While the thermometers are being read, keep all surfaces that are at temperatures other than the environment (such as the hands, face, and other warmer or colder objects) as far as possible from the thermometer bulbs.

6.3 This method should not be used where there is heavy contamination of the air with gases, vapors, or dust.

7. Apparatus

7.1 *Thermometers for an Aspirated Psychrometer*:

7.1.1 The range of the thermometers shall not exceed the range 0 to 80°C. This range may be achieved by providing more than a single pair of matched thermometers. When the uncertainty in the derived relative humidity is required to be not more than ±3 % RH, the thermometers shall be such that their readings give the temperature depression with an uncertainty of not more than ±0.2°C. When the uncertainty in the relative humidity is required to be not more than ±2 % RH, they shall be such that their readings give the temperature depression with an uncertainty of not more than ±0.1°C. The uncertainty in the reading of the dry-bulb temperature shall be not more than ±0.2°C.

7.1.2 Electrical thermometers may be so connected that the readings give the temperature depression and the dry-bulb temperature directly.

7.1.3 Each thermometer shall consist of a temperature sensor of essentially cylindrical shape which is supported on a single stem, the stem being coaxial with the sensor. The free end of each sensor shall be smoothly rounded. If the diameter of the stems is small, compared with that of the sensors, then both ends of each sensor shall be smoothly rounded. The sensor of a mercury-in-glass thermometer shall be that part of the thermometer extending from the bottom of the bulb to the top of the entrance flare of the capillary.

7.1.4 With transverse ventilation, the diameters of the sensors (excluding wet covering) shall be not less than 1 mm and not greater than 4 mm.

7.1.5 With axial ventilation, the diameters of the sensors (excluding wet covering) shall be not less than 2 mm and not greater than 5 mm, and their length not less than 10 mm and not greater than 30 mm.

7.1.6 The connecting wires of electrical thermometers shall be contained within the supporting stems and shall be isolated from the moisture of the wet covering.

7.1.7 Mercury-in-glass shall be graduated to 0.5°C or closer and be capable of being read to the nearest 0.1°C or better. (A specification for mercury-in-glass thermometers suitable when the uncertainty in the derived relative humidity is required to be not more than ±3 % RH is given in Annex A1.)

7.2 *Wet-Bulb Covering, Wick, and Water Reservoir:*

7.2.1 The covering shall be fabricated from white-cotton muslin of linear density from 1.0 to 1.2 g/m, refer to Practice D 861. A seamless sleeve is preferred, but a seam is permissible, provided that it does not add appreciably to the general roughness which the weave imparts to the surface.

7.2.2 The covering shall completely cover the sensor or bulb of the thermometer, fit snugly but not very tightly, and shall be in physical contact with the bulb over its entire surface. It shall extend onto the stem for such a distance that the error in the observed wet-bulb temperature due to heat conduction along the stem does not exceed 0.05°C. (A method of determining the distance for which the covering must extend onto the stem is outlined in Annex A2. For mercury-in-glass thermometers with solid stems, a distance of twice the stem diameter is usually adequate.)

7.2.3 To maintain a snugly fit cover on the wet bulb, the covering may be secured with a cotton thread at the end of the covering on the stem of the thermometer, at the top of the thermometer bulb, and at the bottom of the bulb. However, whenever a wicking is used, the covering shall not be secured between the thermometer bulb and the cotton wicking which connects the covering to a water reservoir.

7.2.4 After fabrication, the covering and wick shall have been washed in a dilute solution of sodium carbonate and thoroughly rinsed with distilled water. They shall not subsequently be touched with the fingers.

7.2.5 The stem of each thermometer shall, for a length measured from the sensor and not less than 1.5× the length of the extension of the covering required by 7.2.2, be clear of obstructions and freely exposed to the airstream.

7.2.6 During the test, the covering shall be completely permeated with water as evidenced by a glistening appearance in a beam of light.

7.2.7 The covering shall be washed in situ with distilled water from time to time and be renewed when it shows any evidence of permanent change.

7.2.8 When a wick is provided, the free length of a wick shall be at least twice the diameter of the wet bulb and at least three times the wick diameter, ensuring that water arriving at the covering is already at practically the wet-bulb temperature. A wick shall be limp.

7.2.9 A water reservoir shall not obstruct the airflow, and its contents shall not affect the humidity of the sample air.

7.2.10 The level of the water in a water reservoir shall be between 5 and 25 mm below the level of the lowest part of the wet bulb.

7.3 *Water*—Reagent water shall be produced by distillation, or by ion exchange or reverse osmosis followed by distillation, refer to Specification D 1193.

7.4 *Airflow*:

7.4.1 The flow of air over both the wet and dry bulbs shall be a forced draught of 3 to 10 m/s for thermometers with maximum allowable diameter of the sensors.

7.4.2 The sample air shall not pass over any obstruction or through a fan before it passes over the wet and dry bulbs.

7.4.3 With axial flow, the direction of the flow shall be from the free end of each sensor towards the support end.

7.4.4 No air which has been cooled by the wet bulb or by the wick shall impinge on the dry bulb.

7.5 *Radiation Shields*:

7.5.1 Any radiation shields shall be of metal with a thickness of 0.4 to 0.8 mm. Surfaces required to have a polished finish shall be of a bare metal which will retain its brightness.

7.5.2 With transverse ventilation, radiation shields may be provided to shield the wet and dry bulbs from extraneous radiations. The radiation shields, essentially in the form of parallel plates, can be either polished on the outside and blackened on the inside, or polished on both the inside and outside surfaces. The clearance between the wet and dry bulbs and the shields shall be not less than half the overall diameter of the wet bulb. The shields shall be liberally flared outwards at the inlet to prevent the flow separating from the shields on the inside (vena-contracta effect). The shields may form part of a duct for the airflow. A second shield, outside, is not necessary.

7.5.3 With axial ventilation, concentric radiation shields shall be provided for the wet and dry bulbs, and shall be polished inside and out. (The shield around the wet bulb plays a vital role in reducing the radiative heat transfer between that bulb and its surroundings by a factor of about three.) The diameter of the shield shall be not less than 1.8 d and not greater than 2.5 d, where d is the overall diameter of the wet bulb. Its length and position shall be such that its projection beyond each end of the wet covering is not less than d and not greater than 3 d. The entrance to the shield shall be liberally flared to form a bell-mouth to prevent the flow separating from the shield on the inside. The shield may serve also as the duct for the airflow. A second shield, outside, is not necessary.

8. Precautions

8.1 *Safety Precautions*—Mercury vapor is poisonous, even in small quantities, and prolonged exposure can produce serious physical impairment (**1**).[7] If a mercury thermometer is accidentally broken, carefully collect, place, and seal all of the mercury in a strongly made nonmetallic container. Avoid skin contact with mercury.

8.2 *Technical Precautions*—For reliable measurement and control, strict adherence to the exacting technique is necessary. Aside from the obvious mistake of not using a psychrometric chart or table prepared for the existing barometric pressure, most errors of psychrometry tend to restrict lowering of the wet-bulb temperature and thus indicate a higher relative humidity than actually exists.

8.2.1 *Conditions which Contribute to High Wet-Bulb Temperature*:

8.2.1.1 Improper installation of wet-bulb covering (loose fitting, too short, or too long).

8.2.1.2 Dirty or contaminated covering.

8.2.1.3 Contamination of wetting water.

8.2.1.4 Insufficient air flow.

8.2.1.5 Failure to reach or read the minimum point of the wet-bath depression.

[7] The **boldface** numbers in parentheses refer to the list of references at the end of this test method.

8.2.1.6 Moisture or heat generation, or both, from the operator taking readings and from the wet-bulb water reservoir.

8.2.1.7 Radiant heating effects.

8.2.2 Heat from the fan or motor shall not affect the thermometer readings.

8.2.3 Instrument shall be used in the shade and not exposed to direct sunlight.

8.2.4 Prior to a measurement, the instrument shall have been exposed long enough to the test atmosphere to have attained the ambient temperature.

8.2.5 The shield shall not be allowed to become wetted.

9. Calibration

9.1 The thermometers used in a psychrometer should be compared once a year at four or more temperatures with the covering removed from the wet-bulb thermometer. Once every three months, the thermometers should be compared, with the covering removed from the wet-bulb thermometer, at the ambient dry-bulb temperature. The readings shall conform to the requirements (see 7.1.1 and Section 12) when the instruments are totally immersed. For highest accuracy, the thermometers should be calibrated over their range of use while totally immersed. The corrections thus determined should be applied to the readings when making a measurement.

10. Procedure

10.1 *Location*—Avoid locations where proximity to machinery, direct heat from the sun, or other sources of radiation would have undue influence. Stand preferably facing the air current so that the instrument receives the air before the air has passed near you. The site or location is selected so that the air is a representative sample. (Also see Practice D 1357.)

10.2 *Preparing Psychrometer*—Moisten the covering of the wet bulb thoroughly with distilled water. (Before the start of a series of measurements, deliver an excess of clean water directly to the wet-bulb covering from the reduced tip of a clean glass or plastic tube which is a part of a small wash bottle, for example, squeeze bottle, so that drops of water fall from the covering. This flooding procedure will help to remove organic contamination which may be on the surface of the wet-bulb covering.) Wetting should be repeated before each separate measurement. A small bottle or porous porcelain cup will serve as a convenient water container. If new or dry through disuse, several minutes may be required for complete saturation of the fabric. Avoid touching the fabric with the fingers, which may deposit oil or dirt. Replace soiled covering and wick. Maintain the dry bulb absolutely dry.

10.3 *Aspirating the Psychrometer*—Operate the fan motor, thus exposing the thermometers to the action of the air until the minimum wet-bulb temperature is indicated. Continue operating the fan until the readings of the thermometers become constant.

10.3.1 *Reading Psychrometer*—While operating the fan, read the thermometers quickly but carefully. Read the wet bulb first. Under ordinary conditions, an approximate 0.15°C error in wet-bulb depression results in a 1 % error in relative humidity. While the thermometers are being read, keep all surfaces that are at temperatures other than the environment (such as the hands, face, and either warmer or colder objects) as far as possible from the thermometer bulbs.

10.3.2 For measurements in nominally constant conditions, for example, where fluctuation period is long compared with the measurement time, repeat steps 10.3 and 10.3.1, rewetting the covering if necessary, until in three successive readings the greatest temperature depression differs from the least by not more than 0.2°C for an uncertainty of ±3 % RH or not more than 0.1°C for an uncertainty of ±2 % RH.

10.3.3 Where measurements are being made under conditions fluctuating rapidly, take a number of readings over at least two complete cycles.

10.3.4 Where measurements are being made while conditions are changing or are being changed under control, the readings might not be meaningful.

10.4 *Check Readings*—For purposes of checking, make as many readings as necessary until three successive readings agree. If atmospheric conditions are fluctuating, it may be desirable to obtain several readings in order to secure an average (that is, if there is a definite cycling in conditions, then readings should be continued for at least two cycles). It will be necessary to rewet the covering of the wet bulb when the fabric starts to dry, as indicated by a rising wet-bulb temperature.

11. Calculation

11.1 Subtract the wet-bulb reading from the dry-bulb reading ($T - T_w$). The difference is the *wet-bulb depression*. Knowing the dry-bulb temperature and the wet-bulb depression, the relative humidity could be calculated by using the basic psychrometric equation shown in the following section. In practice, calculations directly involving the basic equation are seldom needed. Instead, tables, charts, curves, and other calculating devices developed from the basic equation are used, such as the table in Appendix X3.

11.2 When calculating relative humidity from the psychrometric equation, use the following equation or one that for the prevailing conditions is equivalent:

$$e = e_w(T_w) - AP(T - T_w) \quad (1)$$

where:

e = the partial pressure of water vapor in the atmosphere, Pa,

$e_w(T_w)$ = the saturation pressure of water vapor at the wet-bulb temperature t_w, Pa, see Appendix X2,

T = the dry-bulb temperature in °C,

T_w = the wet-bulb temperature in °C,

P = the total (atmospheric) pressure, Pa, see Test Methods D 3631,

A = the psychrometer coefficient in K^{-1}, and

where e, $e_w(T_w)$ and P are expressed in the same units, see Practice E 380.

11.2.1 The value of A shall be chosen in the range 6.2×10^{-4} to 6.9×10^{-4} K^{-1}. The psychrometer coefficient developed by Ferrel, $A = 6.6 \times 10^{-4}(1 + 0.00115\ T_w)$, falls within this range. If a value of A has been determined for the particular design of psychrometer and lies in this range, then it shall be used. If a value has been determined, but lies outside this range, then the closer extreme value of the range shall be used. If no value of A has been determined, then use the value developed by Ferrel. (It may be noted that if, for example, at 20°C and standard atmospheric pressure use of the value $6.5 \times 10^{-4}\ K^{-1}$ led to a derived relative humidity of 50.0 %, then use of the value $6.9 \times 10^{-4}\ K^{-1}$ would lead to a derived relative humidity of 48.9 %.)

11.3 *Saturation Vapor Pressure*—Saturation vapor pressure of pure water vapor over a plane surface of water, ew in hPa at the wet-bulb temperature, T_w in Celsius can be calculated by this exponential expression: (**6**)

$$e_w(T_w) = 6.1094 \cdot e^{[17.625T_w/(243.04 + T_w)]} \quad (2)$$

The saturation vapor pressure (e_s) for water in the temperature range between 0°C and 100°C can also be calculated by the following polynomial expression (**7, 8**):

$$e_s = 2.70102980826 \times 10^{-5}\,T^5 + 2.92123923916\,x\,10^{-4}\,T^4 + 2.53760036868 \times 10^{-2}\,T^3 + 1.48376504190\,T^2 + 4.37196700302 \times 10^1\,T + 6.13141885322 \times 10^2 \quad (3)$$

11.4 *Relative Humidity*—The psychrometric equation gives the partial pressure of the water vapor. In the meterological range of pressure and temperature, the saturation vapor pressure of the pure water phase and of the moist air will be assumed to be equal. (Water vapor and air mixture is assumed to behave as ideal gas.) This assumption will introduce an error of approximately 0.5 % or less in the calculated partial pressure of water vapor and an error of less than 0.5 % in the calculated relative humidity. (See Test Method D 4230.) If water vapor and air are assumed to behave as ideal gases, then

$$RH = e/e_s \cdot 100\ \% \quad (4)$$

where:

e = the partial pressure of the water vapor and
e_s = the saturation vapor pressure of water at the dry-bulb temperature, see Appendix X2.

12. Precision and Bias

12.1 The uncertainty in the derived relative humidity is estimated not to exceed the values shown in Table 1 if the temperature depression and the dry-bulb temperature measurement do not exceed the uncertainty values shown in Table 1.

METHOD B—PSYCHROMETER VENTILATED BY WHIRLING (SLING PSYCHROMETER)

13. Interferences

13.1 (See 6.2 and 6.3.)

TABLE 1

Uncertainty in Derived Relative Humidity, %, RH	Uncertainty in Temperature Depression, °C	Uncertainty in Dry-bulb Temperature,° C
±4	±0.3	±0.2
±3	±0.2	±0.2
±2	±0.1	±0.2
±5	±0.3	±0.6
±4	±0.2	±0.6
±3	±0.1	±0.6

14. Apparatus

14.1 *Thermometers for Sling Psychrometers*:

14.1.1 The thermometers shall be mercury-in-glass thermometers.

14.1.2 The range of the thermometers shall not exceed the range 0 to 50°C; however, this range may be achieved by providing more than a single pair of matched thermometers. When the uncertainty in the derived relative humidity is required to be not more than ±5 % RH, the thermometers shall be such that their readings give the temperature depression with an uncertainty of not more than ±0.3°C and the uncertainty in the reading of the dry-bulb temperature shall be not more than ±0.6°C. When the uncertainty in the derived relative humidity is required to be not more than ±3 % RH, the thermometers shall be such that their readings given the temperature depression and the dry-bulb temperature with an uncertainty of not more than ±0.2°C.

14.1.3 The diameters of the thermometer bulbs (excluding wet covering) shall be not greater than 4 mm.

14.1.4 (See 7.1.7.)

14.2 *Wet-Bulb Covering*:

14.2.1 (See 7.2.1.)

14.2.2 The covering shall completely cover the sensor or bulb of the thermometer, fit snugly but not very tightly, and shall be in physical contact with the bulb over its entire surface. It shall extend onto the stem for such a distance that the error in the observed wet-bulb temperature due to heat conduction along the stem does not exceed 0.05°C. For mercury-in-glass thermometers with solid stems, a distance of twice the stem diameter is usually adequate.

14.2.3 To maintain a snugly fit cover on the wet bulb, the covering may be secured with a cotton thread at the end of the covering on the stem of the thermometer, at the top of the thermometer bulb, and at the bottom of the bulb.

14.2.4 (See 7.2.4.)

14.2.5 The stem of each thermometer shall, for a length measured from the sensor and not less than 1.5 × the length of the extension of the covering required by 14.2.2, be clear of obstructions and freely exposed to the airstream.

14.2.6 (See 7.2.6 and 7.2.7.)

14.3 *Water*—(See 7.3.)

14.4 *Airflow*:

14.4.1 The psychrometer shall be whirled so that the flow of air over both the wet and dry bulbs is equivalent to 3 to 10 m/s for thermometers with maximum allowable diameter of the sensors.

14.4.2 The sample air shall not pass over any obstruction before it passes over the wet and dry bulbs.

14.4.3 (See 7.4.4.)

14.5 *Radiation Shields*—Radiation shields are not necessary.

15. Precautions

15.1 *Safety Precautions*:

15.1.1 Mercury vapor is poisonous, even in small quantities, and prolonged exposure can produce serious physical impairment (**1**), see 8.1.

15.1.2 Before using a sling psychrometer, check for adequate clearance to freely sling or whirl the thermometers without hitting any solid surfaces; for example, the knee.

15.1.3 If a mercury thermometer is accidentally broken, follow the handling procedure in 8.1.

15.2 *Technical Precautions*—(See 8.2.)

15.2.1 *Conditions which Contribute to High Wet-Bulb Temperature*—(See 8.2.1.1-8.2.1.7.)

15.2.2 (See 8.2.3 and 8.2.4.)

16. Calibration

16.1 The thermometers used in a psychrometer should be compared once a year at four or more temperatures with the covering removed from the wet-bulb thermometer. Once every three months, the thermometers should be compared, with the covering removed from the wet-bulb thermometer, at the ambient dry-bulb temperature. The readings shall conform to the requirements, (see 14.1.2 and Section 19) when the instruments are totally immersed. For highest accuracy, the thermometers should be calibrated over their range of use while totally immersed. The corrections thus determined should be applied to the readings when making a measurement.

17. Procedure

17.1 *Location*—(See 10.1.)

17.2 *Preparing Psychrometer*—(See 10.2.)

17.3 *Ventilating the Psychrometer*—Holding the instrument well away from the body, and for outdoor measurements to windward and in the shade, whirl it at such a rate as to achieve the specified airspeed at the wet and dry bulbs (see 14.4) and then stop the motion after 30 s to read the thermometers. Resume whirling for an additional 10 s before stopping the motion to read the thermometers. Continue this procedure of whirling for 10 s, rewetting the covering if necessary (see 10.4), until a minimum wet-bulb temperature has been attained. (About 2-min ventilation time is usually necessary.)

17.3.1 *Reading Psychrometer*—After whirling the psychrometer, read the thermometers quickly but carefully. Read the wet bulb first. Under ordinary conditions, an approximate 0.3°C error in wet-bulb depression results in a 2 % error in relative humidity. While the thermometers are being read, keep all surfaces that are at temperatures other than the environment (such as the hands, face, and either warmer or colder objects) as far as possible from the thermometer bulbs.

17.3.2 For measurements in nominally constant conditions, for example, where a fluctuation period is long compared with the measurement time, repeat Steps 17.3 and 17.3.1, rewetting the covering if necessary, until in three successive readings the greatest temperature depression differs from the least by not more than 0.3°C for an uncertainty of ±5 % RH.

17.3.3 (See 10.3.3 and 10.3.4.)

17.4 *Check Readings*—(See 10.4.)

18. Calculation—(See Section 11.)

19. Precision and Bias

19.1 The uncertainty in the derived relative humidity is estimated not to exceed the values shown in Table 2 if the temperature depression and the reading of the dry-bulb temperature do not exceed the uncertainty values shown in Table 2.

20. Keywords

20.1 aspiration; humidity; psychrometer; psychrometric table; temperature; vapor pressure; ventilation; wet-bulb temperature

TABLE 2

Uncertainty in Derived Relative Humidity, %, RH	Uncertainty in Temperature Depression, °C	Uncertainty in Dry-bulb Temperature,° C
±4	±0.3	±0.2
±3	±0.2	±0.2
±5	±0.3	±0.6
±4	±0.2	±0.6

ANNEXES

(Mandatory Information)

A1. MERCURY-IN-GLASS THERMOMETERS SUITABLE WHEN THE UNCERTAINTY IN THE MEASURED RELATIVE HUMIDITY IS REQUIRED NOT TO EXCEED ±3 % RH

A1.1 Mercury-in-glass thermometers conforming to the following specification are suitable when the uncertainty in the measured relative humidity is required not to exceed ±3 % RH.

A1.1.1 *Type*—The thermometers shall be of the solid-stem type, and the stem may have a slight neck near the bulb to allow the wet-bulb covering to be secured more easily by a cotton thread.

A1.1.2 *Temperature Scale*—The thermometers shall be graduated for total immersion and in accordance with the Celsius scale which corresponds with the International Practical Temperature Scale of 1968.

A1.1.3 *Range*—The nominal temperature range of the thermometers shall be 0 to 80°C for an aspirated psychrometer and 0 to 50°C for a sling psychrometer.

A1.1.4 *Materials*—The stem shall be made of suitable thermometer glass with an enamel back. The bulb shall be made of glass meeting the Specification E 1.

A1.1.5 *Annealing and Stabilization*—The glass shall be suitably annealed, and the thermometers shall be stabilized by a suitable heat treatment before they are filled with mercury.

A1.1.6 *Expansion Chamber*—Each thermometer shall include an expansion chamber above the highest scale line so that a temperature of at least 100°C can be sustained without the likelihood of damage.

A1.1.7 *Dimensions*:

	mm
Length from bottom of bulb to underside of button or ring top (maximum)	240
Scale length corresponding to the nominal range (minimum)	130
Bulb length[4]	10 to 30
Bulb diameter	3 to 4
Stem diameter	4 to 5
Distance of neck (if any) from top of bulb[4]	8 to 12
Distance of lowest scale line from top of bulb[4] (min)	30
Distance of expansion chamber from highest scale line (min)	10

mm

[4]The top of the entrance flare of the capillary is taken to be the top of the bulb.

A1.1.8 *Graduation and Figuring*—The thermometers shall be graduated at each 0.5°C, with a spacing of approximately 2 mm and with a longer line at each 1°C. The graduations shall be numbered at each 5°C.

A1.1.9 *Accuracy*—Readings of each thermometer made by a knowledgeable and experienced observer with the thermometers totally immersed shall not be in error by more than 0.2°C for any temperature in the nominal range. For any two temperatures in the nominal range, readings of the two thermometers, so made, shall give the difference of the temperatures with an error not exceeding 0.2°C.

A1.1.10 *Spare Thermometer*—If a third thermometer is associated with the psychrometer, then A1.1.9 shall apply to each of the three possible combinations of two thermometers.

A2. DETERMINATION OF THE DISTANCE FOR WHICH THE WET-BULB COVERING MUST EXTEND ONTO THE THERMOMETER STEM TO LIMIT THE HEAT-CONDUCTION ERROR TO 0.05°C

A2.1 Temporarily fit the bulbs (sensors) of both thermometers with coverings similar to that to be used on the wet bulb, but allow the coverings to extend onto the stems considerably further than usual, say 1.5 ×, the usual distance.

A2.2 Operate the instrument in the usual manner but with both coverings wet, choosing a location where the conditions are steady. Observe the difference of the thermometer readings as accurately as possible. (This difference is due mainly to the errors of the thermometers themselves.)

A2.3 Progressively reduce the extension of one of the coverings onto the stem until the difference of the readings of the thermometers is estimated to have changed by 0.05°C. The extension existing at that stage is the minimum permissible.

A2.4 A more accurate determination can be made if the difference of the readings is plotted against the extension for a number of extensions both greater than and less than that corresponding to a change of 0.05°C. The minimum extension which corresponds to a change of this amount may then easily be read from the plot.

A2.5 During the procedure, as in normal operation of the psychrometer, care must be taken to preserve the cleanliness of the coverings, and in particular to avoid touching them with the fingers.

A2.6 The procedure determines the extension necessary for the conditions which prevail at the time. If it is carried out under conditions which differ substantially from those under which the psychrometer is normally used, then allowance should be made for the fact that for a given extension of the covering the temperature error due to the heat conduction is roughly proportional to the temperature depression. For example, if the present procedure is carried out under atmospheric conditions such that the temperature depression is twice the value which occurs in the normal use of the instrument, then the extension which results in a change of 0.1°C in the temperature difference is the required minimum.

APPENDIXES

(Nonmandatory Information)

X1. SKELETON TABLE OF RELATIVE HUMIDITIES

X1.1 Relative humidities rounded to the nearest 0.5 % RH are tabulated for various temperatures and temperature depressions and for standard atmospheric pressure and three values of the psychrometer coefficient. Table X1.1 is given so that other more detailed tables may be compared with it. The dry-bulb temperature interval of 10°C and the temperature depression interval of 2°C are too wide to allow the table to be used for routine humidity measurement. The saturation vapor pressure of water has been taken from A. Wexler, Appendix X2. Standard atmospheric pressure is 1.01325×10^5 Pa.

Values	
Upper	$A = 6.5 \times 10^{-4}\ K^{-1}$
Intermediate	$A = 6.7 \times 10^{-4}$
Lower	$A = 6.9 \times 10^{-4}$

X2. SATURATION VAPOR PRESSURE OVER WATER

X2.1 The saturation vapor pressure of the pure phase over plane surface of pure water for temperatures 0 to 100°C was obtained from Wexler's 1976 formulation (**2**). Other suitable saturation vapor pressure tables are given in the Smithsonian Meteorological Tables (**3**), International Meteorological Tables (**4**), and ASHRAE Handbook and Product Directory (**5**). The following simplified equation (**2**) yields values of the saturation vapor pressure over water which differ from those given in

TABLE X1.1 Comparison of the Calculated Relative Humidity Using Three Different Values of the Psychrometer Coefficient *A*

	Dry-Bulb Temperature in °C									Dry-Bulb Temperature in °C							
$t - t_w$	10	20	30	40	50	60	70	80	$t - t_w$	10	20	30	40	50	60	70	80
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0		...	...	...	8.5	19.0	26.0	31.0	35.5
0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	22.0	...	...	...	7.5	18.5	26.0	31.0	35.0
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0		...	...	...	7.0	18.0	26.5	31.0	35.0
	76.5	82.5	86.0	88.0	89.5	90.5	91.0	92.0		...	...	...	3.0	14.5	22.0	27.5	31.5
2.0	76.5	82.5	86.0	88.0	89.5	90.5	91.0	92.0	24.0	...	...	...	2.5	14.0	21.5	27.0	31.5
	76.0	82.5	86.0	88.0	89.5	90.5	91.0	92.0		...	...	...	2.0	13.5	21.5	27.0	31.5
	54.5	66.5	73.0	77.0	79.5	81.5	83.0	84.5		...	...	...	...	10.5	18.0	23.5	28.0
4.0	54.0	66.0	73.0	77.0	79.5	81.5	83.0	84.5	26.0	...	...	...	...	10.0	18.0	23.5	28.0
	53.5	66.0	72.5	77.0	79.5	81.5	83.0	84.5		...	...	...	...	9.5	17.5	23.5	28.0
	34.0	51.5	61.0	67.0	70.5	73.5	75.5	77.0		...	...	...	...	6.5	14.5	20.5	25.0
6.0	33.0	51.0	60.5	66.5	70.5	73.5	75.5	77.0	28.0	...	...	...	...	6.0	14.5	20.0	24.5
	32.0	50.5	60.5	66.5	70.5	73.0	75.5	77.0		...	...	...	...	5.5	14.0	20.0	24.5
	14.5	37.5	50.0	57.5	62.0	65.5	63.5	70.5		...	...	...	...	3.0	11.5	17.5	22.0
8.0	13.5	36.5	49.5	57.0	62.0	65.5	63.5	70.5	30.0	...	...	...	...	2.5	11.0	17.0	22.0
	12.0	36.0	49.0	57.0	62.0	65.5	63.5	70.5		...	...	...	...	2.0	11.0	17.0	21.5
	...	24.5	39.5	48.5	54.5	58.5	62.0	64.5		...	...	...	...	...	8.5	14.5	19.0
10.0	...	23.5	39.0	48.5	54.5	58.5	62.0	64.5	32.0	...	...	...	...	...	8.0	14.5	19.0
	...	22.5	38.5	48.0	54.0	58.5	61.5	64.5		...	...	...	...	...	7.5	14.0	19.0
	...	12.0	30.0	40.5	47.5	52.0	55.5	58.5		...	...	...	...	...	5.5	12.0	16.5
12.0	...	11.0	29.5	40.0	47.0	52.0	55.5	58.5	34.0	...	...	...	...	...	5.5	11.5	16.5
	...	10.0	29.0	40.0	47.0	52.0	55.5	58.5		...	...	...	...	...	5.0	11.5	16.5
	...	0.5	21.0	33.0	40.5	46.0	50.0	53.5		...	...	...	...	...	3.0	9.5	14.0
14.0	...	...	20.5	32.5	40.5	46.0	50.0	53.0	36.0	...	...	...	...	...	2.5	9.0	14.0
	...	...	20.0	32.5	40.0	45.5	50.0	53.0		...	...	...	...	...	2.5	9.0	14.0
	...	...	13.0	26.0	34.5	40.5	45.0	48.5		...	...	...	...	...	0.5	7.0	12.0
16.0	...	...	12.0	25.5	34.5	40.0	44.5	48.0	38.0	...	...	...	...	...	0.5	7.0	12.0
	...	...	11.5	25.5	34.0	40.0	44.5	48.0		...	...	...	...	...	...	6.5	11.5
	...	...	5.0	20.0	29.0	35.0	40.0	43.5		...	...	...	...	...	...	5.0	10.0
18.0	...	...	4.5	19.5	28.5	35.0	40.0	43.5	40.0	...	...	...	...	...	...	5.0	10.0
	...	...	3.5	19.0	28.5	35.0	39.5	43.5		...	...	...	...	...	...	4.5	9.5
	...	...	...	14.0	23.5	30.5	35.5	39.5									
20.0	...	...	...	13.5	23.5	30.0	35.0	39.0									
	...	...	...	12.5	23.0	30.0	35.0	39.0									

Table X2.1 by 20 ppm or less:

$$\ln e_s = \sum_{i=1}^{4} g_i (T_{68})^{i-2} \quad \text{(X2.1)}$$

where:

g_1 = -0.63536311×10^4,
g_2 = 0.3404926034×10^2,
g_3 = $-0.19509874 \times 10^{-1}$,
g_4 = $0.12811805 \times 10^{-4}$,
e_s = in Pascal, and
T_{68} = $273.15 + t_{68}$, and
t_{68} = −degree Celsius (International Practical Temperature Scale of 1968).

TABLE X2.1 Saturation Vapor Pressure Over Water (IPTS—68)[A]

Temp °C	0.0 Pa	0.1 Pa	0.2 Pa	0.3 Pa	0.4 Pa	0.5 Pa	0.6 Pa	0.7 Pa	0.8 Pa	0.9 Pa
0	611.213	615.667	620.150	624.662	629.203	633.774	638.373	643.003	647.662	652.350
1	657.069	661.819	666.598	671.408	676.249	681.121	686.024	690.958	695.923	700.920
2	705.949	711.010	716.103	721.228	726.386	731.576	736.799	742.055	747.344	752.667
3	758.023	763.412	768.836	774.294	779.786	785.312	790.873	796.469	802.100	807.766
4	813.467	819.204	824.977	830.786	836.631	842.512	848.429	854.384	860.375	866.403
5	872.469	878.572	884.713	890.892	897.109	903.364	909.658	915.991	922.362	928.773
6	935.223	941.712	948.241	954.810	961.419	968.069	974.759	981.490	988.262	995.075
7	1001.93	1008.83	1015.76	1022.74	1029.77	1036.83	1043.94	1051.09	1058.29	1065.52
8	1072.80	1080.13	1087.50	1094.91	1102.37	1109.87	1117.42	1125.01	1132.65	1140.33
9	1148.06	1155.84	1163.66	1171.53	1179.45	1187.41	1195.42	1203.48	1211.58	1219.74
10	1227.94	1236.19	1244.49	1252.84	1261.24	1269.68	1278.18	1286.73	1295.33	1303.97
11	1312.67	1321.42	1330.22	1339.08	1347.98	1356.94	1365.95	1375.01	1384.12	1393.29
12	1402.51	1411.79	1421.11	1430.50	1439.93	1449.43	1458.97	1468.58	1478.23	1487.95
13	1497.72	1507.54	1517.43	1527.36	1537.36	1547.42	1557.53	1567.70	1577.93	1588.21
14	1598.56	1608.96	1619.43	1629.95	1640.54	1651.18	1661.89	1672.65	1683.48	1694.37
15	1705.32	1716.33	1727.41	1738.54	1749.75	1761.01	1772.34	1783.73	1795.18	1806.70
16	1818.29	1829.94	1841.66	1853.44	1865.29	1877.20	1889.18	1901.23	1913.34	1925.53
17	1937.78	1950.10	1962.48	1974.94	1987.47	2000.06	2012.73	2025.46	2038.27	2051.14
18	2064.09	2077.11	2090.20	2103.37	2116.61	2129.92	2143.30	2156.75	2170.29	2183.89
19	2197.57	2211.32	2225.15	2239.06	2253.04	2267.10	2281.23	2295.44	2309.73	2324.10
20	2338.54	2353.07	2367.67	2382.35	2397.11	2411.95	2426.88	2441.88	2456.94	2472.13
21	2487.37	2502.70	2518.11	2533.61	2549.18	2564.85	2580.59	2596.42	2612.33	2628.33
22	2644.42	2660.59	2676.85	2693.19	2709.62	2726.14	2742.75	2759.45	2776.23	2793.10
23	2810.06	2827.12	2844.26	2861.49	2878.82	2896.23	2913.74	2931.34	2949.04	2966.82
24	2984.70	3002.68	3020.74	3038.91	3057.17	3075.52	3093.97	3112.52	3131.16	3149.90
25	3168.74	3187.68	3206.71	3225.85	3245.08	3264.41	3283.85	3303.38	3323.02	3342.76
26	3362.60	3382.54	3402.59	3422.73	3442.99	3463.34	3483.81	3504.37	3525.05	3545.83
27	3566.71	3857.71	3608.81	3630.02	3651.33	3672.76	3694.29	3715.94	3737.69	3759.56
28	3781.54	3803.63	3825.83	3848.14	3870.57	3893.11	3915.77	3938.54	3961.42	3984.42
29	4007.54	4030.77	4054.12	4077.59	4101.18	4124.88	4148.71	4172.65	4196.71	4220.90
30	4245.20	4269.63	4294.18	4318.85	4343.64	4368.56	4393.60	4418.77	4444.06	4469.48
31	4495.02	4520.69	4546.49	4572.42	4598.47	4624.65	4650.96	4677.41	4703.98	4730.68
32	4757.52	4784.48	4811.58	4838.81	4866.18	4893.68	4921.32	4949.09	4976.99	5005.04
33	5033.22	5061.53	5089.99	5118.58	5147.32	5176.19	5205.20	5234.36	5263.65	5293.09
34	5322.67	5352.39	5382.26	5412.27	5442.43	5472.73	5503.18	5533.78	5564.52	5595.41
35	5626.45	5657.64	5688.97	5720.46	5752.10	5783.89	5815.83	5847.93	5880.17	5912.58
36	5945.13	5977.84	6010.71	6043.73	6076.91	6110.25	6143.75	6177.40	6211.22	6245.19
37	6279.33	6313.62	6348.08	6382.70	6417.48	6452.43	6487.54	6522.82	6558.26	6593.87
38	6629.65	6665.59	6701.71	6737.99	6774.44	6811.06	6847.85	6884.82	6921.95	6959.26
39	6996.75	7034.40	7072.24	7110.24	7148.43	7186.79	7225.33	7264.04	7302.94	7342.02
40	7381.27	7420.71	7460.33	7500.13	7540.12	7580.28	7620.64	7661.18	7701.90	7742.81
41	7783.91	7825.20	7866.96	7908.34	7950.19	7992.24	8034.47	8076.90	8119.53	8162.34
42	8205.36	8248.56	8291.96	8335.56	8379.36	8423.36	8467.55	8511.94	8556.54	8601.33
43	8646.33	8691.53	8736.93	8782.54	8828.35	8874.37	8920.59	8967.02	9013.66	9060.51
44	9107.57	9154.84	9202.32	9250.01	9297.91	9346.03	9394.36	9442.91	9491.67	9540.65
45	9589.84	9639.25	9688.89	9738.74	9788.81	9839.11	9889.62	9940.36	9991.32	10042.51
46	10093.92	10145.56	10197.43	10249.52	10301.84	10354.39	10407.18	10460.19	10513.43	10566.91
47	10620.62	10674.57	10728.75	10783.16	10837.82	10892.71	10947.84	11003.21	11058.82	11114.67
48	11170.76	11227.10	11283.68	11340.50	11397.57	11454.88	11512.45	11570.26	11628.32	11686.63
49	11745.19	11804.00	11863.07	11922.38	11981.96	12041.78	12101.87	12162.21	12222.81	12283.66
50	12344.78	12406.16	12467.79	12529.70	12591.86	12654.29	12716.98	12779.94	12843.17	12906.66
51	12970.42	13034.46	13098.76	13163.33	13228.18	13293.30	13358.70	13424.37	13490.32	13556.54
52	13623.04	13689.82	13756.88	13824.23	13891.85	13959.76	14027.95	14096.43	14165.19	14234.24
53	14303.57	14373.20	14443.11	14513.32	14583.82	14654.61	14725.69	14797.07	14868.74	14940.72
54	15012.98	15085.55	15158.42	15231.59	15305.06	15378.83	15452.90	15527.28	15601.97	15676.96
55	15752.26	15827.87	15903.79	15980.02	16056.57	16133.42	16210.59	16288.07	16365.87	16443.99
56	16522.43	16601.18	16680.26	16759.65	16839.37	16919.41	16999.78	17080.47	17161.49	17242.84
57	17324.51	17406.52	17488.86	17571.52	17654.53	17737.86	17821.53	17905.54	17989.88	18074.57
58	18159.59	18244.95	18330.66	18416.71	18503.10	18589.84	18676.92	18764.35	18852.13	18940.26
59	19028.74	19117.58	19206.76	19296.30	19386.20	19476.45	19567.06	19658.03	19749.35	19841.04
60	19933.09	20025.51	20118.29	20211.43	20304.95	20398.82	20493.07	20587.69	20682.68	20778.05
61	20873.78	20969.90	21066.39	21163.25	21260.50	21358.12	21456.13	21554.51	21653.28	21752.44
62	21851.98	21951.91	22052.23	22152.93	22254.03	22355.52	22457.40	22559.68	22662.35	22765.42
63	22868.89	22972.75	23077.02	23181.69	23286.76	23392.23	23498.12	23604.40	23711.10	23818.20

TABLE X2.1 *Continued*

Temp °C	0.0 Pa	0.1 Pa	0.2 Pa	0.3 Pa	0.4 Pa	0.5 Pa	0.6 Pa	0.7 Pa	0.8 Pa	0.9 Pa
64	23925.72	24033.65	24141.99	25250.74	24359.91	24469.50	24579.51	24689.93	24800.78	24912.04
65	25023.74	25135.85	25248.39	25361.36	25474.76	25588.58	25702.84	25817.53	25932.66	26048.22
66	26164.21	26280.64	26397.52	26514.83	26632.58	26750.78	26869.42	26988.51	27108.04	27228.02
67	27348.46	27469.34	27590.68	27712.46	27834.71	27957.41	28080.57	28204.19	28328.26	28452.80
68	28577.81	28703.28	28829.21	28955.61	29082.48	29209.82	29337.64	29465.92	29594.68	29723.92
69	29853.63	29983.82	30114.49	30245.65	30377.28	30509.40	30642.01	30775.10	30908.69	31042.75
70	31177.32	31312.37	31447.92	31583.97	31720.51	31857.55	31995.09	32133.14	32271.68	32410.73
71	32550.29	32690.35	32830.93	32972.01	33113.61	33255.71	33398.34	33541.48	33685.13	33829.31
72	33974.01	34119.23	34264.97	34411.24	34558.03	34705.36	34853.21	35001.59	35150.51	35299.96
73	35449.95	35600.47	35751.54	35903.14	36055.29	36207.98	36361.21	36514.99	36669.32	36824.20
74	36979.63	37135.61	37292.15	37449.24	37606.89	37765.10	37923.87	38083.21	38243.10	38403.56
75	38564.59	38726.19	38888.36	39051.10	39214.41	39378.30	39542.76	39707.80	39873.42	40039.63
76	40206.41	40373.78	40541.74	40710.28	40879.42	41049.14	41219.46	41390.37	41561.88	41733.99
77	41906.69	42080.00	42253.91	42428.42	42603.54	42779.27	42955.61	43132.55	43310.11	43488.29
78	43667.08	43846.48	44026.51	44207.16	44388.43	44570.33	44752.85	44936.00	45119.77	45304.18
79	45489.23	45674.91	45861.22	46048.17	46235.76	46424.00	46612.87	46802.39	46992.56	47183.38
80	47374.85	47566.97	47759.74	47953.17	48147.25	48342.00	48537.40	48733.47	48930.20	49127.60
81	49325.67	49524.40	49723.81	49923.89	50124.64	50326.08	50528.19	50730.98	50934.45	51138.61
82	51343.45	51548.98	51755.20	51962.11	52169.72	52378.01	52587.01	52796.70	53007.10	53218.20
83	53430.00	53642.50	53855.72	54069.64	54284.28	54499.63	54715.69	54932.47	55149.97	55368.19
84	55587.13	55806.80	56027.20	56248.32	56470.17	56692.76	56916.08	57140.13	57364.92	57590.45
85	57816.73	58043.74	58271.51	58500.02	58729.27	58959.28	59190.05	59421.57	59653.84	59886.87
86	60120.67	60355.23	60590.55	60826.64	61063.50	61301.12	61539.52	61778.70	62018.65	62259.38
87	62500.89	62743.18	62986.26	63230.12	63474.78	63720.22	63966.45	64213.48	64461.31	64709.93
88	64959.35	65209.58	65460.61	65712.45	65965.09	66218.55	66472.82	66727.90	66983.80	67240.52
89	67498.06	67756.42	68015.60	68275.62	68536.46	68798.13	69060.74	69323.98	69588.15	69853.17
90	70119.03	70385.73	70653.28	70921.67	71190.91	71461.01	71731.96	72003.76	72276.42	72549.95
91	72824.33	73099.58	73375.70	73652.68	73930.54	74209.27	74488.87	74769.35	75050.71	75332.95
92	75616.07	75900.08	76184.98	76470.77	76757.44	77045.02	77333.49	77622.86	77913.13	78204.30
93	78496.38	78789.36	79083.26	79378.06	79673.78	79970.42	80267.97	80566.45	80865.85	81166.17
94	81467.42	81769.60	82072.71	82376.75	82681.73	82987.65	83294.51	83602.31	83911.06	84220.75
95	94531.40	84842.99	85155.54	85469.05	85783.51	86098.94	86415.33	86732.68	87051.00	87370.29
96	87690.56	88011.80	88334.01	88657.20	88981.38	89306.54	89632.68	89959.82	90287.94	90617.06
97	90947.17	91278.28	91610.39	91943.50	92277.62	92612.74	92948.87	93286.02	93624.18	93963.35
98	94303.54	94644.76	94986.99	95330.26	95674.55	96019.87	96366.23	96713.62	97062.05	97411.51
99	97762.02	98113.58	98466.18	98819.83	99174.54	99530.30	99887.11	100244.99	100603.93	100963.93
100	101324.99	...	...	...	...	...	...	...	...	...

[A]Metastable state.

X3. RELATIVE HUMIDITY—PSYCHROMETRIC TABLE

X3.1 Relative humidities rounded to the nearest 1 % RH are tabulated by using Ferral's formulation for the psychrometer coefficient and standard atmospheric pressure. For barometer pressures differing from the standard atmospheric pressure (101325 Pa) see Appendix X4.

$$RH = \frac{e}{e_s} \times 100\,\% = \frac{e_w(t_w) - Ap(t - t_w)}{e_s} \times 100\,\% \qquad (X3.1)$$

where:

A = $6.60 \times 10^{-4}(1 + 0.00115\ t_w)$,
p = 101325 Pa,
e_w, e_s in Pa, and
t, t_w in °C.

For definitions of symbols, see 11.2.

TABLE X3.1 Relative Humidity, Percent (Pressure = 101 325 Pa) (See Appendix X4)

Air Temperature	Depression of Wet-Bulb Thermometer ($t - t_w$), °C														
(t), °C	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
2	98	97	95	93	92	90	88	87	85	84	...	...	...	...	...
3	98	97	95	94	92	90	89	87	86	84	83	81	80	78	77
4	98	97	95	94	92	91	89	88	86	85	83	82	80	79	78
5	99	97	96	94	93	91	90	88	87	86	84	83	81	80	78
6	99	97	96	94	93	92	90	89	87	86	85	83	82	81	79
7	99	97	96	95	93	92	91	89	88	87	85	84	83	81	80
8	99	97	96	95	93	92	91	90	88	87	86	85	83	82	81
9	99	97	96	95	94	92	91	90	89	88	86	85	84	83	81
10	99	98	96	95	94	93	92	90	89	88	87	86	84	83	82
11	99	98	96	95	94	93	92	91	90	88	87	86	85	84	83
12	99	98	97	95	94	93	92	91	90	89	88	87	85	84	83
13	99	98	97	96	94	93	92	91	90	89	88	87	86	85	84
14	99	98	97	96	95	94	93	92	90	89	88	87	86	85	84
15	99	98	97	96	95	94	93	92	91	90	89	88	87	86	85
16	99	98	97	96	95	94	93	92	91	90	89	88	87	86	85
17	99	98	97	96	95	94	93	92	91	90	89	88	87	87	86
18	99	98	97	96	95	94	93	92	91	91	90	89	88	87	86
19	99	98	97	96	95	94	94	93	92	91	90	89	88	87	86
20	99	98	97	96	95	95	94	93	92	91	90	89	88	88	87
21	99	98	97	96	96	95	94	93	92	91	90	90	89	88	87
22	99	98	97	96	96	95	94	93	92	91	91	90	89	88	87
23	99	98	97	97	96	95	94	93	92	92	91	90	89	88	88
24	99	98	97	97	96	95	94	93	93	92	91	90	89	89	88
25	99	98	98	97	96	95	94	94	93	92	91	90	90	89	88
26	99	98	98	97	96	95	94	94	93	92	91	91	90	89	88
27	99	98	98	97	96	95	95	94	93	92	92	91	90	89	89
28	99	98	98	97	96	95	95	94	93	92	92	91	90	90	89
29	99	98	98	97	96	95	95	94	93	93	92	91	90	90	89
30	99	98	98	97	96	96	95	94	93	93	92	91	91	90	89
31	99	99	98	97	96	96	95	94	94	93	92	91	91	90	89
32	99	99	98	97	96	96	95	94	94	93	92	92	91	90	90
33	99	99	98	97	96	96	95	94	94	93	92	92	91	90	90
34	99	99	98	97	97	96	95	95	94	93	93	92	91	91	90
35	99	99	98	97	97	96	95	95	94	93	93	92	91	91	90
36	99	99	98	97	97	96	95	95	94	93	93	92	92	91	90
37	99	99	98	97	97	96	95	95	94	94	93	92	92	91	90
38	99	99	98	97	97	96	95	95	94	94	93	92	92	91	91
39	99	99	98	97	97	96	96	95	94	94	93	92	92	91	91
40	99	99	98	97	97	96	96	95	94	94	93	93	92	91	91
41	99	99	98	97	97	96	96	95	94	94	93	93	92	92	91
42	99	99	98	98	97	96	96	95	95	94	93	93	92	92	91
43	99	99	98	98	97	96	96	95	95	94	93	93	92	92	91
44	99	99	98	98	97	96	96	95	95	94	94	93	92	92	91
45	99	99	98	98	97	96	96	95	95	94	94	93	93	92	91
46	99	99	98	98	97	97	96	95	95	94	94	93	93	92	91
47	99	99	98	98	97	97	96	95	95	94	94	93	93	92	92
48	99	99	98	98	97	97	96	95	95	94	94	93	93	92	92
49	99	99	98	98	97	97	96	96	95	94	94	93	93	92	92
50	99	99	98	98	97	97	96	96	95	95	94	93	93	92	92

TABLE X3.1 *Continued*

Air Temperature (t), °C	Depression of Wet-Bulb Thermometer ($t - t_w$), °C														
	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0
3	75	74	72	70	69	...	...	...	...	...	...	...	...	...	...
4	76	75	73	72	70	69	67	66	65	63	62	60	59	57	56
5	77	76	74	73	71	70	69	67	66	65	63	62	61	59	58
6	78	77	75	74	73	71	70	69	67	66	65	63	62	61	59
7	79	77	76	75	74	72	71	70	69	67	66	65	64	62	61
8	80	78	77	76	75	73	72	71	70	68	67	66	65	64	62
9	80	79	78	77	75	74	73	72	71	70	68	67	66	65	64
10	81	80	79	77	76	75	74	73	72	71	70	68	67	66	65
11	82	80	79	78	77	76	75	74	73	72	71	69	68	67	66
12	82	81	80	79	78	77	76	75	74	73	72	70	69	68	67
13	83	82	81	80	79	78	76	75	74	73	72	71	70	69	68
14	83	82	81	80	79	78	77	76	75	74	73	72	71	70	69
15	84	83	82	81	80	79	78	77	76	75	74	73	72	71	70
16	84	83	82	81	80	79	79	78	77	76	75	74	73	72	71
17	85	84	83	82	81	80	79	78	77	76	75	75	74	73	72
18	85	84	83	82	81	81	80	79	78	77	76	75	74	74	73
19	85	85	84	83	82	81	80	79	78	78	77	76	75	74	73
20	86	85	84	83	82	82	81	80	79	78	77	77	76	75	74
21	86	85	84	84	83	82	81	80	80	79	78	77	76	75	75
22	86	86	85	84	83	82	82	81	80	79	78	78	77	76	75
23	87	86	85	84	84	83	82	81	80	80	79	78	77	77	76
24	87	86	85	85	84	83	82	82	81	80	79	79	78	77	76
25	87	87	86	85	84	84	83	82	81	81	80	79	78	78	77
26	88	87	86	85	85	84	83	82	82	81	80	80	79	78	77
27	88	87	86	86	85	84	83	83	82	81	81	80	79	79	78
28	88	87	87	86	85	85	84	83	82	82	81	80	80	79	78
29	88	88	87	86	86	85	84	83	83	82	81	81	80	79	79
30	89	88	87	86	86	85	84	84	83	82	82	81	80	80	79
31	89	88	87	87	86	85	85	84	83	83	82	81	81	80	79
32	89	88	88	87	86	86	85	84	84	83	82	82	81	80	80
33	89	88	88	87	86	86	85	85	84	83	83	82	81	81	80
34	89	89	88	87	87	86	85	85	84	84	83	82	82	81	80
35	89	89	88	88	87	86	86	85	84	84	83	83	82	81	81
36	90	89	88	88	87	87	86	85	85	84	84	83	82	82	81
37	90	89	89	88	87	87	86	86	85	84	84	83	83	82	81
38	90	89	89	88	88	87	86	86	85	85	84	83	83	82	82
39	90	89	89	88	88	87	87	86	85	85	84	84	83	82	82
40	90	90	89	88	88	87	87	86	86	85	84	84	83	83	82
41	90	90	89	89	88	87	87	86	86	85	85	84	84	83	82
42	90	90	89	89	88	88	87	87	86	85	85	84	84	83	83
43	91	90	89	89	88	88	87	87	86	86	85	84	84	83	83
44	91	90	90	89	88	88	87	87	86	86	85	85	84	84	83
45	91	90	90	89	89	88	88	87	86	86	85	85	84	84	83
46	91	90	90	89	89	88	88	87	87	86	86	85	85	84	84
47	91	91	90	89	89	88	88	87	87	86	86	85	85	84	84
48	91	91	90	90	89	89	88	87	87	86	86	85	85	84	84
49	91	91	90	90	89	89	88	88	87	87	86	86	85	85	84
50	91	91	90	90	89	89	88	88	87	87	86	86	85	85	84

TABLE X3.1 *Continued*

Air Temperature (t), °C	Depression of Wet-Bulb Thermometer ($t - t_w$), °C														
	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5
5	56	55	54	52	51	50	48	47	46	45	...	...	...	...	...
6	58	57	56	54	53	52	51	49	48	47	46	44	43	42	41
7	60	59	57	56	55	54	52	51	50	49	48	46	45	44	43
8	61	60	59	58	57	55	54	53	52	51	50	48	47	46	45
9	63	62	60	59	58	57	56	55	54	53	51	50	49	48	47
10	64	63	62	61	60	58	57	56	55	54	53	52	51	50	49
11	65	64	63	62	61	60	59	58	57	56	55	54	53	52	51
12	66	65	64	63	62	61	60	59	58	57	56	55	54	53	52
13	67	66	65	64	63	62	61	60	60	59	58	57	56	55	54
14	68	67	66	66	65	64	63	62	61	60	59	58	57	56	55
15	69	68	67	67	66	65	64	63	62	61	60	59	58	57	57
16	70	69	68	68	67	66	65	64	63	62	61	60	60	59	58
17	71	70	69	68	68	67	66	65	64	63	62	62	61	60	59
18	72	71	70	69	68	68	67	66	65	64	63	63	62	61	60
19	73	72	71	70	69	68	68	67	66	65	64	64	63	62	61
20	73	72	72	71	70	69	68	68	67	66	65	64	64	63	62
21	74	73	72	72	71	70	69	68	68	67	66	65	65	64	63
22	75	74	73	72	71	71	70	69	68	68	67	66	65	65	64
23	75	74	74	73	72	71	71	70	69	68	68	67	66	66	65
24	76	75	74	73	73	72	71	71	70	69	68	68	67	66	66
25	76	75	75	74	73	73	72	71	70	70	69	68	68	67	66
26	77	76	75	75	74	73	72	72	71	70	70	69	68	68	67
27	77	76	76	75	74	74	73	72	72	71	70	70	69	68	68
28	78	77	76	76	75	74	74	73	72	72	71	70	70	69	68
29	78	77	77	76	75	75	74	73	73	72	72	71	70	70	69
30	78	78	77	76	76	75	75	74	73	73	72	71	71	70	70
31	79	78	78	77	76	76	75	74	74	73	73	72	71	71	70
32	79	79	78	77	77	76	75	75	74	74	73	72	72	71	71
33	80	79	78	78	77	76	76	75	75	74	73	73	72	72	71
34	80	79	79	78	77	77	76	76	75	74	74	73	73	72	72
35	80	80	79	78	78	77	77	76	75	75	74	74	73	73	72
36	81	80	79	79	78	78	77	76	76	75	75	74	74	73	72
37	81	80	80	79	79	78	77	77	76	76	75	75	74	73	73
38	81	81	80	79	79	78	78	77	77	76	75	75	74	74	73
39	81	81	80	80	79	79	78	77	77	76	76	75	75	74	74
40	82	81	81	80	79	79	78	78	77	77	76	76	75	75	74
41	82	81	81	80	80	79	79	78	78	77	77	76	75	75	74
42	82	82	81	81	80	79	79	78	78	77	77	76	76	75	75
43	82	82	81	81	80	80	79	79	78	78	77	77	76	76	75
44	83	82	82	81	80	80	79	79	78	78	77	77	76	76	75
45	83	82	82	81	81	80	80	79	79	78	78	77	77	76	76
46	83	82	82	81	81	80	80	79	79	78	78	77	77	76	76
47	83	83	82	82	81	81	80	80	79	79	78	78	77	77	76
48	83	83	82	82	81	81	80	80	79	79	78	78	78	77	77
49	84	83	83	82	82	81	81	80	80	79	79	78	78	77	77
50	84	83	83	82	82	81	81	80	80	79	79	78	78	78	77

TABLE X3.1 *Continued*

Air Temperature (t), °C	Depression of Wet-Bulb Thermometer ($t - t_w$), °C														
	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	6.0
6	39	38	37	36	34	...	...	...	...	...	...	...	...	...	...
7	42	40	39	38	37	36	35	33	32	31	30	29	28	27	25
8	44	43	42	40	39	38	37	36	35	34	33	32	30	29	28
9	46	45	44	43	42	40	39	38	37	36	35	34	33	32	31
10	48	47	46	45	44	43	42	40	39	38	37	36	35	34	33
11	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36
12	51	50	49	48	47	46	45	44	44	43	42	41	40	39	38
13	53	52	51	50	49	48	47	46	45	44	43	43	42	41	40
14	54	53	52	52	51	50	49	48	47	46	45	44	43	43	42
15	56	55	54	53	52	51	50	50	49	48	47	46	45	44	43
16	57	56	55	54	54	53	52	51	50	49	48	48	47	46	45
17	58	57	56	56	55	54	53	52	52	51	50	49	48	48	47
18	59	58	58	57	56	55	54	54	53	52	51	51	50	49	48
19	60	60	59	58	57	56	56	55	54	53	53	52	51	50	50
20	61	61	60	59	58	58	57	56	55	55	54	53	52	52	51
21	62	62	61	60	59	59	58	57	56	56	55	54	54	53	52
22	63	63	62	61	60	60	59	58	57	57	56	55	55	54	53
23	64	63	63	62	61	61	60	59	58	58	57	56	56	55	54
24	65	64	64	63	62	61	61	60	59	59	58	57	57	56	55
25	66	65	64	64	63	62	62	61	60	60	59	58	58	57	56
26	66	66	65	64	64	63	62	62	61	60	60	59	59	58	57
27	67	66	66	65	64	64	63	63	62	61	61	60	59	59	58
28	68	67	66	66	65	65	64	63	63	62	61	61	60	60	59
29	68	68	67	66	66	65	65	64	63	63	62	62	61	60	60
30	69	68	68	67	66	66	65	65	64	63	63	62	62	61	61
31	69	69	68	68	67	66	66	65	65	64	64	63	62	62	61
32	70	69	69	68	68	67	66	66	65	65	64	64	63	62	62
33	71	70	69	69	68	68	67	67	66	65	65	64	64	63	63
34	71	70	70	69	69	68	67	67	66	66	65	65	64	64	63
35	71	71	70	70	69	69	68	68	67	66	66	65	65	64	64
36	72	71	71	70	70	69	69	68	68	67	66	66	65	65	64
37	72	72	71	71	70	70	69	69	68	68	67	66	66	65	65
38	73	72	72	71	71	70	70	69	69	68	67	67	66	66	65
39	73	73	72	72	71	71	70	69	69	68	68	67	67	66	66
40	74	73	72	72	71	71	70	70	69	69	68	68	67	67	66
41	74	73	73	72	72	71	71	70	70	69	69	68	68	67	67
42	74	74	73	73	72	72	71	71	70	70	69	69	68	68	67
43	75	74	74	73	73	72	72	71	71	70	70	69	69	68	68
44	75	74	74	73	73	72	72	71	71	71	70	70	69	69	68
45	75	75	74	74	73	73	72	72	71	71	70	70	69	69	69
46	76	75	75	74	74	73	73	72	72	71	71	70	70	69	69
47	76	75	75	74	74	73	73	72	72	72	71	71	70	70	69
48	76	76	75	75	74	74	73	73	72	72	71	71	71	70	70
49	76	76	75	75	74	74	74	73	73	72	72	71	71	70	70
50	77	76	76	75	75	74	74	73	73	73	72	72	71	71	70

TABLE X3.1 *Continued*

Air Temperature (t), °C	Depression of Wet-Bulb Thermometer ($t - t_w$), °C														
	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5
8	27	26	25	24	23	22	21	20	19	18	...	...	...	...	...
9	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
10	32	31	30	29	28	27	26	25	24	23	22	21	20	20	19
11	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21
12	37	36	35	34	33	32	31	30	29	29	28	27	26	25	24
13	39	38	37	36	35	34	34	33	32	31	30	29	28	27	27
14	41	40	39	38	37	37	36	35	34	33	32	31	31	30	29
15	43	42	41	40	39	38	38	37	36	35	34	34	33	32	31
16	44	44	43	42	41	40	39	39	38	37	36	35	35	34	33
17	46	45	44	44	43	42	41	40	40	39	38	37	37	36	35
18	47	47	46	45	44	44	43	42	41	41	40	39	38	38	37
19	49	48	47	47	46	45	44	44	43	42	41	41	40	39	39
20	50	49	49	48	47	47	46	45	44	44	43	42	42	41	40
21	51	51	50	49	49	48	47	46	46	45	44	44	43	42	42
22	53	52	51	50	50	49	48	48	47	46	46	45	44	44	43
23	54	53	52	52	51	50	50	49	48	48	47	46	46	45	44
24	55	54	53	53	52	51	51	50	50	49	48	48	47	46	46
25	56	55	54	54	53	53	52	51	51	50	49	49	48	48	47
26	57	56	55	55	54	54	53	52	52	51	50	50	49	49	48
27	58	57	56	56	55	54	54	53	53	52	51	51	50	50	49
28	58	58	57	57	56	55	55	54	54	53	52	52	51	51	50
29	59	59	58	57	57	56	56	55	55	54	53	53	52	52	51
30	60	59	59	58	58	57	57	56	55	55	54	54	53	53	52
31	61	60	60	59	58	58	57	57	56	56	55	55	54	53	53
32	61	61	60	60	59	59	58	58	57	56	56	55	55	54	54
33	62	61	61	60	60	59	59	58	58	57	57	56	56	55	55
34	63	62	62	61	61	60	59	59	58	58	57	57	56	56	55
35	63	63	62	62	61	61	60	60	59	59	58	58	57	57	56
36	64	63	63	62	62	61	61	60	60	59	59	58	58	57	57
37	64	64	63	63	62	62	61	61	60	60	59	59	58	58	57
38	65	64	64	63	63	62	62	61	61	60	60	59	59	58	58
39	65	65	64	64	63	63	62	62	61	61	61	60	60	59	59
40	66	65	65	64	64	63	63	63	62	62	61	61	60	60	59
41	66	66	65	65	64	64	63	63	63	62	62	61	61	60	60
42	67	66	66	65	65	64	64	64	63	63	62	62	61	61	60
43	67	67	66	66	65	65	64	64	64	63	63	62	62	61	61
44	68	67	67	66	66	65	65	64	64	64	63	63	62	62	61
45	68	68	67	67	66	66	65	65	64	64	64	63	63	62	62
46	68	68	68	67	67	66	66	65	65	64	64	64	63	63	62
47	69	68	68	67	67	67	66	66	65	65	64	64	64	63	63
48	69	69	68	68	67	67	67	66	66	65	65	64	64	64	63
49	70	69	69	68	68	67	67	66	66	66	65	65	64	64	64
50	70	69	69	69	68	68	67	67	66	66	66	65	65	64	64

TABLE X3.1 *Continued*

Air Temperature (t), °C	Depression of Wet-Bulb Thermometer ($t - t_w$), °C														
	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
9	15	14	13	12	11	...	...	...	...	...	...	...	...	...	...
10	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4
11	20	20	19	18	17	16	15	14	13	12	11	10	10	9	8
12	23	22	21	21	20	19	18	17	16	15	14	14	13	12	11
13	26	25	24	23	22	21	21	20	19	18	17	16	16	15	14
14	28	27	26	26	25	24	23	22	21	21	20	19	18	17	17
15	30	29	29	28	27	26	25	25	24	23	22	22	21	20	19
16	32	32	31	30	29	28	28	27	26	25	25	24	23	22	22
17	34	34	33	32	31	31	30	29	28	28	27	26	25	25	24
18	36	35	35	34	33	32	32	31	30	30	29	28	28	27	26
19	38	37	36	36	35	34	34	33	32	32	31	30	29	29	28
20	39	39	38	37	37	36	35	35	34	33	33	32	31	31	30
21	41	40	40	39	38	38	37	36	36	35	34	34	33	32	32
22	42	42	41	40	40	39	39	38	37	37	36	35	35	34	33
23	44	43	43	42	41	41	40	39	39	38	38	37	36	36	35
24	45	44	44	43	43	42	41	41	40	40	39	38	37	37	36
25	46	46	45	44	44	43	43	42	42	41	40	40	39	39	38
26	47	47	46	46	45	44	44	43	43	42	42	41	40	40	39
27	49	48	47	47	46	46	45	45	44	43	43	42	42	41	41
28	50	49	48	48	47	47	46	46	45	45	44	43	43	42	42
29	51	50	49	49	48	48	47	47	46	46	45	45	44	43	43
30	51	51	50	50	49	49	48	48	47	47	46	46	45	45	44
31	52	52	51	51	50	50	49	49	48	48	47	47	46	46	45
32	53	53	52	52	51	51	50	50	49	49	48	48	47	47	46
33	54	54	53	52	52	51	51	50	50	49	49	48	48	47	47
34	55	54	54	53	53	52	52	51	51	50	50	49	49	48	48
35	56	55	55	54	54	53	53	52	52	51	51	50	50	49	49
36	56	56	55	55	54	54	53	53	52	52	51	51	50	50	50
37	57	56	56	55	55	54	54	54	53	53	52	52	51	51	50
38	58	57	57	56	56	55	55	54	54	53	53	52	52	51	51
39	58	58	57	57	56	56	55	55	54	54	54	53	53	52	52
40	59	58	58	57	57	56	56	56	55	55	54	54	53	53	52
41	59	59	58	58	57	57	57	56	56	55	55	54	54	53	53
42	60	59	59	58	58	58	57	57	56	56	55	55	55	54	54
43	60	60	59	59	59	58	58	57	57	56	56	56	55	55	54
44	61	60	60	60	59	59	58	58	57	57	57	56	56	55	55
45	61	61	60	60	60	59	59	58	58	57	57	57	56	56	55
46	62	61	61	61	60	60	59	59	58	58	58	57	57	56	56
47	62	62	61	61	61	60	60	59	59	58	58	58	57	57	56
48	63	62	62	61	61	61	60	60	59	59	59	58	58	57	57
49	63	63	62	62	61	61	61	60	60	59	59	59	58	58	57
50	64	63	63	62	62	61	61	61	60	60	59	59	59	58	58

TABLE X3.1 *Continued*

Air Temperature (t), °C	Depression of Wet-Bulb Thermometer ($t - t_w$), °C														
	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9	10.0	10.1	10.2	10.3	10.4	10.5
11	7	6	5	4	3	2	2	...	...	...	...	...	...	...	...
12	10	9	8	8	7	6	5	4	3	2	...	...	...	...	...
13	13	12	11	11	10	9	8	7	7	6	5	4	3	3	2
14	16	15	14	13	13	12	11	10	10	9	8	7	6	6	5
15	18	18	17	16	15	15	14	13	12	12	11	10	9	9	8
16	21	20	19	19	18	17	17	16	15	14	14	13	12	11	11
17	23	23	22	21	20	20	19	18	18	17	16	15	15	14	13
18	25	25	24	23	23	22	21	21	20	19	19	18	17	17	16
19	27	27	26	25	25	24	23	23	22	21	21	20	19	19	18
20	29	29	28	27	27	26	25	25	24	24	23	22	22	21	20
21	31	31	30	29	29	28	27	27	26	25	25	24	24	23	22
22	33	32	32	31	30	30	29	29	28	27	27	26	26	25	24
23	34	34	33	33	32	31	31	30	30	29	28	28	27	27	26
24	36	35	35	34	34	33	32	32	31	31	30	30	29	28	28
25	37	37	36	36	35	35	34	33	33	32	32	31	31	30	30
26	39	38	38	37	37	36	35	35	34	34	33	33	32	32	31
27	40	40	39	38	38	37	37	36	36	35	35	34	34	33	33
28	41	41	40	40	39	39	38	38	37	36	36	35	35	34	34
29	42	42	41	41	40	40	39	39	38	38	37	37	36	36	35
30	44	43	42	42	41	41	40	40	39	39	38	38	37	37	36
31	45	44	44	43	43	42	42	41	41	40	40	39	39	38	38
32	46	45	45	44	44	43	43	42	42	41	41	40	40	39	39
33	46	46	45	45	45	44	44	43	43	42	42	41	41	40	40
34	47	47	46	46	45	45	45	44	44	43	43	42	42	41	41
35	48	48	47	47	46	46	45	45	44	44	44	43	43	42	42
36	49	49	48	48	47	47	46	46	45	45	44	44	44	43	43
37	50	49	49	48	48	48	47	47	46	46	45	45	44	44	44
38	51	50	50	49	49	48	48	47	47	47	46	46	45	45	44
39	51	51	50	50	50	49	49	48	48	47	47	46	46	46	45
40	52	52	51	51	50	50	49	49	49	48	48	47	47	46	46
41	53	52	52	51	51	50	50	50	49	49	48	48	48	47	47
42	53	53	52	52	52	51	51	50	50	49	49	49	48	48	47
43	54	53	53	53	52	52	51	51	51	50	50	49	49	49	48
44	54	54	54	53	53	52	52	52	51	51	50	50	50	49	49
45	55	55	54	54	53	53	53	52	52	51	51	51	50	50	49
46	56	55	55	54	54	54	53	53	52	52	52	51	51	50	50
47	56	56	55	55	54	54	54	53	53	52	52	52	51	51	51
48	57	56	56	55	55	55	54	54	53	53	53	52	52	52	51
49	57	57	56	56	55	55	55	54	54	54	53	53	52	52	52
50	58	57	57	56	56	56	55	55	54	54	54	53	53	53	52

TABLE X3.1 *Continued*

Air Temperature (t), °C	Depression of Wet-Bulb Thermometer ($t - t_w$), °C														
	10.6	10.7	10.8	10.9	11.0	11.1	11.2	11.3	11.4	11.5	11.6	11.7	11.8	11.9	12.0
14	4	3	3	2	...	...	...	...	...	...	...	...	...	...	...
15	7	6	6	5	4	4	3	2	...	...	...	...	...	...	...
16	10	9	9	8	7	7	6	5	4	4	3	2	2	...	...
17	13	12	11	11	10	9	9	8	7	7	6	5	5	4	3
18	15	15	14	13	13	12	11	11	10	9	9	8	7	7	6
19	18	17	16	16	15	14	14	13	12	12	11	11	10	9	9
20	20	19	18	18	17	17	16	15	15	14	14	13	12	12	11
21	22	21	21	20	19	19	18	18	17	16	16	15	15	14	14
22	24	23	23	22	21	21	20	20	19	19	18	17	17	16	16
23	26	25	24	24	23	23	22	22	21	20	20	19	19	18	18
24	27	27	26	26	25	25	24	23	23	22	22	21	21	20	20
25	29	28	28	27	27	26	26	25	25	24	24	23	23	22	22
26	31	30	29	29	28	28	27	27	26	26	25	25	24	24	23
27	32	31	31	30	30	29	29	28	28	27	27	26	26	25	25
28	33	33	32	32	31	31	30	30	29	29	28	28	27	27	26
29	35	34	34	33	33	32	32	31	31	30	30	29	29	28	28
30	36	35	35	34	34	34	33	33	32	32	31	31	30	30	29
31	37	37	36	36	35	35	34	34	33	33	32	32	32	31	31
32	38	38	37	37	36	36	35	35	35	34	34	33	33	32	32
33	39	39	38	38	38	37	37	36	36	35	35	34	34	33	33
34	40	40	39	39	39	38	38	37	37	36	36	35	35	35	34
35	41	41	40	40	40	39	39	38	38	37	37	37	36	36	35
36	42	42	41	41	41	40	40	39	39	38	38	38	37	37	36
37	43	43	42	42	41	41	41	40	40	39	39	38	38	38	37
38	44	44	43	43	42	42	41	41	41	40	40	39	39	39	38
39	45	44	44	44	43	43	42	42	42	41	41	40	40	39	39
40	46	45	45	44	44	44	43	43	42	42	42	41	41	40	40
41	46	46	46	45	45	44	44	44	43	43	42	42	42	41	41
42	47	47	46	46	45	45	45	44	44	43	43	43	42	42	42
43	48	47	47	47	46	46	45	45	45	44	44	43	43	43	42
44	48	48	48	47	47	46	46	46	45	45	45	44	44	43	43
45	49	49	48	48	47	47	47	46	46	46	45	45	44	44	44
46	50	49	49	48	48	48	47	47	47	46	46	46	45	45	44
47	50	50	49	49	49	48	48	48	47	47	46	46	46	45	45
48	51	50	50	50	49	49	49	48	48	47	47	47	46	46	46
49	51	51	51	50	50	49	49	49	48	48	48	47	47	47	46
50	52	51	51	51	50	50	50	49	49	49	48	48	48	47	47

TABLE X3.1 *Continued*

Air Temperature (t), °C	Depression of Wet-Bulb Thermometer ($t - t_w$), °C														
	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	12.9	13.0	13.1	13.2	13.3	13.4	13.5
17	3	2	...	...	...	...	...	...	...	...	...	...	...	...	...
18	5	5	4	4	3	2	2	...	...	...	...	...	...	...	...
19	8	8	7	6	6	5	4	4	3	3	2	...	...	...	...
20	11	10	9	9	8	8	7	6	6	5	5	4	4	3	2
21	13	12	12	11	11	10	9	9	8	8	7	7	6	6	5
22	15	15	14	13	13	12	12	11	11	10	10	9	9	8	7
23	17	17	16	16	15	14	14	13	13	12	12	11	11	10	10
24	19	19	18	18	17	17	16	15	15	14	14	13	13	12	12
25	21	20	20	19	19	18	18	17	17	16	16	15	15	14	14
26	23	22	22	21	21	20	20	19	19	18	18	17	17	16	16
27	24	24	23	23	22	22	21	21	20	20	20	19	19	18	18
28	26	25	25	24	24	24	23	23	22	22	21	21	20	20	19
29	27	27	26	26	26	25	25	24	24	23	23	22	22	21	21
30	29	28	28	27	27	27	26	26	25	25	24	24	23	23	22
31	30	30	29	29	28	28	27	27	27	26	26	25	25	24	24
32	31	31	31	30	30	29	29	28	28	27	27	27	26	26	25
33	33	32	32	31	31	30	30	30	29	29	28	28	27	27	27
34	34	33	33	32	32	32	31	31	30	30	30	29	29	28	28
35	35	34	34	34	33	33	32	32	32	31	31	30	30	29	29
36	36	35	35	35	34	34	33	33	33	32	32	31	31	31	30
37	37	36	36	36	35	35	34	34	34	33	33	32	32	32	31
38	38	37	37	37	36	36	35	35	35	34	34	33	33	33	32
39	39	38	38	38	37	37	36	36	36	35	35	34	34	34	33
40	40	39	39	38	38	38	37	37	36	36	36	35	35	35	34
41	40	40	40	39	39	38	38	38	37	37	37	36	36	36	35
42	41	41	40	40	40	39	39	39	38	38	37	37	37	36	36
43	42	42	41	41	40	40	40	39	39	39	38	38	38	37	37
44	43	42	42	42	41	41	40	40	40	39	39	39	38	38	38
45	43	43	43	42	42	42	41	41	41	40	40	39	39	39	38
46	44	44	43	43	43	42	42	42	41	41	41	40	40	39	39
47	45	44	44	44	43	43	43	42	42	42	41	41	41	40	40
48	45	45	45	44	44	44	43	43	43	42	42	42	41	41	41
49	46	46	45	45	45	44	44	44	43	43	43	42	42	42	41
50	47	46	46	45	45	45	44	44	44	43	43	43	42	42	42

Air Temperature (t), °C	Depression of Wet-Bulb Thermometer ($t - t_w$), °C														
	13.6	13.7	13.8	13.9	14.0	14.1	14.2	14.3	14.4	14.5	14.6	14.7	14.8	14.9	15.0
20	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...
21	4	4	3	3	2	2	...	...	...	...	...	...	...	...	...
22	7	6	6	5	5	4	4	3	3	2	2	...	...	...	...
23	9	9	8	8	7	7	6	6	5	5	4	4	3	3	2
24	11	11	10	10	9	9	8	8	7	7	6	6	5	5	4
25	13	13	12	12	11	11	10	10	10	9	9	8	8	7	7
26	15	15	14	14	13	13	12	12	12	11	11	10	10	9	9
27	17	17	16	16	15	15	14	14	13	13	13	12	12	11	11
28	19	18	18	18	17	17	16	16	15	15	14	14	14	13	13
29	21	20	20	19	19	18	18	17	17	17	16	16	15	15	14
30	22	22	21	21	20	20	19	19	19	18	18	17	17	16	16
31	24	23	23	22	22	21	21	21	20	20	19	19	18	18	18
32	25	24	24	24	23	23	22	22	22	21	21	20	20	20	19
33	26	26	25	25	25	24	24	23	23	23	22	22	21	21	21
34	27	27	27	26	26	25	25	25	24	24	24	23	23	22	22
35	29	28	28	28	27	27	26	26	26	25	25	24	24	24	23
36	30	29	29	29	28	28	28	27	27	26	26	26	25	25	24
37	31	31	30	30	29	29	29	28	28	28	27	27	26	26	26
38	32	32	31	31	30	30	30	29	29	29	28	28	28	27	27
39	33	33	32	32	31	31	31	30	30	30	29	29	29	28	28
40	34	34	33	33	32	32	32	31	31	31	30	30	30	29	29
41	35	34	34	34	33	33	33	32	32	32	31	31	31	30	30
42	36	35	35	35	34	34	34	33	33	33	32	32	31	31	31
43	36	36	36	35	35	35	34	34	34	33	33	33	32	32	32
44	37	37	37	36	36	36	35	35	35	34	34	34	33	33	33
45	38	38	37	37	37	36	36	36	35	35	35	34	34	34	33
46	39	38	38	38	37	37	37	36	36	36	35	35	35	35	34
47	40	39	39	39	38	38	38	37	37	37	36	36	36	35	35
48	40	40	40	39	39	39	38	38	38	37	37	37	36	36	36
49	41	41	40	40	40	39	39	39	38	38	38	37	37	37	36
50	42	41	41	41	40	40	40	39	39	39	38	38	38	37	37

TABLE X3.1 *Continued*

Air Temperature (t), °C	Depression of Wet-Bulb Thermometer ($t - t_w$), °C 15.1	15.2	15.3	15.4	15.5	15.6	15.7	15.8	15.9	16.0	16.1	16.2	16.3	16.4	16.5
23	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...
24	4	3	3	3	2	2	...	...	...	...	...	...	...	...	...
25	6	6	5	5	4	4	3	3	3	2	2	...	...	...	...
26	8	8	7	7	7	6	6	5	5	4	4	3	3	3	2
27	10	10	9	9	9	8	8	7	7	6	6	6	5	5	4
28	12	12	11	11	10	10	10	9	9	8	8	8	7	7	6
29	14	14	13	13	12	12	11	11	11	10	10	9	9	9	8
30	16	15	15	14	14	14	13	13	12	12	12	11	11	10	10
31	17	17	16	16	16	15	15	14	14	14	13	13	12	12	12
32	19	18	18	18	17	17	16	16	16	15	15	14	14	14	13
33	20	20	19	19	19	18	18	18	17	17	16	16	16	15	15
34	22	21	21	20	20	20	19	19	19	18	18	17	17	17	16
35	23	23	22	22	21	21	21	20	20	20	19	19	18	18	18
36	24	24	23	23	23	22	22	22	21	21	21	20	20	19	19
37	25	25	25	24	24	24	23	23	22	22	22	21	21	21	20
38	26	26	26	25	25	25	24	24	24	23	23	23	22	22	22
39	28	27	27	26	26	26	25	25	25	24	24	24	23	23	23
40	29	28	28	28	27	27	26	26	26	25	25	25	24	24	24
41	30	29	29	29	28	28	28	27	27	27	26	26	26	25	25
41	30	30	30	29	29	29	28	28	28	28	27	27	27	26	26
43	31	31	31	30	30	30	29	29	29	28	28	28	27	27	27
44	32	32	32	31	31	31	30	30	30	29	29	29	28	28	28
45	33	33	32	32	32	31	31	31	31	30	30	30	29	29	29
46	34	34	33	33	33	32	32	32	31	31	31	30	30	30	30
47	35	34	34	34	33	33	33	32	32	32	32	31	31	31	30
48	35	35	35	34	34	34	34	33	33	33	32	32	32	31	31
49	36	36	35	35	35	35	34	34	34	33	33	33	32	32	32
50	37	36	36	36	36	35	35	35	34	34	34	33	33	32	33

Air Temperature (t), °C	Depression of Wet-Bulb Thermometer ($t - t_w$), °C 16.6	16.7	16.8	16.9	17.0	17.1	17.2	17.3	17.4	17.5	17.6	17.7	17.8	17.9	18.0
26	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...
27	4	3	3	3	2	2	...	...	...	...	...	...	...	...	...
28	6	5	5	5	4	4	3	3	3	2	2	...	...	...	...
29	8	7	7	7	6	6	5	5	5	4	4	3	3	3	2
30	10	9	9	8	8	8	7	7	7	6	6	5	5	5	4
31	11	11	11	10	10	9	9	9	8	8	8	7	7	6	6
32	13	13	12	12	11	11	11	10	10	10	9	9	9	8	8
33	15	14	14	13	13	13	12	12	12	11	11	11	10	10	10
34	16	16	15	15	15	14	14	14	13	13	12	12	12	11	11
35	17	17	17	16	16	16	15	15	15	14	14	14	13	13	13
36	19	18	18	18	17	17	17	16	16	16	15	15	15	14	14
37	20	20	19	19	19	18	18	18	17	17	17	16	16	16	15
38	21	21	21	20	20	20	19	19	19	18	18	18	17	17	17
39	22	22	22	21	21	21	20	20	20	19	19	19	19	18	18
40	24	23	23	23	22	22	22	21	21	21	20	20	20	19	19
41	25	24	24	24	23	23	23	22	22	22	21	21	21	20	20
42	26	25	25	25	24	24	24	23	23	23	22	22	22	22	21
43	27	26	26	26	25	25	25	24	24	24	23	23	23	23	22
44	27	27	27	27	26	26	26	25	25	25	24	24	24	24	23
45	28	28	28	27	27	27	27	26	26	26	25	25	25	24	24
46	29	29	29	28	28	28	27	27	27	27	26	26	26	25	25
47	30	30	29	29	29	29	28	28	28	27	27	27	27	26	26
48	31	31	30	30	30	29	29	29	28	28	28	28	27	27	27
49	32	31	31	31	30	30	30	30	29	29	29	28	28	28	28
50	32	32	32	31	31	31	31	30	30	30	30	29	29	29	28

TABLE X3.1 *Continued*

Air Temperature (t), °C	Depression of Wet-Bulb Thermometer ($t - t_w$), °C														
	18.1	18.2	18.3	18.4	18.5	18.6	18.7	18.8	18.9	19.0	19.1	19.2	19.3	19.4	19.5
29	2	2	2	...	...	...	...	...	...	...	...	...	...	...	...
30	4	3	3	3	2	2	2	...	...	...	...	...	...	...	...
31	6	5	5	5	4	4	4	3	3	2	2	2	...	...	...
32	7	7	7	6	6	6	5	5	5	4	4	4	3	3	3
33	9	9	8	8	8	7	7	7	6	6	6	5	5	5	4
34	11	10	10	10	9	9	9	8	8	8	7	7	7	6	6
35	12	12	12	11	11	11	10	10	10	9	9	9	8	8	8
36	14	13	13	13	12	12	12	11	11	11	10	10	10	9	9
37	15	15	14	14	14	13	13	13	12	12	12	12	11	11	11
38	16	16	16	15	15	15	14	14	14	13	13	13	13	12	12
39	18	17	17	17	16	16	16	15	15	15	14	14	14	14	13
40	19	18	18	18	18	17	17	17	16	16	16	15	15	15	15
41	20	20	19	19	19	18	18	18	17	17	17	17	16	16	16
42	21	21	20	20	20	19	19	19	19	18	18	18	17	17	17
43	22	22	21	21	21	21	20	20	20	19	19	19	19	18	18
44	23	23	22	22	22	22	21	21	21	20	20	20	20	19	19
45	24	24	23	23	23	22	22	22	22	21	21	21	21	20	20
46	25	25	24	24	24	23	23	23	23	22	22	22	21	21	21
47	26	25	25	25	25	24	24	24	23	23	23	23	22	22	22
48	27	26	26	26	25	25	25	25	24	24	24	24	23	23	23
49	27	27	27	27	26	26	26	25	25	25	25	24	24	24	24
50	28	28	28	27	27	27	26	26	26	26	25	25	25	25	24
Air Temperature (t), °C	**Depression of Wet-Bulb Thermometer ($t - t_w$), °C**														
	19.6	19.7	19.8	19.9	20.0	20.1	20.2	20.3	20.4	20.5	20.6	20.7	20.8	20.9	21.0
32	2	2	2	...	...	...	...	...	...	...	...	...	...	...	...
33	4	4	3	3	3	2	2	2	...	...	...	...	...	...	...
34	6	5	5	5	4	4	4	3	3	3	3	2	2	2	...
35	7	7	7	6	6	6	5	5	5	5	4	4	4	3	3
36	9	9	8	8	8	7	7	7	6	6	6	5	5	5	5
37	10	10	10	9	9	9	8	8	8	8	7	7	7	6	6
38	12	11	11	11	10	10	10	10	9	9	9	8	8	8	8
39	13	13	12	12	12	12	11	11	11	10	10	10	10	9	9
40	14	14	14	13	13	13	13	12	12	12	11	11	11	11	10
41	15	15	15	15	14	14	14	13	13	13	13	12	12	12	12
42	17	16	16	16	15	15	15	15	14	14	14	14	13	13	13
43	18	17	17	17	17	16	16	16	15	15	15	15	14	14	14
44	19	18	18	18	18	17	17	17	17	16	16	16	15	15	15
45	20	19	19	19	19	18	18	18	18	17	17	17	17	16	16
46	21	20	20	20	20	19	19	19	19	18	18	18	18	17	17
47	22	21	21	21	21	20	20	20	20	19	19	19	18	18	18
48	22	22	22	22	21	21	21	21	20	20	20	20	19	19	19
49	23	23	23	23	22	22	22	22	21	21	21	21	20	20	20
50	24	24	24	23	23	23	23	22	22	22	22	21	21	21	21
Air Temperature (t), °C	**Depression of Wet-Bulb Thermometer ($t - t_w$), °C**														
	21.1	21.2	21.3	21.4	21.5	21.6	21.7	21.8	21.9	22.0	22.1	22.2	22.3	22.4	22.5
35	3	2	2	2	2	...	...	...	...	...	...	...	...	...	...
36	4	4	4	3	3	3	3	2	2	2	...	...	...	...	...
37	6	6	5	5	5	4	4	4	4	3	3	3	2	2	2
38	7	7	7	6	6	6	6	5	5	5	4	4	4	4	3
39	9	8	8	8	8	7	7	7	6	6	6	6	5	5	5
40	10	10	9	9	9	9	8	8	8	8	7	7	7	7	6
41	11	11	11	10	10	10	10	9	9	9	9	8	8	8	8
42	12	12	12	12	11	11	11	11	10	10	10	10	9	9	9
43	14	13	13	13	13	12	12	12	12	11	11	11	11	10	10
44	15	14	14	14	14	13	13	13	13	12	12	12	12	11	11
45	16	16	15	15	15	14	14	14	14	14	13	13	13	13	12
46	17	17	16	16	16	16	15	15	15	15	14	14	14	14	13
47	18	17	17	17	17	16	16	16	16	16	15	15	15	15	14
48	19	18	18	18	18	17	17	17	17	16	16	16	16	16	15
49	20	19	19	19	19	18	18	18	18	17	17	17	17	16	16
50	20	20	20	20	19	19	19	19	19	18	18	18	18	17	17

TABLE X3.1 *Continued*

Air Temperature (t), °C	Depression of Wet-Bulb Thermometer ($t - t_w$), °C														
	22.6	22.7	22.8	22.9	23.0	23.1	23.2	23.3	23.4	23.5	23.6	23.7	23.8	23.9	24.0
37	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...
38	3	3	3	2	2	2	2	...	...	...	...	...	...	...	...
39	5	4	4	4	4	3	3	3	3	2	2	2	...	...	...
40	6	6	5	5	5	5	4	4	4	4	3	3	3	3	2
41	7	7	7	7	6	6	6	6	5	5	5	5	4	4	4
42	9	8	8	8	8	7	7	7	7	6	6	6	6	5	5
43	10	10	9	9	9	9	8	8	8	8	7	7	7	7	6
44	11	11	10	10	10	10	9	9	9	9	9	8	8	8	8
45	12	12	12	11	11	11	11	10	10	10	10	9	9	9	9
46	13	13	13	12	12	12	12	11	11	11	11	11	10	10	10
47	14	14	14	13	13	13	13	12	12	12	12	12	11	11	11
48	15	15	15	14	14	14	14	13	13	13	13	13	12	12	12
49	16	16	16	15	15	15	15	14	14	14	14	14	13	13	13
50	17	17	16	16	16	16	16	15	15	15	15	14	14	14	14

Air Temperature (t), °C	Depression of Wet-Bulb Thermometer ($t - t_w$), °C														
	24.1	24.2	24.3	24.4	24.5	24.6	24.7	24.8	24.9	25.0	25.1	25.2	25.3	25.4	25.5
40	2	2	2	...	...	...	...	...	...	...	...	...	...	...	...
41	4	3	3	3	3	2	2	2	2	...	...	...	...	...	...
42	5	5	4	4	4	4	3	3	3	3	3	2	2	2	2
43	6	6	6	5	5	5	5	5	4	4	4	4	3	3	3
44	7	7	7	7	6	6	6	6	6	5	5	5	5	4	4
45	9	8	8	8	8	7	7	7	7	6	6	6	6	6	5
46	10	9	9	9	9	8	8	8	8	8	7	7	7	7	7
47	11	10	10	10	10	10	9	9	9	9	8	8	8	8	8
48	12	11	11	11	11	11	10	10	10	10	10	9	9	9	9
49	13	12	12	12	12	12	11	11	11	11	11	10	10	10	10
50	14	13	13	13	13	12	12	12	12	12	11	11	11	11	11

Air Temperature (t), °C	Depression of Wet-Bulb Thermometer ($t - t_w$), °C														
	25.6	25.7	25.8	25.9	26.0	26.1	26.2	26.3	26.4	26.5	26.6	26.7	26.8	26.9	27.0
43	3	3	2	2	2	2	...	...	...	...	...	...	...	...	...
44	4	4	4	3	3	3	3	2	2	2	2	2	...	...	...
45	5	5	5	5	4	4	4	4	3	3	3	3	3	2	2
46	6	6	6	6	5	5	5	5	5	4	4	4	4	4	3
47	7	7	7	7	7	6	6	6	6	6	5	5	5	5	5
48	8	8	8	8	8	7	7	7	7	7	6	6	6	6	6
49	9	9	9	9	9	8	8	8	8	8	7	7	7	7	7
50	10	10	10	10	10	9	9	9	9	9	8	8	8	8	8

Air Temperature (t), °C	Depression of Wet-Bulb Thermometer ($t - t_w$), °C														
	27.1	27.2	27.3	27.4	27.5	27.6	27.7	27.8	27.9	28.0	28.1	28.2	28.3	28.4	28.5
45	2	2	2	...	...	...	...	...	...	...	...	...	...	...	...
46	3	3	3	3	2	2	2	2	2	...	...	...	...	...	...
47	4	4	4	4	4	3	3	3	3	3	2	2	2	2	2
48	5	5	5	5	5	4	4	4	4	4	4	3	3	3	3
49	6	6	6	6	6	6	5	5	5	5	5	4	4	4	4
50	8	7	7	7	7	7	6	6	6	6	6	5	5	5	5

Air Temperature (t), °C	Depression of Wet-Bulb Thermometer ($t - t_w$), °C														
	28.6	28.7	28.8	28.9	29.0	29.1	29.2	29.3	29.4	29.5	29.6	29.7	29.8	29.9	30.0
48	3	2	2	2	2	2	2	...	...	...	...	...	...	...	...
49	4	4	3	3	3	3	3	2	2	2	2	2	2	...	...
40	5	5	4	4	4	4	4	3	3	3	3	3	3	2	2

X4. FACTORS (B)

X4.1 Factors (B) shown in Table X4.1 are to be used in obtaining corrections to values of relative humidity as given in Appendix X3 and Table X3.1, in cases when barometric pressure (p) differs from standard atmospheric pressure (101325 Pa).

X4.2 Application of the factors in Table X4.1 is indicated by the following equation:

$$RH = RH_o + B\,(t - t_w)\,(101325 - p), \text{ in percent} \quad (X4.1)$$

where:

RH = actual relative humidity (%) at dry-bulb temperature t, wet-bulb temperature t_w, and barometer pressure p (in Pa);

RH_o = relative humidity (%) as given in X3 corresponding to observed values of t and $(t - t_w)$, on assumption barometer pressure is 101325 Pa;

B = factor from Table X4.1 corresponding to observed dry-bulb temperature, t.

TABLE X4.1 Factors (B) Used in Obtaining Corrections to Values of Relative Humidity in Appendix X3

Air Temperature (t), °C	Correction factor B, ($\times 10^{-5}$)
1	10.0
3	8.72
5	7.58
7	6.61
9	5.78
11	5.06
13	4.44
15	3.91
17	3.45
19	3.05
21	2.70
23	2.39
25	2.12
27	1.89
29	1.68
31	1.50
33	1.34
35	1.21
37	1.08
39	0.973
41	0.876
43	0.790
45	0.713
47	0.645
49	0.584
50	0.556

NOTE X4.1—When p is greater than 101325 Pa the correction will be negative, and when p is less than 101325 Pa the correction will be positive. Examples:

(*1*) $t = 20°C$, $(t - t_w) = 1.1°C$, $p = 70928$ Pa.

From Appendix X3, $RH_o = 90\ \%$; from Table X4.1, B $= 2.875 \times 10^{-5}$.

$RH = 90\ \% + 2.875 \times 10^{-5}(1.1)(101325 - 70928)\% = 90\ \% + 1\ \% = 91\ \%$.

(*2*) $t = 31°C$, $(t - t_w) = 14.1°C$, $p = 131722$ Pa.

From Appendix X3, $RH_o = 21\ \%$; from Table X4.1, B $= 1.50 \times 10^{-5}$.

$RH = 21\ \% + 1.50 \times 10^{-5}(14.1)(101325 - 131722)\% = 21\ \% - 6\ \% = 15\ \%$.

X5. PRESSURE CONVERSION FACTORS

X5.1 The following are three equations for pressure conversion factors:

X5.1.1 To convert millibar (mb) to pascal (Pa):

$$\text{Pa} = (\text{mb}) \times 100 \quad (X5.1)$$

X5.1.2 To convert millimeter mercury (mm Hg) to Pa:

$$\text{Pa} = (\text{mm}) \times 133.32 \quad (X5.2)$$

X5.1.3 To convert inches mercury (in Hg) to Pa:

$$\text{Pa} = (\text{in Hg}) \times 3386.4 \quad (X5.3)$$

REFERENCES

(1) *Toxic and Hazardous Substances*, Occupational Safety and Health Standards Subpart Z, Section 1910.1000 Air Contaminants, Table Z-2.29 Code of Federal Regulations.

(2) Wexler, A., "Vapor Pressure Formulation for Water in Range 0 to 100°C, A Revision," *Journal of Research*, National Bureau of Standards (U.S.), Vol 80A, (Sept–Dec., 1976) pp. 775–785.

(3) *Smithsonian Meteorological Tables*, Smithsonian Press, Washington, DC, 1968.

(4) *International Meteorological Tables*, World Meteorological Organization, (WMO) No. 188, TP94, 1966, Secretariat of WMO, Geneva, Switzerland.

(5) *Handbook and Product Directory*, American Society of Heating, Refrigeration, and Airconditioning Engineers, 1977 Fundamentals, New York, NY.

(6) Alduchov, Oleg A., and Eskridge, Robert A., "Improved Magnus Form Approximation of Saturation Vapor Pressure." *Journal of Applied Meteorology*, 35, April 1996, pp. 601-609

(7) "New Equations for Water Vapor Pressure in the Temperature Range -100°C to 100°C for Use with the 1997 NIST/ASME Steam Tables," *Proceedings of the Third International Symposium on Humidity and Moisture*, p. 68-76, 1998.

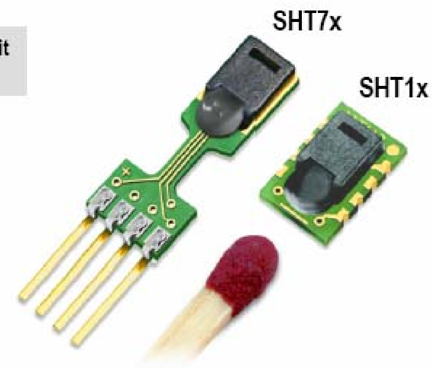
(8) "The IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam," *Transactions of the ASME*, vol. 22, p.150-182, 2000.

Anexo B. Hoja de datos SHT75

SHT1x / SHT7x

Humidity & Temperature Sensor

Evaluation Kit Available



- Relative humidity and temperature sensors
- Dew point
- Fully calibrated, digital output
- Excellent long-term stability
- No external components required
- Ultra low power consumption
- Surface mountable or 4-pin fully interchangeable
- Small size
- Automatic power down

SHT1x / SHT7x Product Summary

The SHTxx is a single chip relative humidity and temperature multi sensor module comprising a calibrated digital output. Application of industrial CMOS processes with patented micro-machining (CMOSens® technology) ensures highest reliability and excellent long term stability. The device includes a capacitive polymer sensing element for relative humidity and a bandgap temperature sensor. Both are seamlessly coupled to a 14bit analog to digital converter and a serial interface circuit on the same chip. This results in superior signal quality, a fast response time and insensitivity to external disturbances (EMC) at a very competitive price.
Each SHTxx is individually calibrated in a precision humidity chamber. The calibration coefficients are programmed into the OTP memory. These coefficients are used internally during measurements to calibrate the signals from the sensors.
The 2-wire serial interface and internal voltage regulation allows easy and fast system integration. Its tiny size and low power consumption makes it the ultimate choice for even the most demanding applications.
The device is supplied in either a surface-mountable LCC (Leadless Chip Carrier) or as a pluggable 4-pin single-in-line type package. Customer specific packaging options may be available on request.

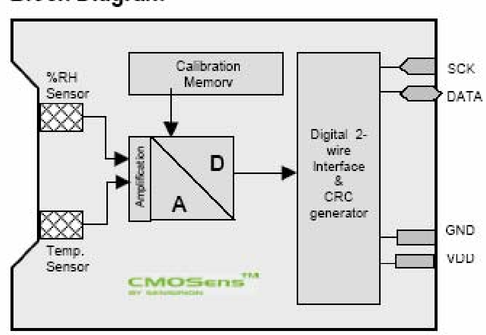
Applications

_ HVAC
_ Automotive
_ Consumer Goods
_ Weather Stations
_ Humidifiers
_ Dehumidifiers
_ Test & Measurement
_ Data Logging
_ Automation
_ White Goods
_ Medical

Ordering Information

Part Number	Humidity accuracy [%RH]	Temperature accuracy [K] @ 25 °C	Package
SHT10	±4.5	±0.5	SMD (LCC)
SHT11	±3.0	±0.4	SMD (LCC)
SHT15	±2.0	±0.3	SMD (LCC)
SHT71	±3.0	±0.4	4-pin single-in-line
SHT75	±1.8	±0.3	4-pin single-in-line

Block Diagram



1 Sensor Performance Specifications

Parameter	Conditions	Min.	Typ.	Max.	Units
Humidity					
Resolution (2)		0.5	0.03	0.03	%RH
		8	12	12	bit
Repeatability			±0.1		%RH
Accuracy (1) Uncertainty	linearized	see figure 1			
Interchangeability		Fully interchangeable			
Nonlinearity	raw data		±3		%RH
	linearized		<<1		%RH
Range		0		100	%RH
Response time	1/e (63%) slowly moving air		4		s
Hysteresis			±1		%RH
Long term stability	typical		< 0.5		%RH/yr
Temperature					
Resolution (2)		0.04	0.01	0.01	°C
		0.07	0.02	0.02	°F
		12	14	14	bit
Repeatability			±0.1		°C
			±0.2		°F
Accuracy		see figure 1			
Range		-40		123.8	°C
		-40		254.9	°F
Response Time	1/e (63%)	5		30	s

Table 1 Sensor Performance Specifications

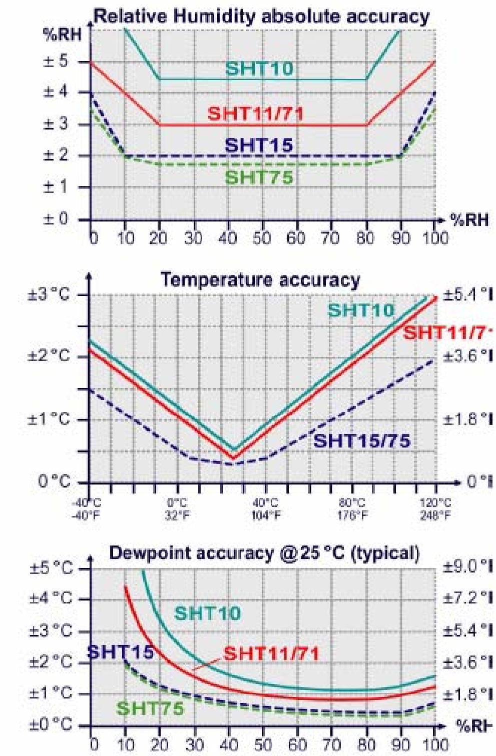


Figure 1 Rel. Humidity, Temperature and Dewpoint accuracies

2 Interface Specifications

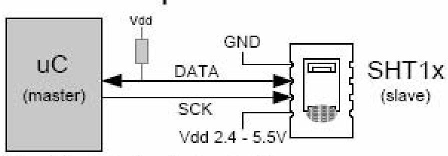


Figure 2 Typical application circuit

2.1 Power Pins

The SHTxx requires a voltage supply between 2.4 and 5.5 V. After powerup the device needs 11ms to reach its "sleep" state. No commands should be sent before that time.
Power supply pins (VDD, GND) may be decoupled with a 100 nF capacitor.

2.2 Serial Interface (Bidirectional 2-wire)

The serial interface of the SHTxx is optimized for sensor readout and power consumption and is not compatible with I²C interfaces, see FAQ for details.

2.2.1 Serial clock input (SCK)

The SCK is used to synchronize the communication between a microcontroller and the SHTxx. Since the interface consists of fully static logic there is no minimum SCK frequency.

2.2.2 Serial data (DATA)

The DATA tristate pin is used to transfer data in and out of the device. DATA **changes after the falling edge** and is **valid on the rising edge** of the serial clock SCK. During transmission the DATA line must remain stable while SCK is high. To avoid signal contention the microcontroller should only drive DATA low. An external pull-up resistor (e.g. 10 kΩ) is required to pull the signal high. (See Figure 2) Pull-up resistors are often included in I/O circuits of microcontrollers. See Table 5 for detailed IO characteristics.

(1) Each SHTxx is tested to be fully within RH accuracy specifications at 25 °C (77 °F) and 48 °C (118.4 °F)
(2) The default measurement resolution of 14bit (temperature) and 12bit (humidity) can be reduced to 12 and 8 bit through the status register.

2.2.3 Sending a command

To initiate a transmission, a "Transmission Start" sequence has to be issued. It consists of a lowering of the DATA line while SCK is high, followed by a low pulse on SCK and raising DATA again while SCK is still high.

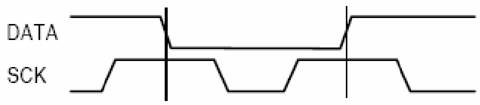


Figure 3 "Transmission Start" sequence

The subsequent command consists of three address bits (only "000" is currently supported) and five command bits. The SHTxx indicates the proper reception of a command by pulling the DATA pin low (ACK bit) after the falling edge of the 8th SCK clock. The DATA line is released (and goes high) after the falling edge of the 9th SCK clock.

Command	Code
Reserved	0000x
Measure Temperature	**00011**
Measure Humidity	**00101**
Read Status Register	00111
Write Status Register	00110
Reserved	0101x-1110x
Soft reset, resets the interface, clears the status register to default values wait minimum 11 ms before next command	**11110**

Table 2 SHTxx list of commands

2.2.4 Measurement sequence (RH and T)

After issuing a measurement command ('00000101' for RH, '00000011' for Temperature) the controller has to wait for the measurement to complete. This takes approximately 11/55/210 ms for a 8/12/14bit measurement. The exact time varies by up to ±15% with the speed of the internal oscillator. To signal the completion of a measurement, the SHTxx pulls down the data line and enters idle mode. The controller **must** wait for this "data ready" signal before restarting SCK to readout the data. Measurement data is stored until readout, therefore the controller can continue with other tasks and readout as convenient.

Two bytes of measurement data and one byte of CRC checksum will then be transmitted. The uC must acknowledge each byte by pulling the DATA line low. All values are MSB first, right justified. (e.g. the 5th SCK is MSB for a 12bit value, for a 8bit result the first byte is not used).
Communication terminates after the acknowledge bit of the CRC data. If CRC-8 checksum is not used the controller may terminate the communication after the measurement data LSB by keeping ack high.
The device automatically returns to sleep mode after the measurement and communication have ended.

Warning: To keep self heating below 0.1 °C the SHTxx should not be active for more than 10% of the time (e.g. max. 2 measurements / second for 12bit accuracy).

2.2.5 Connection reset sequence

If communication with the device is lost the following signal sequence will reset its serial interface:
While leaving DATA high, toggle SCK 9 or more times. This must be followed by a "Transmission Start" sequence preceding the next command. This sequence resets the interface only. The status register preserves its content.

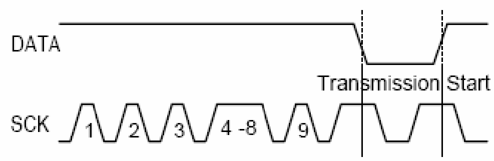


Figure 4 Connection reset sequence

2.2.6 CRC-8 Checksum calculation

The whole digital transmission is secured by a 8 bit checksum. It ensures that any wrong data can be detected and eliminated.
Please consult application note "CRC-8 Checksum Calculation" for information on how to calculate the CRC.

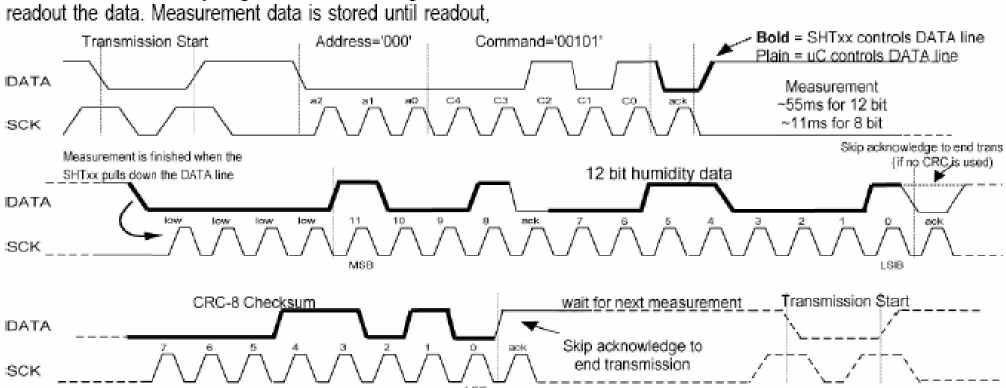


Figure 5 Example RH measurement sequence for value "0000'1001 ' 0011'0001"= 2353 = 75.79 %RH (without temperature compensation)

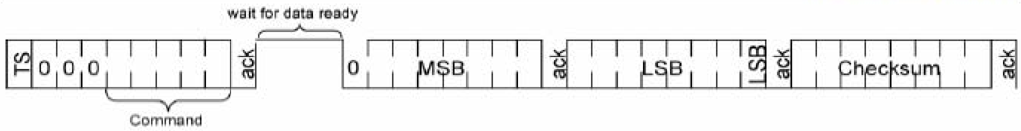


Figure 6 Overview of Measurement Sequence (TS = Transmission Start)

2.3 Status Register

Some of the advanced functions of the SHTxx are available through the status register. The following section gives a brief overview of these features. A more detailed description is available in the application note "Status Register"

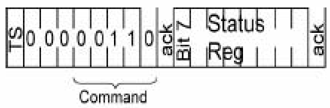


Figure 7 Status Register Write

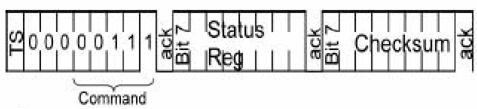


Figure 8 Status Register Read

Bit	Type	Description	Default	
7		reserved	0	
6	R	End of Battery (low voltage detection) '0' for Vdd > 2.47 '1' for Vdd < 2.47	X	No default value, bit is only updated after a measurement
5		reserved	0	
4		reserved	0	
3		For Testing only, do not use	0	
2	R/W	Heater	0	off
1	R/W	no reload from OTP	0	reload
0	R/W	'1' = 8bit RH / 12bit Temperature resolution '0' = 12bit RH / 14bit Temperature resolution	0	12bit RH 14bit Temp.

Table 3 Status Register Bits

2.3.1 Measurement resolution

The default measurement resolution of 14bit (temperature) and 12bit (humidity) can be reduced to 12 and 8bit. This is especially useful in high speed or extreme low power applications.

2.3.2 End of Battery

The "End of Battery" function detects VDD voltages below 2.47 V. Accuracy is ±0.05 V

2.3.3 Heater

An on chip heating element can be switched on. It will increase the temperature of the sensor by 5-15 °C (9-27 °F). Power consumption will increase by ~8 mA @ 5 V.
Applications:
By comparing temperature and humidity values before and after switching on the heater, proper functionality of both sensors can be verified.

- In high (>95 %RH) RH environments heating the sensor element will prevent condensation, improve response time and accuracy

Warning: While heated the SHTxx will show higher temperatures and a lower relative humidity than with no heating.

2.4 Electrical Characteristics[1]

VDD=5V, Temperature = 25 °C unless otherwise noted

Parameter	Conditions	Min.	Typ.	Max.	Units
Power supply DC		2.4	5	5.5	V
Supply current	measuring		550		µA
	average	2[2]	28[3]		µA
	sleep		0.3	1	µA
Low level output voltage		0		20%	Vdd
High level output voltage		75%		100%	Vdd
Low level input voltage	Negative going	0		20%	Vdd
High level input voltage	Positive going	80%		100%	Vdd
Input current on pads				1	µA
Output peak current	on			4	mA
	Tristated (off)		10		µA

Table 4 SHTxx DC Characteristics

	Parameter	Conditions	Min	Typ.	Max.	Unit
F_{SCK}	SCK frequency	VDD > 4.5 V			10	MHz
		VDD < 4.5 V			1	MHz
T_{RFO}	DATA fall time	Output load 5 pF	3.5	10	20	ns
		Output load 100 pF	30	40	200	ns
T_{CLx}	SCK hi/low time		100			ns
T_V	DATA valid time			250		ns
T_{SU}	DATA set up time		100			ns
T_{HO}	DATA hold time		0	10		ns
T_R/T_F	SCK rise/fall time			200		ns

Table 5 SHTxx I/O Signals Characteristics

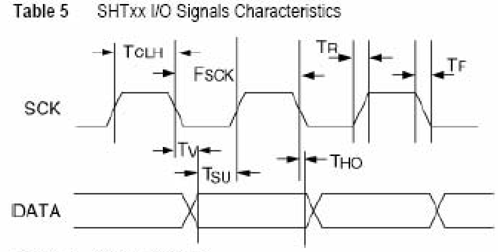


Figure 9 Timing Diagram

1) Parameters are periodically sampled and not 100% tested
(2) With one measurement of 8 bit accuracy without OTP reload per second
(3) With one measurement of 12bit accuracy per second

3 Converting Output to Physical Values

3.1 Relative Humidity

To compensate for the non-linearity of the humidity sensor and to obtain the full accuracy it is recommended to convert the readout with the following formula[1]:

$$RH_{linear} = c_1 + c_2 \bullet SO_{RH} + c_3 \bullet SO_{RH}^2$$

SO_{RH}	c_1	c_2	c_3
12 bit	-4	0.0405	$-2.8 * 10^{-6}$
8 bit	-4	0.648	$-7.2 * 10^{-4}$

Table 6 Humidity conversion coefficients

For simplified, less computation intense conversion formulas see application note "RH and Temperature Non-Linearity Compensation".
Values higher than 99% RH indicate fully saturated air and must be processed and displayed as 100% RH.
The humidity sensor has no significant voltage dependency.

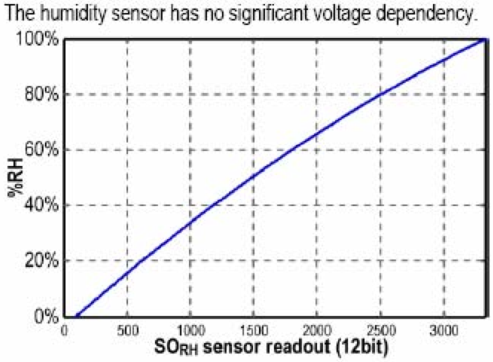


Figure 10 Conversion from SO_{RH} to relative humidity

3.1.1 Humidity Sensor RH/Temperature compensation

For temperatures significantly different from 25 °C (~77 °F) the temperature coefficient of the RH sensor should be considered:

$$RH_{true} = (T_{°C} - 25) \bullet (t_1 + t_2 \bullet SO_{RH}) + RH_{linear}$$

SO_{RH}	t_1	t_2
12 bit	0.01	0.00008
8 bit	0.01	0.00128

Table 7 Temperature compensation coefficients

This equals ~0.12 %RH / °C @ 50 %RH

3.2 Temperature

The bandgap PTAT (Proportional To Absolute Temperature) temperature sensor is very linear by design. Use the following formula to convert from digital readout to temperature:

$$Temperature = d_1 + d_2 \bullet SO_T$$

VDD	d_1 [°C]	d_1 [°F]
5V	-40.00	-40.00
4V	-39.75	-39.50
3.5V	-39.66	-39.35
3V	-39.60	-39.28
2.5V	-39.55	-39.23

	d_2 [°C]	d_2 [°F]
14bit	0.01	0.018
12bit	0.04	0.072

Table 8 Temperature conversion coefficients

For improved accuracies in extreme temperatures with more computation intense conversion formulas see application note "RH and Temperature Non-Linearity Compensation".

3.3 Dewpoint

Since humidity and temperature are both measured on the same monolithic chip, the SHTxx allows superb dewpoint measurements. See application note "Dewpoint calculation" for more.

[1] Where SO_{RH} is the sensor output for relative humidity

4 Applications Information

4.1 Operating and Storage Conditions

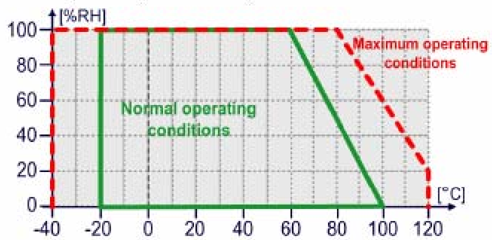


Figure 11 Recommended operating conditions

Conditions outside the recommended range may temporarily offset the RH signal up to ±3 %RH. After return to normal conditions it will slowly return towards calibration state by itself. See 4.3 "Reconditioning Procedure" to accelerate this process. Prolonged exposure to extreme conditions may accelerate ageing.

4.2 Exposure to Chemicals

Chemical vapors may interfere with the polymer layers used for capacitive humidity sensors. The diffusion of chemicals into the polymer may cause a shift in both offset and sensitivity. In a clean environment the contaminants will slowly outgas. The reconditioning procedure described below will accelerate this process. High levels of pollutants may cause permanent damage to the sensing polymer.

4.3 Reconditioning Procedure

The following reconditioning procedure will bring the sensor back to calibration state after exposure to extreme conditions or chemical vapors.

80-90 °C (176-194°F) at < 5 %RH for 24h (baking) followed by
20-30 °C (70-90°F) at > 74 %RH for 48h (re-hydration)

4.4 Temperature Effects

The relative humidity of a gas strongly depends on its temperature. It is therefore essential to keep humidity sensors at the same temperature as the air of which the relative humidity is to be measured.

If the SHTxx shares a PCB with electronic components that give off heat it should be mounted far away and below the heat source and the housing must remain well ventilated.

To reduce heat conduction copper layers between the SHT1x and the rest of the PCB should be minimized and a slit may be milled in between (see figure 13).

4.5 Membranes

A membrane may be used to prevent dirt from entering the housing and to protect the sensor. It will also reduce peak concentrations of chemical vapors. For optimal response times air volume behind the membrane must be kept to a minimum. For the SHT1x package Sensirion recommends the SF1 filter cap for optimal IP67 protection.

4.6 Light

The SHTxx is not light sensitive. Prolonged direct exposure to sunshine or strong UV radiation may age the housing.

4.7 Materials Used for Sealing / Mounting

Many materials absorb humidity and will act as a buffer, increasing response times and hysteresis. Materials in the vicinity of the sensor must therefore be carefully chosen. Recommended materials are: All Metals, LCP, POM (Delrin), PTFE (Teflon), PE, PEEK, PP, PB, PPS, PSU, PVDF, PVF

For sealing and gluing (use sparingly): High filled epoxy for electronic packaging (e.g. glob top, underfill), and Silicone. Outgassing of these materials may also contaminate the SHTxx (cf. 4.2). Store well ventilated after manufacturing or bake at 50°C for 24h to outgas contaminants before packing.

4.8 Wiring Considerations and Signal Integrity

Carrying the SCK and DATA signal parallel and in close proximity (e.g. in wires) for more than 10cm may result in cross talk and loss of communication. This may be resolved by routing VDD and/or GND between the two data signals.

Please see the application note "ESD, Latchup and EMC" for more information.

Power supply pins (VDD, GND) should be decoupled with a 100 nF capacitor if wires are used.

4.9 Qualifications

Extensive tests were performed in various environments. Please contact SENSIRION for detailed information.

Environment	Norm	Results(1)
Temperature Cycles	JESD22-A104-B **-40 °C / 125 °C, 1000 cy**	Within Specifications
HAST Pressure Cooker	JESD22-A110-B **2.3 bar 125 °C 85 %RH**	Reversible shift by +2 %RH
High Temperature and Humidity	JESD22-A101-B **85 °C 85 %RH 1250h**	Reversible shift by +2 %RH
Salt Atmosphere	DIN-50021ss	Within Spec.
Condensing Air	-	Within Spec.
Freezing cycles fully submerged	**-20 / +90 °C, 100 cy** 30min dwell time	Reversible shift by +2 %RH
Various Automotive Chemicals	DIN 72300-5	Within Specifications

Table 9 Qualification tests (excerpt)

4.10 ESD (Electrostatic Discharge)

ESD immunity is qualified according to MIL STD 883E, method 3015 (Human Body Model at ±2 kV)).

Latch-up immunity is provided at a force current of ±100 mA with T_{amb} = 80 °C according to JEDEC 17. See application note "ESD, Latchup and EMC" for more information.

(1) The temperature sensor passed all tests without any detectable drift. Package and electronics also passed 100%

5 Package Information

5.1 SHT1x (surface mountable)

Pin	Name	Comment
1	GND	Ground
2	DATA	Serial data, bidirectional
3	SCK	Serial clock, input
4	VDD	Supply 2.4 - 5.5 V
	NC	Remaining pins must be left unconnected

Table 10 SHT1x Pin Description

5.1.1 Package type

The SHT1x is supplied in a surface-mountable LCC (Leadless Chip Carrier) type package. The sensors housing consists of a Liquid Crystal Polymer (LCP) cap with epoxy glob top on a standard 0.8 mm FR4 substrate. The device is free of Pb, Cd and Hg. (Fully ROHS, WEEE compliant)
Device size is 7.42 x 4.88 x 2.5 mm (0.29 x 0.19 x 0.1 inch)
Weight 100 mg

The production date is printed onto the cap in white numbers in the form wwy. e.g. "351" = week 35, 2001.

5.1.2 Delivery Conditions

The SHT1x are shipped in 12mm tape at 100pcs or 400pcs. (SHT10 at 2000pcs only). Reels are individually labelled with barcode and human readable labels. The lot numbers allow full traceability through production, calibration and test.

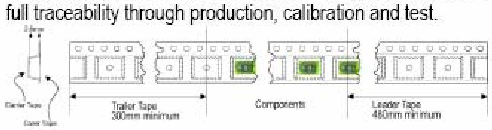


Figure 12 Tape configuration and unit orientation

5.1.3 Soldering Information

Standard reflow soldering ovens may be used. For details please see application note "soldering procedure".

For manual soldering contact time must be limited to 5 seconds at up to 350 °C.
After soldering the devices should be stored at >74 %RH for at least 24h to allow the polymer to rehydrate.
Please consult the application note "Soldering procedure" for more information.

5.1.4 Mounting Examples

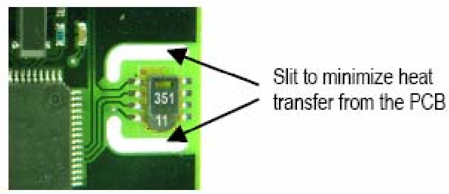


Figure 13 SHT1x PCB Mounting example

The SF1 membrane filter cap is available for optimal IP67 protection. When mounted through a housing the interior can be protected from the environment while still allowing high quality humidity measurements (see example below).

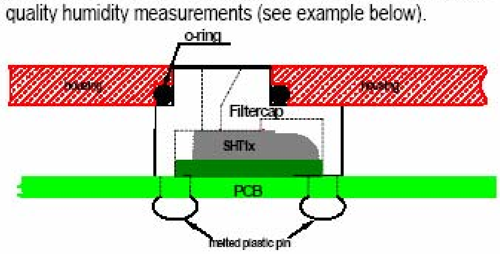


Figure 14 SF1 IP67 filter cap mounting example

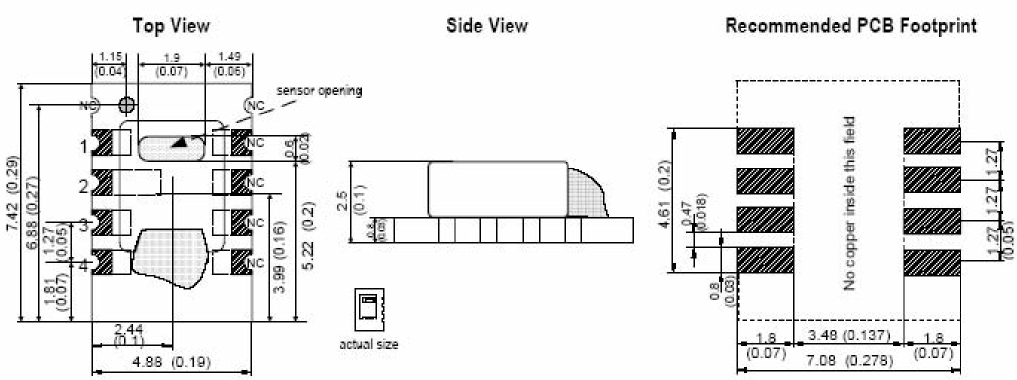


Figure 15 SHT1x drawing and footprint dimensions in mm (inch)

5.2 SHT7x (4-pin single-in-line)

Pin	Name	Comment
1	*SCK*	*Serial clock input*
2	*VDD*	*Supply 2.4 - 5.5 V*
3	*GND*	*Ground*
4	*DATA*	*Serial data bidirectional*

Table 11 SHT7x Pin Description

5.2.1 Package type[1]

The device is supplied in a single-in-line pin type package. The sensor housing consists of a Liquid Crystal Polymer (LCP) cap with epoxy glob top on a standard 0.6 mm FR4 substrate. The device is Cd and Hg free.
The sensor head is connected to the pins by a small bridge to minimize heat conduction and response times. The gold plated back side of the sensor head is connected to the GND pin.
A 100nF capacitor is mounted on the back side between VDD and GND.
All pins are gold plated to avoid corrosion. They can be soldered or mate with most 1.27 mm (0.05'') sockets
e.g.: Preci-dip / Mill-Max 851-93-004-20-001 or similar
Total weight: 168 mg, weight of sensor head: 73 mg

The production date is printed onto the cap in white numbers in the form wwy. e.g. "351" = week 35, 2001.

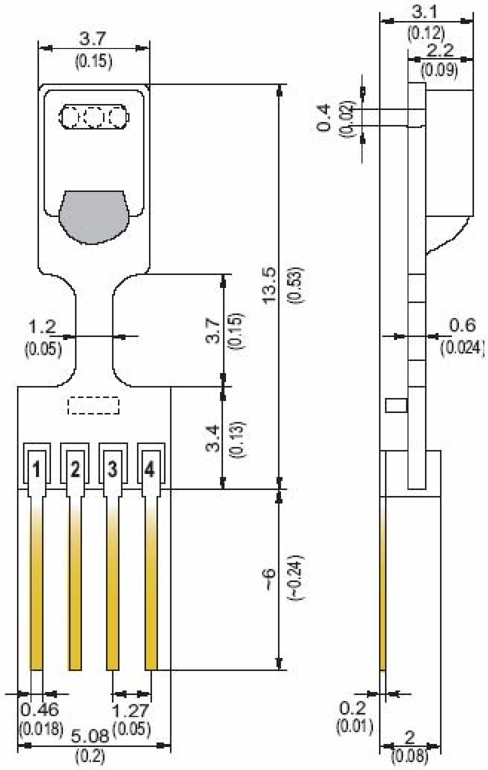


Figure 17 SHT7x dimensions in mm (inch)

5.2.2 Delivery Conditions

The SHT7x are shipped in 32 mm tape. These reeled parts in standard option are shipped with 500 units per 13 inch diameter reel. Reels are individually labelled with barcode and human readable labels.

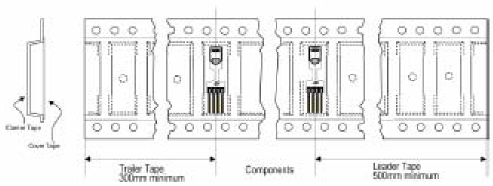


Figure 16 Tape configuration and unit orientation

5.2.3 Soldering Information[2]

Standard wave SHT7x soldering ovens may be used at maximum 235 °C for 20 seconds.
For manual soldering contact time must be limited to 5 seconds at up to 350 °C.
After wave soldering the devices should be stored at >74 %RH for at least 24 h to allow the polymer to rehydrate.
Please consult the application note "Soldering procedure" for more information.

[1] Other packaging options may be available on request.
[2] For maximum accuracy do not solder SHT75!

6 Revision history

Date	Version	Page(s)	Changes
February 2002	Preliminary	1-9	First public release
June 2002	Preliminary		Added SHT7x information
March 2003	Final v2.0	1-9	Major remake, added application information etc. Various small modifications
	V2.01	1-9	Typos, Graph labeling
July 2004	V2.02	1-9	Improved specifications, added SF1 information, improved wording
April 2005	V2.03	1-2	Added SHT10 information
May 2005	V2.04	1-9	Changed company address

The latest version of this document and all application notes can be found at:
www.sensirion.com/humidity

7 Important Notices

7.1 Warning, personal injury

Do not use this product as safety or emergency stop devices or in any other application where failure of the product could result in personal injury. Failure to comply with these instructions could result in death or serious injury.

Should buyer purchase or use SENSIRION AG products for any such unintended or unauthorized application, Buyer shall indemnify and hold SENSIRION AG and its officers, employees, subsidiaries, affiliates and distributors harmless against all claims, costs, damages and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if such claim alleges that SENSIRION AG was negligent regarding the design or manufacture of the part.

7.2 ESD Precautions

The inherent design of this component causes it to be sensitive to electrostatic discharge (ESD). To prevent ESD-induced damage and/or degradation, take normal ESD precautions when handling this product.
See application note "ESD, Latchup and EMC" for more information.

7.3 Warranty

SENSIRION AG makes no warranty, representation or guarantee regarding the suitability of its product for any particular purpose, nor does SENSIRION AG assume any liability arising out of the application or use of any product or circuit and specifically disclaims any and all liability, including without limitation consequential or incidental damages. "Typical" parameters can and do vary in different applications. All operating parameters, including "Typical" must be validated for each customer applications by customer's technical experts.

SENSIRION AG reserves the right, without further notice, to change the product specifications and/or information in this document and to improve reliability, functions and design.

Headquarters and Sales Office

SENSIRION AG
Laubisrütistr. 50
CH-8712 Stäfa ZH
Switzerland

Phone: + 41 (0)44 306 40 00
Fax: + 41 (0)44 306 40 30
e-mail: info@sensirion.com
http://www.sensirion.com/

Sensirion humidity sensors are available from:

find your local representative at:
www.sensirion.com/reps

Anexo C. Hojas de datos de circuitos integrados utilizados

En este anexo se presentan las especificaciones de los circuitos integrados[8] utilizados en la implementación del Medidor y detector de humedad relativa. Para mayor información referirse a las hojas de datos del fabricante.

[8] Tomado directamente de la hoja de datos del fabricante.

C1. MAX232

+5V-Powered, Multichannel RS-232 Drivers/Receivers

ABSOLUTE MAXIMUM RATINGS—MAX220/222/232A/233A/242/243

Supply Voltage (V_{CC}) ....-0.3V to +6V
Input Voltages
T_{IN}...-0.3V to (V_{CC} - 0.3V)
R_{IN} (Except MAX220) ....±30V
R_{IN} (MAX220)...±25V
T_{OUT} (Except MAX220) (Note 1) ....±15V
T_{OUT} (MAX220)...±13.2V
Output Voltages
T_{OUT}...±15V
R_{OUT}..-0.3V to (V_{CC} + 0.3V)
Driver/Receiver Output Short Circuited to GND.........Continuous
Continuous Power Dissipation (T_A = +70°C)
16-Pin Plastic DIP (derate 10.53mW/°C above +70°C)....842mW
18-Pin Plastic DIP (derate 11.11mW/°C above +70°C)....889mW
20-Pin Plastic DIP (derate 8.00mW/°C above +70°C) ..440mW
16-Pin Narrow SO (derate 8.70mW/°C above +70°C) ...696mW
16-Pin Wide SO (derate 9.52mW/°C above +70°C)......762mW
18-Pin Wide SO (derate 9.52mW/°C above +70°C)......762mW
20-Pin Wide SO (derate 10.00mW/°C above +70°C)....800mW
20-Pin SSOP (derate 8.00mW/°C above +70°C) 640mW
16-Pin CERDIP (derate 10.00mW/°C above +70°C).....800mW
18-Pin CERDIP (derate 10.53mW/°C above +70°C).....842mW
Operating Temperature Ranges
MAX2_ _AC_ _, MAX2_ _C_ _...............................0°C to +70°C
MAX2_ _AE_ _, MAX2_ _E_ _ ....-40°C to +85°C
MAX2_ _AM_ _, MAX2_ _M_ _.......................-55°C to +125°C
Storage Temperature Range ....-65°C to +160°C
Lead Temperature (soldering, 10s) ....+300°C

Note 1: Input voltage measured with T_{OUT} in high-impedance state, $\overline{SHDN}$ or V_{CC} = 0V.
Note 2: For the MAX220, V+ and V- can have a maximum magnitude of 7V, but their absolute difference cannot exceed 13V.

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS—MAX220/222/232A/233A/242/243

(V_{CC} = +5V ±10%, C1–C4 = 0.1µF, MAX220, C1 = 0.047µF, C2–C4 = 0.33µF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
RS-232 TRANSMITTERS						
Output Voltage Swing	All transmitter outputs loaded with 3kΩ to GND		±5	±8		V
Input Logic Threshold Low				1.4	0.8	V
Input Logic Threshold High	All devices except MAX220		2	1.4		V
	MAX220: V_{CC} = 5.0V		2.4			
Logic Pull-Up/Input Current	All except MAX220, normal operation			5	40	µA
	$\overline{SHDN}$ = 0V, MAX222/242, shutdown, MAX220			±0.01	±1	
Output Leakage Current	V_{CC} = 5.5V, $\overline{SHDN}$ = 0V, V_{OUT} = ±15V, MAX222/242			±0.01	±10	µA
	V_{CC} = $\overline{SHDN}$ = 0V, V_{OUT} = ±15V			±0.01	±10	
Data Rate				200	116	kbps
Transmitter Output Resistance	V_{CC} = V+ = V- = 0V, V_{OUT} = ±2V		300	10M		Ω
Output Short-Circuit Current	V_{OUT} = 0V		±7	±22		mA
RS-232 RECEIVERS						
RS-232 Input Voltage Operating Range					±30	V
RS-232 Input Threshold Low	V_{CC} = 5V	All except MAX243 $R2_{IN}$	0.8	1.3		V
		MAX243 $R2_{IN}$ (Note 2)	-3			
RS-232 Input Threshold High	V_{CC} = 5V	All except MAX243 $R2_{IN}$		1.8	2.4	V
		MAX243 $R2_{IN}$ (Note 2)		-0.5	-0.1	
RS-232 Input Hysteresis	All except MAX243, V_{CC} = 5V, no hysteresis in shdn.		0.2	0.5	1	V
	MAX243			1		
RS-232 Input Resistance			3	5	7	kΩ
TTL/CMOS Output Voltage Low	I_{OUT} = 3.2mA			0.2	0.4	V
TTL/CMOS Output Voltage High	I_{OUT} = -1.0mA		3.5	V_{CC} - 0.2		V
TTL/CMOS Output Short-Circuit Current	Sourcing V_{OUT} = GND		-2	-10		mA
	Shrinking V_{OUT} = V_{CC}		10	30		

ELECTRICAL CHARACTERISTICS—MAX220/222/232A/233A/242/243 (continued)

(V_{CC} = +5V ±10%, C1–C4 = 0.1µF, MAX220, C1 = 0.047µF, C2–C4 = 0.33µF, $T_A = T_{MIN}$ to T_{MAX}, unless otherwise noted.)

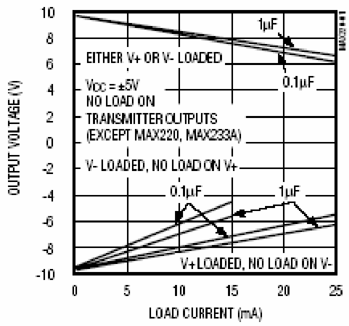
PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
TTL/CMOS Output Leakage Current	$\overline{SHDN} = V_{CC}$ or $\overline{EN} = V_{CC}$ ($\overline{SHDN}$ = 0V for MAX222), $0V \le V_{OUT} \le V_{CC}$			±0.05	±10	µA
$\overline{EN}$ Input Threshold Low	MAX242			1.4	0.8	V
$\overline{EN}$ Input Threshold High	MAX242		2.0	1.4		V
Operating Supply Voltage			4.5		5.5	V
V_{CC} Supply Current ($\overline{SHDN} = V_{CC}$), Figures 5, 6, 11, 19	No load	MAX220		0.5	2	mA
		MAX222/232A/233A/242/243		4	10	
	3kΩ load both inputs	MAX220		12		
		MAX222/232A/233A/242/243		15		
Shutdown Supply Current	MAX222/242	T_A = +25°C		0.1	10	µA
		T_A = 0°C to +70°C		2	50	
		T_A = -40°C to +85°C		2	50	
		T_A = -55°C to +125°C		35	100	
$\overline{SHDN}$ Input Leakage Current	MAX222/242				±1	µA
$\overline{SHDN}$ Threshold Low	MAX222/242			1.4	0.8	V
$\overline{SHDN}$ Threshold High	MAX222/242		2.0	1.4		V
Transition Slew Rate	C_L = 50pF to 2500pF, R_L = 3kΩ to 7kΩ, V_{CC} = 5V, T_A = +25°C, measured from +3V to -3V or -3V to +3V	MAX222/232A/233A/242/243	6	12	30	V/µs
		MAX220	1.5	3	30	
Transmitter Propagation Delay TLL to RS-232 (Normal Operation), Figure 1	t_{PHLT}	MAX222/232A/233A/242/243		1.3	3.5	µs
		MAX220		4	10	
	t_{PLHT}	MAX222/232A/233A/242/243		1.5	3.5	
		MAX220		5	10	
Receiver Propagation Delay RS-232 to TLL (Normal Operation), Figure 2	t_{PHLR}	MAX222/232A/233A/242/243		0.5	1	µs
		MAX220		0.6	3	
	t_{PLHR}	MAX222/232A/233A/242/243		0.6	1	
		MAX220		0.8	3	
Receiver Propagation Delay RS-232 to TLL (Shutdown), Figure 2	t_{PHLS}	MAX242		0.5	10	µs
	t_{PLHS}	MAX242		2.5	10	
Receiver-Output Enable Time, Figure 3	t_{ER}	MAX242		125	500	ns
Receiver-Output Disable Time, Figure 3	t_{DR}	MAX242		160	500	ns
Transmitter-Output Enable Time ($\overline{SHDN}$ Goes High), Figure 4	t_{ET}	MAX222/242, 0.1µF caps (includes charge-pump start-up)		250		µs
Transmitter-Output Disable Time ($\overline{SHDN}$ Goes Low), Figure 4	t_{DT}	MAX222/242, 0.1µF caps		600		ns
Transmitter + to - Propagation Delay Difference (Normal Operation)	$t_{PHLT} - t_{PLHT}$	MAX222/232A/233A/242/243		300		ns
		MAX220		2000		
Receiver + to - Propagation Delay Difference (Normal Operation)	$t_{PHLR} - t_{PLHR}$	MAX222/232A/233A/242/243		100		ns
		MAX220		225		

Note 3: MAX243 $R2_{OUT}$ is guaranteed to be low when $R2_{IN}$ is ≥ 0V or is floating.

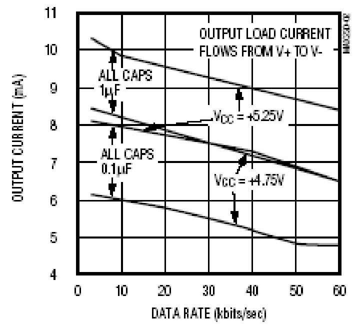
Typical Operating Characteristics

MAX220/MAX222/MAX232A/MAX233A/MAX242/MAX243

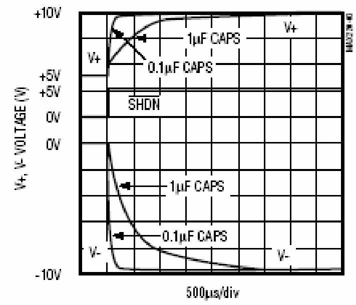
OUTPUT VOLTAGE vs. LOAD CURRENT



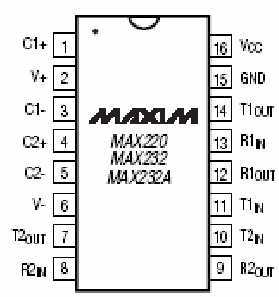
AVAILABLE OUTPUT CURRENT vs. DATA RATE



MAX222/MAX242 ON-TIME EXITING SHUTDOWN



TOP VIEW



DIP/SO

CAPACITANCE (μF)					
DEVICE	C1	C2	C3	C4	C5
MAX220	4.7	4.7	10	10	4.7
MAX232	1.0	1.0	1.0	1.0	1.0
MAX232A	0.1	0.1	0.1	0.1	0.1

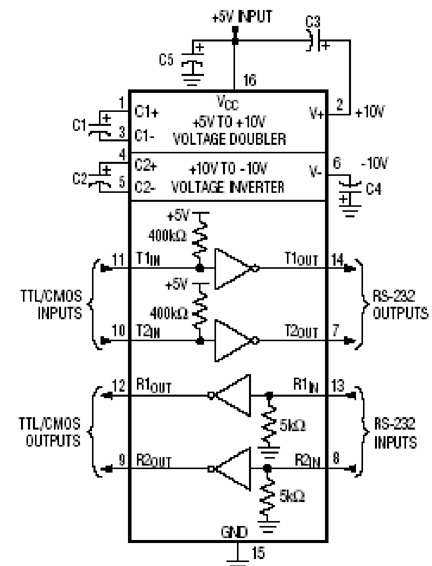


Figure 5. MAX220/MAX232/MAX232A Pin Configuration and Typical Operating Circuit

C2. Microcontrolador MC68HC908GP32

Chapter 1
General Description

1.1 Introduction

The MC68HC908GP32 is a member of the low-cost, high-performance M68HC08 Family of 8-bit microcontroller units (MCUs). All MCUs in the family use the enhanced M68HC08 central processor unit (CPU08) and are available with a variety of modules, memory sizes and types, and package types.

1.2 Features

For convenience, features have been organized to reflect:

- Standard features of the MC68HC908GP32
- Features of the CPU08

1.2.1 Standard Features of the MC68HC908GP32

- High-performance M68HC08 architecture optimized for C-compilers
- Fully upward-compatible object code with M6805, M146805, and M68HC05 Families
- 8-MHz internal bus frequency
- FLASH program memory security[1]
- On-chip programming firmware for use with host personal computer which does not require high voltage for entry
- In-system programming
- System protection features:
  - Optional computer operating properly (COP) reset
  - Low-voltage detection with optional reset and selectable trip points for 3.0-V and 5.0-V operation
  - Illegal opcode detection with reset
  - Illegal address detection with reset
- Low-power design; fully static with stop and wait modes
- Standard low-power modes of operation:
  - Wait mode
  - Stop mode
- Master reset pin and power-on reset (POR)
- 32 Kbytes of on-chip FLASH memory with in-circuit programming capabilities of FLASH program memory
- 512 bytes of on-chip random-access memory (RAM)
- Serial peripheral interface module (SPI)
- Serial communications interface module (SCI)

1. No security feature is absolutely secure. However, Freescale's strategy is to make reading or copying the FLASH difficult for unauthorized users.

- Two 16-bit, 2-channel timer interface modules (TIM1 and TIM2) with selectable input capture, output compare, and PWM capability on each channel
- 8-channel, 8-bit successive approximation analog-to-digital converter (ADC)
- BREAK module (BRK) to allow single breakpoint setting during in-circuit debugging
- Internal pullups on $\overline{IRQ}$ and $\overline{RST}$ to reduce customer system cost
- Clock generator module with on-chip 32-kHz crystal compatible PLL (phase-lock loop)
- Up to 33 general-purpose input/output (I/O) pins, including:
  - 26 shared-function I/O pins
  - Five or seven dedicated I/O pins, depending on package choice
- Selectable pullups on inputs only on ports A, C, and D. Selection is on an individual port bit basis. During output mode, pullups are disengaged.
- High current 10-mA sink/10-mA source capability on all port pins
- Higher current 15-mA sink/source capability on PTC0–PTC4
- Timebase module with clock prescaler circuitry for eight user selectable periodic real-time interrupts with optional active clock source during stop mode for periodic wakeup from stop using an external 32-kHz crystal
- Oscillator stop mode enable bit (OSCSTOPENB) in the CONFIG register to allow user selection of having the oscillator enabled or disabled during stop mode
- 8-bit keyboard wakeup port
- 5-mA maximum current injection on all port pins to maintain input protection
- 40-pin plastic dual-in-line package (PDIP), 42-pin shrink dual-in-line package (SDIP), or 44-pin quad flat pack (QFP)
- Specific features of the MC68HC908GP32 in 40-pin PDIP are:
  - Port C is only 5 bits: PTC0–PTC4
  - Port D is only 6 bits: PTD0–PTD5; single 2-channel TIM module
- Specific features of the MC68HC908GP32 in 42-pin SDIP are:
  - Port C is only 5 bits: PTC0–PTC4
  - Port D is 8 bits: PTD0–PTD7; dual 2-channel TIM modules
- Specific features of the MC68HC908GP32 in 44-pin QFP are:
  - Port C is 7 bits: PTC0–PTC6
  - Port D is 8 bits: PTD0–PTD7; dual 2-channel TIM modules

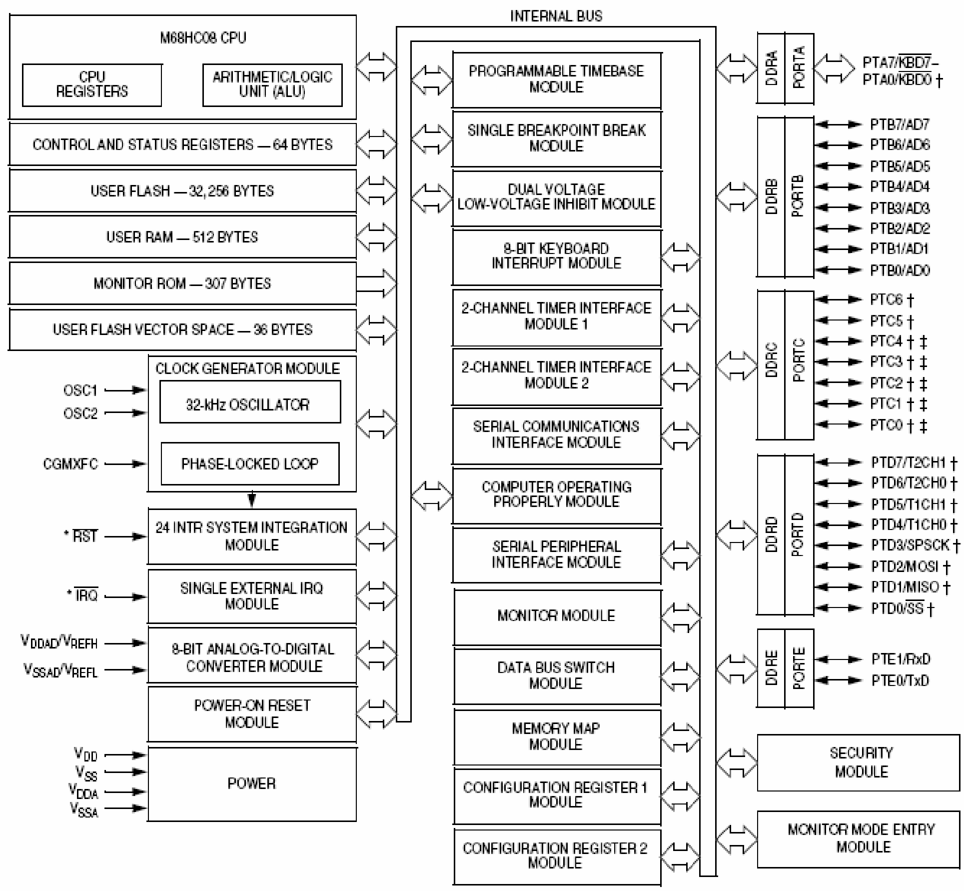
1.2.2 Features of the CPU08

Features of the CPU08 include:

- Enhanced HC05 programming model
- Extensive loop control functions
- 16 addressing modes (eight more than the HC05)
- 16-bit index register and stack pointer
- Memory-to-memory data transfers
- Fast 8 × 8 multiply instruction
- Fast 16/8 divide instruction
- Binary-coded decimal (BCD) instructions
- Optimization for controller applications
- Efficient C language support

1.3 MCU Block Diagram

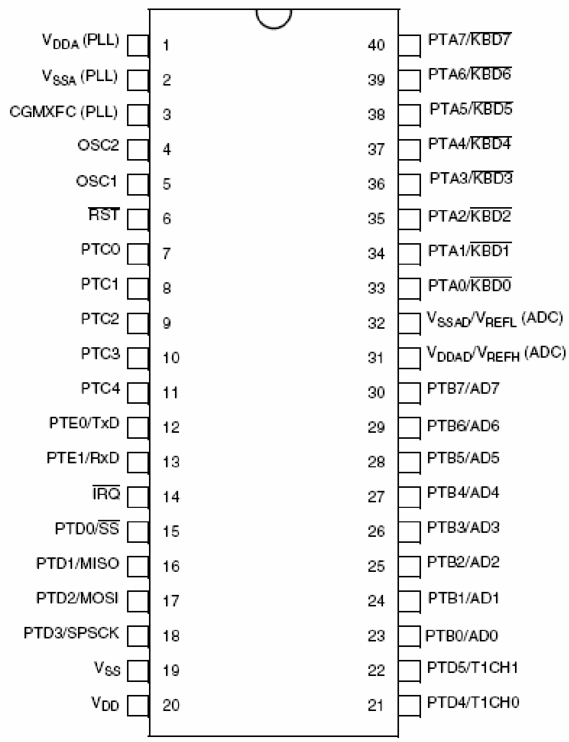
Figure 1-1 shows the structure of the MC68HC908GP32. Text in parentheses within a module block indicates the module name. Text in parentheses next to a signal indicates the module which uses the signal.



† Ports are software configurable with pullup device if input port.
‡ Higher current drive port pins
* Pin contains integrated pullup device

Figure 1-1. MCU Block Diagram

1.4 Pin Assignments



Pins Not Available on 40-Pin Package	Internal Connection
PTC5	Connected to ground
PTC6	Connected to ground
PTD6/T2CH0	Unconnected
PTD7/T2CH1	Unconnected

Figure 1-2. 40-Pin PDIP Pin Assignments

1.5 Pin Functions

Descriptions of the pin functions are provided here.

1.5.1 Power Supply Pins (V_{DD} and V_{SS})

V_{DD} and V_{SS} are the power supply and ground pins. The MCU operates from a single power supply.

Fast signal transitions on MCU pins place high, short-duration current demands on the power supply. To prevent noise problems, take special care to provide power supply bypassing at the MCU as Figure 1-5 shows. Place the C1 bypass capacitor as close to the MCU as possible. Use a high-frequency-response ceramic capacitor for C1. C2 is an optional bulk current bypass capacitor for use in applications that require the port pins to source high current levels.

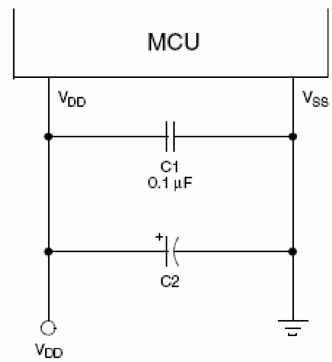


Figure 1-5. Power Supply Bypassing

1.5.2 Oscillator Pins (OSC1 and OSC2)

The OSC1 and OSC2 pins are the connections for the on-chip oscillator circuit. See Chapter 7 Clock Generator Module (CGMC).

1.5.3 External Reset Pin ($\overline{RST}$)

A logic 0 on the $\overline{RST}$ pin forces the MCU to a known startup state. $\overline{RST}$ is bidirectional, allowing a reset of the entire system. It is driven low when any internal reset source is asserted. This pin contains an internal pullup resistor. See Chapter 19 System Integration Module (SIM).

1.5.4 External Interrupt Pin ($\overline{IRQ}$)

$\overline{IRQ}$ is an asynchronous external interrupt pin. This pin contains an internal pullup resistor. See Chapter 12 External Interrupt (IRQ).

1.5.5 CGM Power Supply Pins (V_{DDA} and V_{SSA})

V_{DDA} and V_{SSA} are the power supply pins for the analog portion of the clock generator module (CGM). Connect the V_{DDA} pin to the same voltage potential as V_{DD}, and the V_{SSA} pin to the same voltage potential as V_{SS}. Decoupling of these pins should be as per the digital supply. See Chapter 7 Clock Generator Module (CGMC)

1.5.6 External Filter Capacitor Pin (CGMXFC)

CGMXFC is an external filter capacitor connection for the CGM. See Chapter 7 Clock Generator Module (CGMC)

1.5.7 ADC Power Supply/Reference Pins (V_{DDAD}/V_{REFH} and V_{SSAD}/V_{REFL})

V_{DDAD} and V_{SSAD} are the power supply pins for the analog-to-digital converter (ADC). Connect the V_{DDAD} pin to the same voltage potential as V_{DD}, and the V_{SSAD} pin to the same voltage potential as V_{SS}.

Decoupling of these pins should be as per the digital supply. See Chapter 5 Analog-to-Digital Converter (ADC).

V_{REFH} is the high reference supply for the ADC, and is internally connected to V_{DDAD}. V_{REFL} is the low reference supply for the ADC, and is internally connected to V_{SSAD}.

1.5.8 Port A Input/Output (I/O) Pins (PTA7/$\overline{KBD7}$–PTA0/$\overline{KBD0}$)

PTA7–PTA0 are general-purpose, bidirectional I/O port pins. Any or all of the port A pins can be programmed to serve as keyboard interrupt pins. See Chapter 16 Input/Output (I/O) Ports and Chapter 13 Keyboard Interrupt Module (KBI).

These port pins also have selectable pullups when configured for input mode. The pullups are disengaged when configured for output mode. The pullups are selectable on an individual port bit basis.

1.5.9 Port B I/O Pins (PTB7/AD7–PTB0/AD0)

PTB7–PTB0 are general-purpose, bidirectional I/O port pins that can also be used for analog-to-digital converter (ADC) inputs. See Chapter 16 Input/Output (I/O) Ports and Chapter 5 Analog-to-Digital Converter (ADC).

1.5.10 Port C I/O Pins (PTC6–PTC0)

PTC6–PTC0 are general-purpose, bidirectional I/O port pins. See Chapter 16 Input/Output (I/O) Ports. PTC5 and PTC6 are only available on 44-pin QFP package.

These port pins also have selectable pullups when configured for input mode. The pullups are disengaged when configured for output mode. The pullups are selectable on an individual port bit basis.

1.5.11 Port D I/O Pins (PTD7/T2CH1–PTD0/$\overline{SS}$)

PTD7–PTD0 are special-function, bidirectional I/O port pins. PTD0–PTD3 can be programmed to be serial peripheral interface (SPI) pins, while PTD4–PTD7 can be individually programmed to be timer interface module (TIM1 and TIM2) pins. See Chapter 22 Timer Interface Module (TIM), Chapter 20 Serial Peripheral Interface Module (SPI), and Chapter 16 Input/Output (I/O) Ports. PTD6 and PTD7 are only available on 42-SDIP and 44-pin QFP packages.

These port pins also have selectable pullups when configured for input mode. The pullups are disengaged when configured for output mode. The pullups are selectable on an individual port bit basis.

1.5.12 Port E I/O Pins (PTE1/RxD–PTE0/TxD)

PTE0–PTE1 are general-purpose, bidirectional I/O port pins. These pins can also be programmed to be serial communications interface (SCI) pins. See Chapter 18 Serial Communications Interface Module (SCI) and Chapter 16 Input/Output (I/O) Ports.

NOTE

Any unused inputs and I/O ports should be tied to an appropriate logic level (either V_{DD} or V_{SS}). Although the I/O ports of the MC68HC908GP32 • MC68HC08GP32 do not require termination, termination is recommended to reduce the possibility of static damage.

C3. Regulador de voltaje LM340T 7805

National Semiconductor

November 2004

LM340/LM78XX Series
3-Terminal Positive Regulators

General Description

The LM140/LM340A/LM340/LM78XXC monolithic 3-terminal positive voltage regulators employ internal current-limiting, thermal shutdown and safe-area compensation, making them essentially indestructible. If adequate heat sinking is provided, they can deliver over 1.0A output current. They are intended as fixed voltage regulators in a wide range of applications including local (on-card) regulation for elimination of noise and distribution problems associated with single-point regulation. In addition to use as fixed voltage regulators, these devices can be used with external components to obtain adjustable output voltages and currents.

Considerable effort was expended to make the entire series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

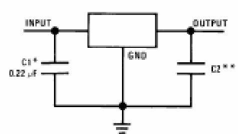
The 5V, 12V, and 15V regulator options are available in the steel TO-3 power package. The LM340A/LM340/LM78XXC series is available in the TO-220 plastic power package, and the LM340-5.0 is available in the SOT-223 package, as well as the LM340-5.0 and LM340-12 in the surface-mount TO-263 package.

Features

- Complete specifications at 1A load
- Output voltage tolerances of ±2% at $T_j = 25°C$ and ±4% over the temperature range (LM340A)
- Line regulation of 0.01% of V_{OUT}/V of ΔV_{IN} at 1A load (LM340A)
- Load regulation of 0.3% of V_{OUT}/A (LM340A)
- Internal thermal overload protection
- Internal short-circuit current limit
- Output transistor safe area protection
- P⁺ Product Enhancement tested

Typical Applications

Fixed Output Regulator

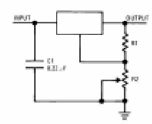


00778101

*Required if the regulator is located far from the power supply filter.

**Although no output capacitor is needed for stability, it does help transient response. (If needed, use 0.1 µF, ceramic disc).

Adjustable Output Regulator

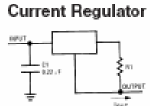


00778102

$V_{OUT} = 5V + (5V/R1 + I_Q)$ R2 5V/R1 > 3 I_Q,

load regulation (L_r) = [(R1 + R2)/R1] (L_r of LM340-5).

Current Regulator

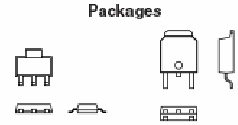


00778103

$$I_{OUT} = \frac{V2\text{-}3}{R1} + I_Q$$

ΔI_Q = 1.3 mA over line and load changes.

Comparison between SOT-223 and D-Pak (TO-252) Packages



00778138

Scale 1:1

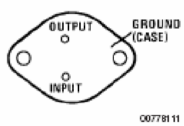
 www.national.com

Ordering Information

Package	Temperature Range	Part Number	Packaging Marking	Transport Media	NSC Drawing
3-Lead TO-3	-55°C to +125°C	LM140K-5.0	LM140K 5.0P+	50 Per Tray	K02A
		LM140K-12	LM140K 12P+	50 Per Tray	
		LM140K-15	LM140K 15P+	50 Per Tray	
	0°C to +125°C	LM340K-5.0	LM340K 5.0 7805P+	50 Per Tray	
		LM340K-12	LM340K 12 7812P+	50 Per Tray	
		LM340K-15	LM340K 15 7815P+	50 Per Tray	
3-lead TO-220	0°C to +125°C	LM340AT-5.0	LM340AT 5.0 P+	45 Units/Rail	T03B
		LM340T-5.0	LM340T5 7805 P+	45 Units/Rail	
		LM340T-12	LM340T12 7812 P+	45 Units/Rail	
		LM340T-15	LM340T15 7815 P+	45 Units/Rail	
		LM7808CT	LM7808CT	45 Units/Rail	
3-Lead TO-263	0°C to +125°C	LM340S-5.0	LM340S-5.0 P+	45 Units/Rail	TS3B
		LM340SX-5.0		500 Units Tape and Reel	
		LM340S-12	LM340S-12 P+	45 Units/Rail	
		LM340SX-12		500 Units Tape and Reel	
		LM340AS-5.0	LM340AS-5.0 P+	45 Units/Rail	
		LM340ASX-5.0		500 Units Tape and Reel	
4-Lead SOT-223	0°C to +125°C	LM340MP-5.0	N00A	1k Units Tape and Reel	MP04A
		LM340MPX-5.0		2k Units Tape and Reel	
Unpackaged Die	–55°C to 125°C	LM140KG-5 MD8		Waffle Pack or Gel Pack	DL069089
		LM140KG-12 MD8		Waffle Pack or Gel Pack	DL059093
		LM140KG-15 MD8		Waffle Pack or Gel Pack	DL059093
	0°C to +125°C	LM340-5.0 MDA		Waffle Pack or Gel Pack	DI074056
		LM7808C MDC		Waffle Pack or Gel Pack	DI074056

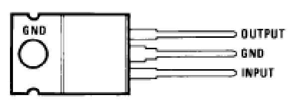
Connection Diagrams

TO-3 Metal Can Package (K)



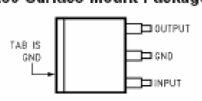
Bottom View
See Package Number K02A

TO-220 Power Package (T)



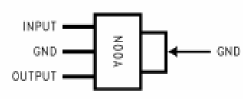
Top View
See Package Number T03B

TO-263 Surface-Mount Package (S)



Top View
See Package Number TS3B

3-Lead SOT-223



Top View
See Package Number MP04A

LM340 Electrical Characteristics (Note 4) (Continued)

$0°C \le T_J \le +125°C$ unless otherwise specified

Symbol	Output Voltage		5V			12V			15V			Units
	Input Voltage (unless otherwise noted)		10V			19V			23V			
	Parameter	Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
		$V_{MIN} \le V_{IN} \le V_{MAX}$	$(7.5 \le V_{IN} \le 20)$			$(14.8 \le V_{IN} \le 27)$			$(17.9 \le V_{IN} \le 30)$			V
		$I_O \le 500$ mA, $0°C \le T_J \le +125°C$			1.0			1.0			1.0	mA
		$V_{MIN} \le V_{IN} \le V_{MAX}$	$(7 \le V_{IN} \le 25)$			$(14.5 \le V_{IN} \le 30)$			$(17.5 \le V_{IN} \le 30)$			V
V_N	Output Noise Voltage	$T_A = 25°C$, 10 Hz $\le f \le$ 100 kHz		40			75			90		µV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	f = 120 Hz, $I_O \le 1A$, $T_J = 25°C$	62	80		55	72		54	70		dB
		f = 120 Hz, or $I_O \le 500$ mA, $0°C \le T_J \le +125°C$	62			55			54			dB
		$V_{MIN} \le V_{IN} \le V_{MAX}$	$(8 \le V_{IN} \le 18)$			$(15 \le V_{IN} \le 25)$			$(18.5 \le V_{IN} \le 28.5)$			V
R_O	Dropout Voltage	$T_J = 25°C$, $I_O = 1A$		2.0			2.0			2.0		V
	Output Resistance	f = 1 kHz		8			18			19		mΩ
	Short-Circuit Current	$T_J = 25°C$		2.1			1.5			1.2		A
	Peak Output Current	$T_J = 25°C$		2.4			2.4			2.4		A
	Average TC of V_{OUT}	$0°C \le T_J \le +125°C$, $I_O = 5$ mA		−0.6			−1.5			−1.8		mV/°C
V_{IN}	Input Voltage Required to Maintain Line Regulation	$T_J = 25°C$, $I_O \le 1A$	7.5			14.6			17.7			V

Note 1: Absolute Maximum Ratings are limits beyond which damage to the device may occur. Operating Conditions are conditions under which the device functions but the specifications might not be guaranteed. For guaranteed specifications and test conditions see the Electrical Characteristics.

Note 2: The maximum allowable power dissipation at any ambient temperature is a function of the maximum junction temperature for operation (T_{JMAX} = 125°C or 150°C), the junction-to-ambient thermal resistance (θ_{JA}), and the ambient temperature (T_A). $P_{DMAX} = (T_{JMAX} - T_A)/\theta_{JA}$. If this dissipation is exceeded, the die temperature will rise above T_{JMAX} and the electrical specifications do not apply. If the die temperature rises above 150°C, the device will go into thermal shutdown. For the TO-3 package (K, KC), the junction-to-ambient thermal resistance (θ_{JA}) is 39°C/W. When using a heatsink, θ_{JA} is the sum of the 4°C/W junction-to-case thermal resistance (θ_{JC}) of the TO-3 package and the case-to-ambient thermal resistance of the heatsink. For the TO-220 package (T), θ_{JA} is 54°C/W and θ_{JC} is 4°C/W. If SOT-223 is used, the junction-to-ambient thermal resistance is 174°C/W and can be reduced by a heatsink (see Applications Hints on heatsinking).

If the TO-263 package is used, the thermal resistance can be reduced by increasing the PC board copper area thermally connected to the package: Using 0.5 square inches of copper area, θ_{JA} is 50°C/W; with 1 square inch of copper area, $\theta_{JA}$is 37°C/W; and with 1.6 or more inches of copper area, θ_{JA} is 32°C/W.

Note 3: ESD rating is based on the human body model, 100 pF discharged through 1.5 kΩ.

Note 4: All characteristics are measured with a 0.22 µF capacitor from input to ground and a 0.1 µF capacitor from output to ground. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques ($t_w \le$ 10 ms, duty cycle $\le$ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

Note 5: Military datasheets are available upon request. At the time of printing, the military datasheet specifications for the LM140K-5.0/883, LM140K-12/883, and LM140K-15/883 complied with the min and max limits for the respective versions of the LM140. The LM140H and LM140K may also be procured as JAN devices on slash sheet JM38510/107.

Anexo D. Fotos de las pruebas realizadas

Figura D. 1. Foto pruebas realizadas

Fuente: Autores del Proyecto

Figura D. 2. foto pruebas realizadas

Fuente: Autores del Proyecto

Figura D. 3. Foto pruebas realizadas

Fuente: Autores del Proyecto

Figura D. 4. Foto pruebas realizadas

Fuente: Autores del Proyecto

Figura D. 5. Foto pruebas realizadas

Fuente: Autores del Proyecto

Figura D. 6. Foto pruebas realizadas

Fuente: Autores del Proyecto

Figura D. 7. Foto pruebas realizadas

Fuente: Autores del Proyecto

Figura D. 8. Foto pruebas realizadas

Fuente: Autores del Proyecto

Figura D. 9.Foto pruebas realizadas

Fuente: Autores del Proyecto

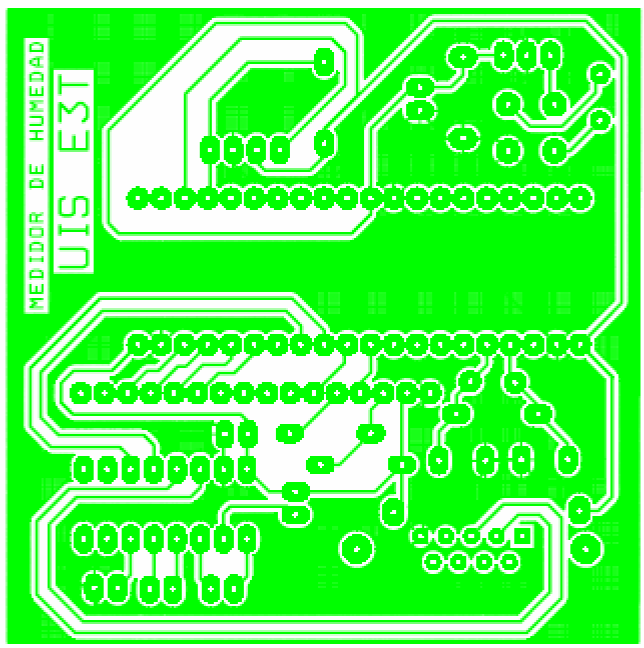
Figura D. 10.Foto pruebas realizadas

Fuente: Autores del Proyecto

Anexo E. Diseño del circuito impreso

El circuito impreso para el montaje del prototipo se realizó con el programa de diseño de PCB de ORCAD, en la siguiente figura encontramos el respectivo circuito.

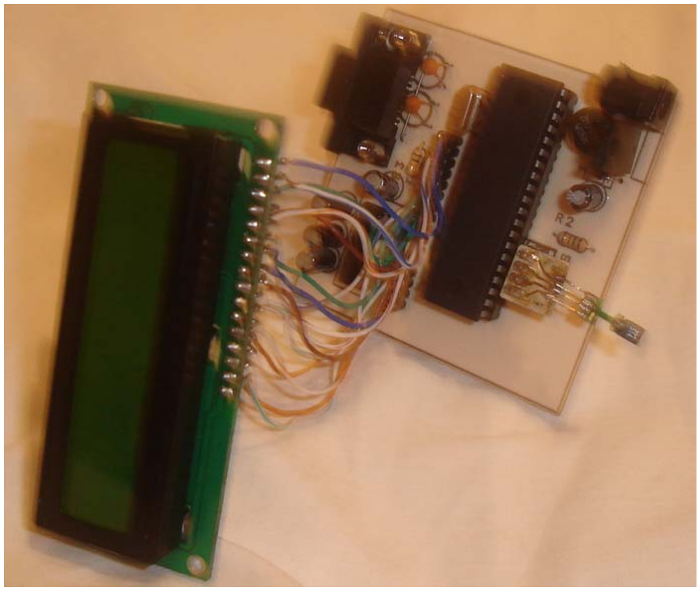
Figura E. 1. Circuito impreso del prototipo



Fuente: Autores del Proyecto

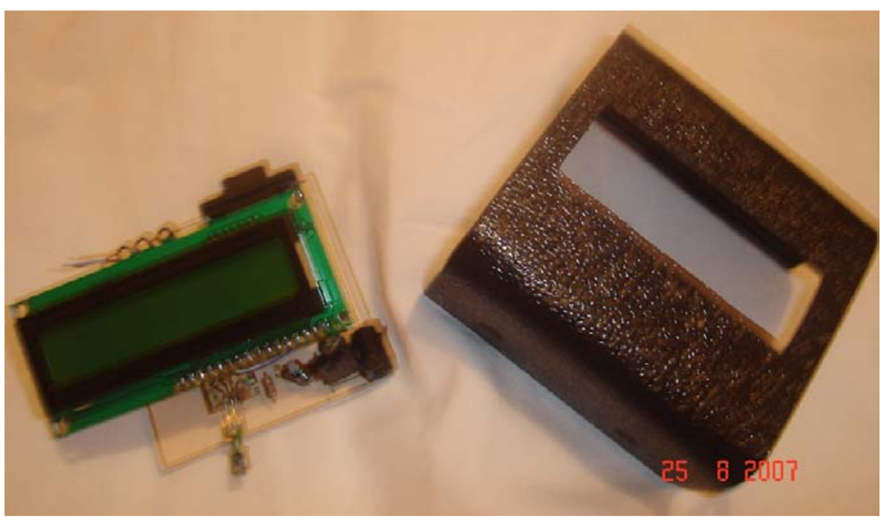
Anexo F. Fotos prototipo terminado

Figura F. 1. Foto prototipo ensamblado



Fuente: Autores del Proyecto

Figura F. 2. Foto prototipo Ensamblado y caja



Fuente: Autores del Proyecto

Figura F. 3. Foto prototipo terminado mostrando el sensor

Fuente: Autores del Proyecto

Figura F. 4. Foto prototipo terminado mostrando el conector de comunicación con el computador.

Fuente: Autores del Proyecto

Figura F. 5. Foto prototitpo terminado vista frontal

Fuente: Autores del Proyecto