Relative Humidity Measurement and Dehydrator Operation

Monitoring of transmission line pressure is standard at most sites. Unfortunately pressure alone does not ensure dehydrators are operating properly. Keeping the transmission lines dry is perhaps the most important antenna related preventive maintenance item we can perform on the ground. Sending wet air up the tower is a guarantee of trouble, especially at high power multiple carrier sites. Transmission line relative humidity is easily monitored, making moisture damage very easy to prevent. If the dehydrator is sending wet air to the antenna it should be shut down and replaced immediately. We can either use an inexpensive sensor to detect an early problem or wait for the antenna to fail.

The relative humidity of air inside a transmission line must be low enough to ensure water vapour does not condense during the coldest possible weather conditions. Moisture can create corrosion on metal surfaces and cause contamination on the surface of insulators. Line attenuation will increase as the surface corrodes. Contaminants could flow over the spiral insulator with the water. When the water evaporates it will leave behind a trace of material that will reduce the high voltage breakdown of the cable. At high power it could create arcing and result in catastrophic cable failure. Just one event in which water is allowed to accumulate on the copper surface of transmission line can cause serious damage.

Even on a summer day with the air temperature well above the dew point I've measured high voltage DC leakage in splitter cables due to the water vapour present. RF leakage current can destroy cables or antenna panels rendering the antenna system useless. The failure can cause extended outages resulting in extensive and expensive repairs.

Relative humidity

Relative humidity refers to the ratio of the moisture content of air compared to the saturated moisture level of air at the same temperature and pressure. It is usually stated as a percentage or %RH.

This site has an interesting explanation of relative humidity.
Relative Humidity - Relative to What? (Included at end of document)
http://www.shorstmeyer.com/wxfaqs/humidity/humidity.html

Relative humidity is largely dependent upon three items; temperature, pressure, and water vapor concentration.
If temperature increases while the other two remain constant, the %RH will decrease.
If pressure increases while the other two remain constant the %RH will increase.
If water vapor concentration increases while the other two remain constant, the %RH will increase.

Dew point

The amount of water vapour in the air at any given time is usually less than that required to saturate the air. If air is gradually cooled while maintaining constant pressure and moisture content its relative humidity will rise until it reaches 100%. The temperature at which the moisture content will saturate the air is called the dew point. If the air is cooled further, some of the moisture will condense. %RH will remain at 100% unless the temperature increases.

Pressure dew point

Because %RH will vary according to pressure the dew point will also vary. By measuring %RH at high pressure, the corresponding dew point at low pressure can be calculated. A measurement of 0.7%RH at 21C results in dew point of about -40C if the pressure remains constant. If the measurement was taken at 100PSI and the pressure reduced to 3PSI while maintaining a constant temperature of 21C the resulting %RH will be 0.14%. The dew point will be about -55C.

Bottled nitrogen (N50) is specified to have a maximum water vapour content of 10ppm. At 2200psi the dew point inside the bottle is only about -16C. Once the air is released and regulated to 3psi the dew point will drop to about -59C. Always ensure nitrogen tanks are chained or strapped securely to prevent tipping and that the top caps are in place when not in use.

Dew point measurement

Dew point is difficult to measure directly. A chilled mirror hygrometer provides a direct reading but is expensive and impractical. In order to provide an inexpensive and reasonably accurate indication, dew point is calculated based on %RH and sample air temperature at a constant pressure. A typical dew point monitor is actually a %RH meter calibrated to display an equivalent calculated dew point. We do a similar type conversion with RF wattmeters by measuring the RF voltage and indicating an equivalent power level on the meter scale.

Transmission lines are pressurized at room temperature and the air is sent outdoors to the tower where the temperature can drop considerably. By measuring the %RH at the dehydrator output, the expected dew point outside on the tower can be calculated.

Be careful when allowing air from transmission lines to purge back into the building and over the sensor. During winter the air could be very cold and thus the measured %RH may be considerably higher than expected. This is entirely normal. For reliable interpretation or measurement of dew point, both air temperature and %RH are needed.

Dew point calculation

The US National Weather Service, Hydrometeorological Prediction Center, uses the following equations. Check the html source code to extract the equations.

http://www.hpc.ncep.noaa.gov/html/dewrh.shtml

Es = 6.11* 10^ (7.5*T/(237.7+T))
E = 6.11* 10^ (7.5*DP/(237.7+DP))
RH = (E/Es)*100

Es = Saturation vapour pressure E = Actual vapour pressure
RH = % Relative humidity DP = Dew point C
T = Air temperature C

Place the equations for E and Es in the RH equation and the only variables that remain are T and DP. Solve the equation for DP and this formula can be used for calculating dew point based on %RH and air temperature. It works well in Excel.

DP=237.7*LOG_{10}(0.01*RH*10^(7.5*T/(237.7+T)))/(7.5-LOG_{10}(0.01*RH*10^(7.5*T/(237.7+T))))

It can be simplified by using an intermediate calculation. I use this in my TI83+ calculator.
A = 0.01*R*10^(7.5*T/(237.7+T)) (Single letters replace RH and DP for the TI83+)
D = 237.7*LOG_{10}(A)/(7.5-LOG_{10}(A))

Assume the line pressure remains constant. This table converts %RH to expected dew point at various sample air temperatures using this formula. Knowledge of the sample air temperature is critical for an accurate dew point calculation.

Here is another set of equations based upon another model.
http://andrew.rsmas.miami.edu/bmcnoldy/Humidity.html
* Spreadsheet-ready equations for each unknown in terms of the two knowns:
RH: =100*(EXP((17.625*TD)/(243.04+TD))/EXP((17.625*T)/(243.04+T)))
TD: =243.04*(LN(RH/100)+((17.625*T)/(243.04+T)))/(17.625-LN(RH/100)-((17.625*T)/(243.04+T)))
T: =243.04*(((17.625*TD)/(243.04+TD))-LN(RH/100))/(17.625+LN(RH/100)-((17.625*TD)/(243.04+TD)))
(• replace "T", "TD", and "RH" with your actual cell references)
(• T and TD inputs/outputs to the equations are in Celcius)

	Dew point at sample air temperature			
%RH	@15C	@21C	@27C	@32C
50	4.7C	10.2C	15.7C	20.3C
40	1.5C	6.9C	12.2C	16.7C
30	-2.4C	2.8C	7.9C	12.2C
20	-7.8C	-2.8C	2.1C	6.2C
15	-11.4	-6.6C	-1.9C	2.1C
10	-16.4C	-11.7C	-7.2C	-3.4C
5.0	-24.3C	-20.1C	-15.9C	-12.4C
4.0	-26.8C	-22.6C	-18.5C	-15.1C
3.0	-29.9C	-25.8C	-21.8C	-18.5C
2.0	-34.0C	-30.1C	-26.3C	-23.1C
1.0	-40.8C	-37.2C	-33.6C	-30.6C
0.75	-43.5C	-40.0	-36.5C	-33.6C
0.5	-47.2C	-43.7C	-40.4C	-37.6C

Moisture calculators
I use PhyCalc for most moisture related calculations. It can determine change in pressure dew points, moisture concentration, % relative humidity, and many other items. It is by far the most versatile moisture related software I've found. If you plan to get a humidity calculator this one should be at the top of the list. It can be downloaded for free from PhyMetrix web site.

http://www.phymetrix.com/Software.htm
Download moisture calculator

Environment Canada suggested the Vaisala calculator. Here is the link:
http://www.vaisala.com/humiditycalculator.html

The results will vary slightly due to the use of different humidity models and formulas, particularly at very low levels of %RH. Here are some other useful online calculators that are available.

Pressure dew point conversion
http://www.howelllabs.com/dew_point_conversion.xls

Weather conversion calculator
http://www.eustis.army.mil/weather/Weather_Products/wxconversions.htm

Relative Humidity Measurement

Many dehydrators use an indicating silica gel to display proper operation. It is a bead or granule that has been washed with a concentration of cobalt chloride (a heavy metal salt). The cobalt chloride is a deep blue color when dry and turns from blue to violet to pink as it becomes saturated with moisture. The desiccant beads are an inexpensive but unfortunately unreliable indicator of dehydrator performance. The beads will gradually start to change color from blue to violet at about 10%RH and then to pink and eventually white at about 50%RH. The dew point for 10%RH is about -10C. 50%RH dew point is about 10C. By the time a gradual color change is noticed the lines will be filled with wet air. It cannot be monitored remotely.

A more reliable approach is to use the remote control system at each transmitter site to continuously monitor %RH of air supplied by the dehydrators and to use a sensitive dew point monitor as part of routine maintenance or following drying system repair.

I have experimented with Honeywell HIH4000 and Ohmic Instruments HS-00-1 sensors. The HIH4000 easily connects to the remote control system. The HS-00-1 could be used for confirmation during preventive maintenance or following dehydrator rebuild. Spec sheets are included near the end of this document.

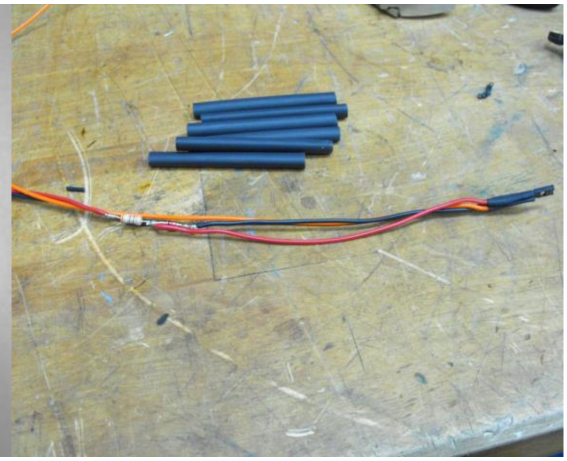
Other sensors
The Davicom RHS-1 relative humidity sensor uses a HM1500LF sensor. Its measurement range is 10-95%RH. It is meant for monitoring room air or from a mechanical cooling system, not air from a dehydrator. Its price is $130. Notice the coefficients are similar to those for the HIH4000.
http://www.davicom.com/_catalogue/cat/17/id/80

The HM1520LF sensor is optimized for 0-20%RH measurement. It may be another useful sensor for monitoring dehydrator systems. It is available at Digi-Key for about $60.
http://ca.digikey.com/1/1/2608453-sensor-rh-dedicated-humidity-hm1520lf.html
http://www.meas-spec.com/downloads/HM1520LF.pdf

Other sensors are available to provide simultaneous temperature and %RH readings but they use a serial data output. This is more difficult to connect to a remote monitoring system analog input.

1. Honeywell HIH4000

This is a wide range sensor 0-99%RH that uses a +5VDC supply. It is used in the $300 humidity option in several Andrew dehydrators. It is the active element (relabeled HC610) in the Ohmic Instruments ($1000) AMM-15 Airline Moisture Monitor.
http://ohmicinstruments.com/pdf/Manuals/HC-610man.pdf

Remove the case and microprocessor from the AMM-15 dew point monitor and mount the HIH4000 sensor in a brass Tee fitting. The site remote control system can supply the smarts to replace the microprocessor for continuous monitoring. The total cost is less than $25. In the picture above, the black and orange wires connect directly to the sensor. The red wire has an inline 5V regulator consisting of a 390 ohm resistor and a Zener diode sealed under heat shrink tubing. It can then be powered by the site 12VDC power supply or a 9V battery. Operating current is less than 20mA. A 100kohm terminating resistor across the RTU analog input terminals is suggested.

Parts list, %RH sensor		
Honeywell HIH4000 sensor		$15.62
¼" Tee connector, 2203P-04		$3.65
2x ¼" NPT male to 3/8" compression fitting 68C-06-04	2x $1.94	$3.88
¼" NPT dome connector RD07AA		$1.40
1N4733 5.1V zener		
390 ohm resistor		
Hookup wire		
Heat shrink tubing		
Total		$24.55

I've used the HIH4000-001 version. It has the pins spread for 0.1 inch spacing. It does not come with a calibration sheet. Sensor calibration will be described below.

There are also slight variances in each HIH4000 sensor. It is also sensitive to supply voltage changes. Each 5V zener diode will provide a slightly different output voltage. For these reasons, each assembled sensor will supply a slightly different 0%RH output voltage. This makes calibration more critical when operating at very low %RH levels. For optimal measurements the 0%RH reference must be determined experimentally.

This problem is not exclusive to the HIH4000. It also applies to the MPX5100 pressure sensor, temperature sensors, and most other sensors being operated near their absolute limits.

The Ohmic Instruments AMM-15 dew point meter is calibrated to the specific sensor installed and must be returned to the factory for calibration if the sensor is replaced.

Similarly, each RTU will have a slightly different ADC reference voltage. Using the RTU voltages during calibration will factor its ADC errors into the VTS coefficients. This will provide better measurement accuracy compared to an external voltmeter for determining the zero reference.

Liquid Air N50 grade nitrogen (<10ppm water vapour) is about 0.05%RH at 3PSI and 21C. This is a reasonable and readily available 0%RH reference. Connect the sensor to the RTU and allow nitrogen to flow past the sensor to pressurize the lines. Leave it for about 30 minutes to ensure all moisture has purged from the surface. Set the VTS coefficients to A=0 B=1 C=0 D=0. Display two decimal places in order to measure the actual voltage reading. Monitor for the minimum voltage. This will be the 0%RH reference voltage. It should be between about 780mV and 850mV.

The slope of the response curve is needed for measurements above 0%RH. Unfortunately I have only a single calibration point. At least one more point is needed to determine slope precisely. As a compromise, 29mV/%RH seems to be a reasonable value. %RH can be calculated.
%RH = (V - 780mV) / 29mV where V is the measured sensor output voltage and 780mV is the measured 0%RH voltage from calibration above.

Using quadratic formula, %RH = $Ax^2 + Bx + C$, the following VTS coefficients are used.
A=0 B= 1 / 0.029 = 34.48 C= -0.780 / 0.029 = -26.89

Alternately, C = - B x (zero value), -34.48 x 0.78 = -26.89

Where 0.029V / %RH is the response slope, and 0.780V is the 0%RH calibration.
Install the sensor, select B=34.48 and tweak the C coefficient to show 0%RH with nitrogen. Monitor for a few minutes to ensure the %RH value does not become negative.

You can also set C=0 and monitor the minimum VTS reading with nitrogen or a known dry air source. The highest %RH reading will be the -C coefficient.

Most broadcast sites have relatively high levels of RF inside the building. Bypass capacitors should be installed across the power and analog sensing lines to help stabilize readings. Two 0.1uF capacitors on each end seem to work well. Shielded wire with the shield connected at the remote control system end assists as well.

Don’t be scared by the nitrogen calibration. A simplified mode of operation could be to monitor for an increase of %RH. Calibrate with a known good dehydrator and monitor the output voltage for a rise of 150mVDC. This will indicate an increase of about 5%RH and can be used to trigger an alarm. The absolute value is less important than the measured increase. Andrew dehydrators set the sample trip point at 1.0VDC to alarm at about 7.5%RH. Using the MARC system to monitor for a sensor output voltage above 1.0VDC would provide an early warning that the transmission lines are wet. This is considerably better (and easier to fix) than detecting a problem when transmitters shut off due to VSWR caused by arcing or water filled lines.

The sensor should be placed inline immediately following the dehydrator. It should be the first item that moisture, oil, or other contamination touches. A contaminated sensor can be cleaned or replaced. A new part isn’t expensive and is much easier to replace than antenna or transmission line components.

A valid question is whether we really need accuracy to within 1%RH or the ability measure dew point precisely to within ±1C. A properly operating dehydrator will produce air with less than 1%RH. The dew point will be lower than -40C. A failure will cause the %RH to rise, even if adequate output pressure is maintained. The rise in %RH is what we need to detect. A failed dehydrator will often produce air with about 20%RH. The sensor voltage will be about 1.35VDC.

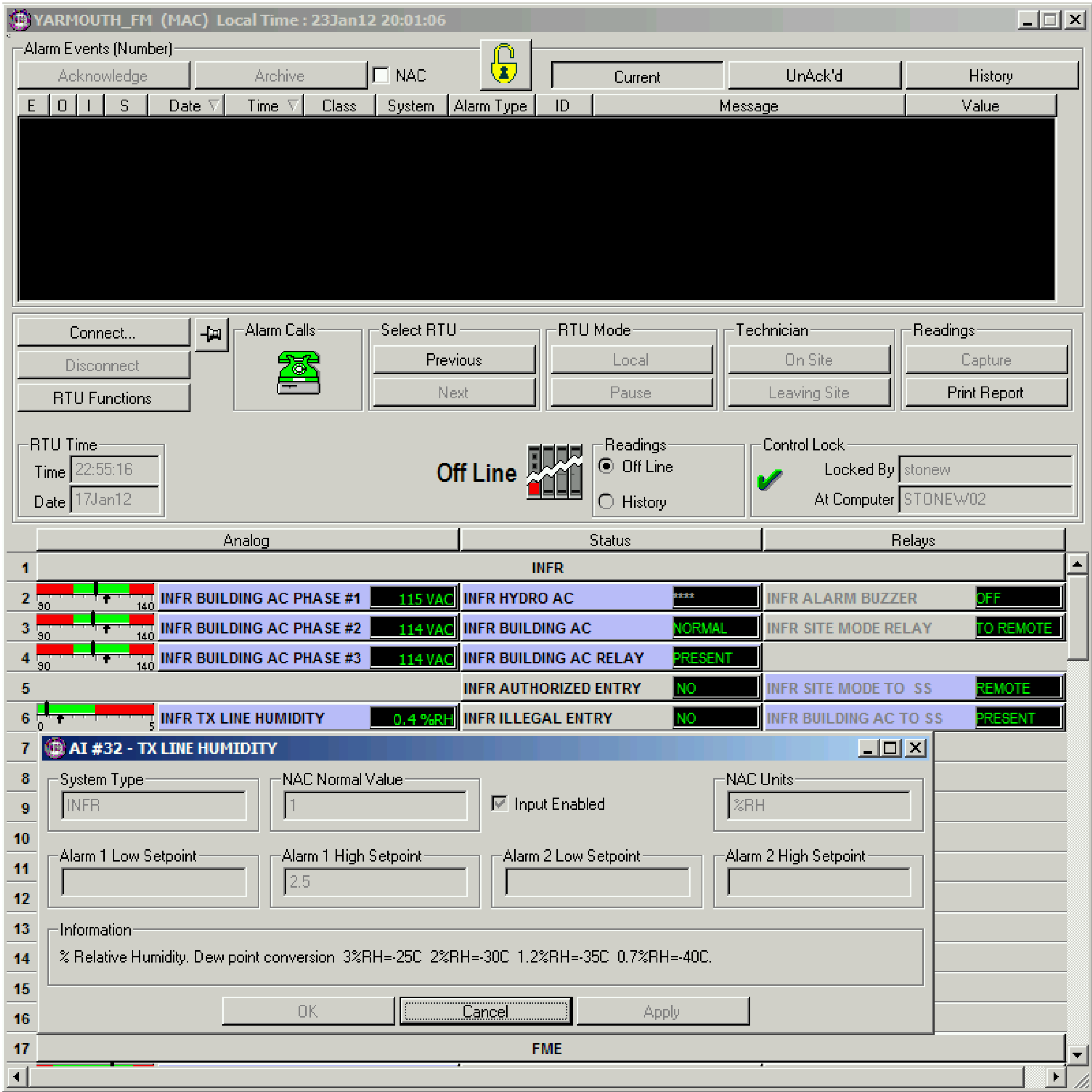
As a wide range sensor the HIH4000 isn't specifically designed for our requirements of monitoring near 0%RH. However, if its shortcomings are known and understood the results can be used. These sensors have been implemented in expensive dew point monitors using the calibration techniques described. There is no reason we can not use them in a similar manner. Constant monitoring for an increase in %RH will provide an immediate indication that something has failed. You can then visit the site to determine what has happened before condensation causes damage. It is an inexpensive and reliable sensor that can detect early failures within dehydrating systems. A $25 investment can easily save many thousands of dollars by providing an early alert of moisture. Compare to the expense of replacing a transmission line and an extended outage. A failed antenna is 100% reliable at eventually detecting a failed drying system, but considerably more work and effort to put back together.

The sensor also needs a slight flow of air. Still air, even if perfectly dry may cause the output voltage to increase. I've seen this even after purging with pure nitrogen and closing the valves. I'm uncertain of the reason for this, but it has been suggested that plastic air line could have some effect on the air. Some dew point monitor manufacturers recommend against using plastic air lines and others suggest opening a valve to allow a small amount air to escape over the sensor. The use of copper lines may improve the problem but is a less than practical solution in many cases.

Look closely at the plastic fitting that holds the HIH4000 sensor. It is meant for sealing wires entering an electrical enclosure. Normal operating pressure would be 0psi. It is used in the Andrew dehydrators up to about 7PSI. It is perfectly acceptable at 3PSI for normal transmission line pressure. I have one monitoring air at 30-50PSI. If you plan to install the sensor at higher pressures another approach may be required.

Install a sensor and monitor the transmission line humidity anywhere you have a dehydrator. I've used crimp connectors to attach terminals at each wire end. A 9V battery terminal allows the sensor to be battery powered, and a multimeter displays sensor output voltage. This creates a super simple and effective dehydrator test tool. Measure the voltage on the orange wire during routine maintenance visits. It should always be less than 1.0V.

If there is money to burn there are many other dew point monitors using the HIH4000 as the active sensing element that claim to measure down to -40C. At $1000 per system you will need very deep pockets. The remote control system is usually capable of monitoring the sensor output voltage and triggering an alarm at a predetermined level. That is all we need.


YARMOUTH_FM (MAC) Local Time : 23Jan12 20:01:06
Alarm Events (Number)
Acknowledge
Archive
NAC
Current
UnAck'd
History
E O I S Date Time Class System Alarm Type ID Message Value
Connect...
Disconnect
RTU Functions
Alarm Calls
Select RTU
Previous
Next
RTU Mode
Local
Pause
Technician
On Site
Leaving Site
Readings
Capture
Print Report
RTU Time
Time 22:55:16
Date 17Jan12
Off Line
Readings
Off Line
History
Control Lock
Locked By stonew
At Computer STONEW02
Analog
Status
Relays
INFR
INFR BUILDING AC PHASE #1 115 VAC
INFR BUILDING AC PHASE #2 114 VAC
INFR BUILDING AC PHASE #3 114 VAC
INFR TX LINE HUMIDITY 0.4 %RH
INFR HYDRO AC
INFR BUILDING AC NORMAL
INFR BUILDING AC RELAY PRESENT
INFR AUTHORIZED ENTRY NO
INFR ILLEGAL ENTRY NO
INFR ALARM BUZZER OFF
INFR SITE MODE RELAY TO REMOTE
INFR SITE MODE TO SS REMOTE
INFR BUILDING AC TO SS PRESENT
AI #32 - TX LINE HUMIDITY
System Type
INFR
NAC Normal Value
1
Input Enabled
NAC Units
%RH
Alarm 1 Low Setpoint
Alarm 1 High Setpoint
2.5
Alarm 2 Low Setpoint
Alarm 2 High Setpoint
Information
% Relative Humidity. Dew point conversion 3%RH=-25C 2%RH=-30C 1.2%RH=-35C 0.7%RH=-40C.
OK
Cancel
Apply
FME

Honeywell HIH4000 Relative Humidity Sensor

Remote control setup 20 January 2010 - Warren Stone

Wiring

Orange	%RH analog output
Red	+12VDC supply with +5V regulator to sensor
Black	Ground

NAC Setup

Digital type select	Analog input
System type select	INFR
NAC Description	TX LINE HUMIDITY
RTU Description	TX LINE HUMIDITY
Alarm NAC View	Yes
Alarm Priority	Major
Alarm Schedule Select	None
RTN Priority	RTN
Information	%Relative Humidity. Dew point conversion 3%RH=-25C 2%RH=-30C 1.2%RH=-35C 0.7%RH=-40C

	Davicom MAC	Electralert Site Sentry
MARC Scaling		
Bar Scale Low	0	0
Bar Scale High	5	5
NAC Normal Value	1	1
NAC Scaling Required	No	Yes
Coefficient A	0	0
Coefficient B	1	34.48
Coefficient C	0	-26.9
Coefficient D	0	0
NAC Units	%RH	%RH
NAC Decimal places	1	1

RTU Scaling

Normal Value	0
Input Range	10
Coefficient A	0
Coefficient B	34.48
Coefficient C	-26.9
Coefficient D	0
NAC Units	%RH

Alarm General

Input Enabled	Yes	Active Notification	Yes
Active Notification	Yes	Data Logging	Yes
RTN Notification	Yes		
Active Delay	0:01:00	0:01:00	
RTN Delay	0:01:00	0:01:00	
Change Coeff	1		

Alarm 1

Alarm 2 High Setpoint	2	0.840 (calculated for 2%RH)	
Alarm 1 High Hysteresis	0.5	0.015	
Level 1 Action	MAJ	Alarm Low Setpoint	0

2. Dunmore sensor

"One of the first mass-produced humidity sensors was the Dunmore type, developed by NIST in the 1940s and still in use today. It consists of a dual winding of palladium wire on a plastic cylinder that is then coated with a mixture of polyvinyl alcohol (binder) and either lithium bromide or lithium chloride. Varying the concentration of LiBr or LiCl results in very high-resolution sensors that cover humidity spans of 20%–40% RH. For very low RH control function in the 1%–2% RH range, accuracies of 0.1% can be achieved. Dunmore sensors are widely used in precision air conditioning controls to maintain the environment of computer rooms and as monitors for pressurized transmission lines, antennas, and waveguides used in telecommunications."
http://www.sensorsmag.com/sensors/humidity-moisture/choosing-a-humidity-sensor-a-review-three-technologies-840

Caution: The sensor must be used with AC only. DC current will permanently damage the sensor. Never measure its resistance with a multimeter!

A Dunmore sensor can provide accurate measurement at very low levels of RH for dehydrator confirmation but is more difficult to work with and monitor remotely when compared to the HIH4000. It can be used to build a very simple and accurate dew point monitor capable of measurements well below -40C. During operation you can sometimes watch the dew point change gradually as the drying towers switch and purge.

I've assembled two simple prototype dew point monitors using model HS-00-1 Dunmore sensors provided by Ohmic Instruments. This version of the sensor is designed to measure as low as 0.5%RH or dew point -40.3 at 21C sample temperature. The sensor costs about $31.50US. Measurement is taken with an external digital voltmeter. A lookup table indicates the dew point. It is the ultimate KISS dew point monitor, but should rival any other in terms of sensitivity.

Two XLR connectors confirm operation of the transformer box. One has a jumper between pins 2 and 3. It should indicate an output voltage of 5.0VAC. The other uses a 10M resistor to display very close to 0.625mVAC for -40C dew point.

For further development I had started to design circuitry to provide an analog DC output for MARC, adjustable alarm output, sensor failure alert, and visual indication on an analog meter. Unfortunately due to time restraints and lack of support I was unable to continue. MARC analog and alarm outputs really are not needed with the HIH4000 option available.

The sensor creates a variable resistance according to %RH. Practical sensor resistance range is about 1kohms to 10Mohms. Through experimentation I've determined the upper resistance limit is about 44Mohms. The HS-00-1 sensor in the shop built dew point monitor will measure 10Mohms at 0.7%RH or about -40C dew point. The manufacturer says the sensor resistance becomes unstable beyond this point. Higher readings are likely meaningless, other than to indicate the dew point is considerably better than -40C.

The sensor has a long response time. It can take up to 30 minutes for a saturated sensor to provide accurate readings for very dry air. Measurements may not be immediately accurate if you start with a saturated sensor. Prior to taking measurements connect a source of known dry air, such as from a tank of nitrogen to purge all moisture from the sensor. This can be considered a confirmation of the sensor calibration. Allow the reading to stabilize before connecting the sensor to the air source. Don't merely connect a saturated sensor to a dehydrator and assume the air supplied is wet. Similarly do not compare readings from two dew point monitors if both start with wet sensors. The drying time of the sensors will vary and give conflicting readings.

During winter allow the sensor to warm up to room temperature if it's been stored in a truck overnight. When it is brought inside moisture may condense on the sensor and have to be purged prior to taking measurements. The calculations shown later assume 21C supply air temperature. A very cold sensor will indicate higher %RH.

Ideally the sensor should be connected to a spare air manifold output during storage. Otherwise it should be exposed to dry air to purge moisture from its surface and the air sample ports closed and capped to limit moisture leakage into the housing.

Dew point monitor design

Similar to that used with the HIH4000, the plastic fitting that holds the sensor is meant for sealing wires entering an electrical enclosure. It is perfectly acceptable at normal transmission line pressures but it should not be used at high pressure. If you plan to install the sensor at 100PSI another approach will be required. Newport Scientific sells a high pressure pipe fitting, part 6146A and matching cable, part 6020-72 that work very well.

As with other sensors, the Dunmore sensor measures % relative humidity. If the sample air temperature is known, the expected dew point temperature can be calculated.

The Ohmic Instruments manual for Dunmore sensors has the pages arranged for printing onto double sided paper to assemble into a booklet. It is difficult to read on a computer screen. Note that graphs shown are for 80F(27C) instead of 70F(21C).
http://ohmicinstruments.com/pdf/Manuals/HS%20Seriesman.pdf

The pertinent pages of the manual are available near the end of this document. Page 7 has been edited to show the new component values I've used. A Hammond 161D120 produces a 143VAC excitation source. The higher voltage favors the dry end of the sensor range and creates a better signal to noise ratio for measurements, important in a high RF environment. For 100uA maximum current, the total circuit resistance must be 1.43Mohms. The voltage across a series resistor is measured instead of circuit current. This makes measurements easier and further reduces the effect of noise. A BNC connector and shielded coaxial cable connect to the voltmeter. For 0-5VAC measurements, the series resistor must be 50kohms and the load resistor must be 1.38Mohms. The 1.38Mohm resistor is created with 1.6Mohm and 10Mohm resistors in parallel. The sensor resistance is calculated by measuring the output voltage. Next the %RH can be determined by using the formula on page 10. Air temperature of 21C / 70F is used for calculations and to convert to dew point temperature. A lookup table on the transformer box converts voltage to dew point.

Sensor voltage to dew point conversion

VAC	DPºC	VAC	DPºC	VAC	DPºC
0.15	<-40	2.00	-35	4.00	-28
0.625	-40	2.50	-33	4.50	-25
1.00	-38	3.00	-32	4.80	-21
1.50	-36	3.50	-30	4.90	-18

The 0.150VAC reading is the sensor's lowest measured value. Calculated dew point at this voltage is -45C. Some further reduction may be experienced but is likely due to reduced AC supply voltage.

By placing the HS-00-1 sensor at the 100PSI drying tower output, dew point measurement at 3PSI can be greatly enhanced by using pressure dew point conversion.

VAC	DPºC	VAC	DPºC	VAC	DPºC
0.15	<-55	2.00	-50	4.00	-45
0.625	-55	2.50	-49	4.50	-42
1.00	-54	3.00	-48	4.80	-39
1.50	-52	3.50	-47	4.90	-36

Parts list, dew point monitor

Ohmic Instruments humidity sensor HS-00-1	$31.50
3/4" Tee connector 022T-12-12	$22.31
2x 3/8" NPT male to 3/8" compression fitting 68C-06-06 2x $2.53	$5.06
3x 3/4" NPT male to 3/8"NPT female reducer 209P-12-06 3x $2.59	$7.77
3/8" NPT dome connector RD09NA	$1.51
Slide on pin connectors	
Single pair shielded wire	
XLR3-M connector	
Hammond case 1141H	
Hammond transformer 161D120	$6.26
XLR3-F chassis mount connector	
BNC chassis connector	
3/8" NPT dome connector RD09NA $1.51, nut NN09BK $0.36	$1.87
2.7M, 3.6M, 6.8M, 6.8M, 4.3M, 10M, 1k resistors	
Heat shrink tubing, various sizes	
Single pair shielded wire	
AC power cord	
Total	$76.28

Hygrodynamics

Newport Scientific / Hygrodynamics manufactures dew point monitors that use a Dunmore sensor. They also supply sensors and circuit boards to APPL, Canadian PureGas and others. The Hygrodynamics 8072 ($1400) portable dew point monitor uses a type 1205DM Dunmore sensor. It assumes 80F / 27C sample temperature for dew point conversion. Its response curve is shown near the end.

The 'knee' of the sensor curve occurs at about -18F (-28C) where the sensor impedance is about 10Mohms. Its impedance rapidly increases in a non-linear manner below that point. Compare to the HS-00-1 sensor where the non-linear section of the curve above about 10Mohms starts at about 0.7%RH or roughly -40C dew point.

The Hygrodynamics dew point monitor uses a very low excitation voltage (~6VAC), further limiting its ability and resolution at very low %RH. Connect a digital multimeter in place of the sensor to measure the excitation voltage. The 10Mohm meter impedance will produce a reading about -28C dew point.

The 8072 dew point monitor measurements are likely more accurate towards -9C than the prototype, but this is insignificant considering -40C dew point is the goal. The 8072 has a digital readout that indicates to -9C to -40C. With the sensor unplugged the display shows -40C. There is no way to detect a broken or disconnected sensor. Using the prototype monitor, there is a minimum of about 150mVAC present at the output. If the sensor is disconnected the voltage drops to 0. This provides a fail-safe reading.

During testing of a twin-tower drying system the prototype dew point monitor indicated the air from one tower was rapidly increasing towards -30C dew point as it was becoming saturated. When the second tower was active the dew point reduced to about -40C. When the output filter was opened it was covered in compressor oil. The desiccant had been contaminated, greatly limiting its ability to dry the air. The Hygrodynamics dew point monitor did not detect a problem and continuously displayed -40C. This helped to demonstrate the shop built prototype as a more sensitive instrument. $80 vs $1400 should provide further motivation.

The 8072 is likely an acceptable dew point monitor for its intended purpose, monitoring plastics drying but its capabilities are being pushed beyond the design limits.

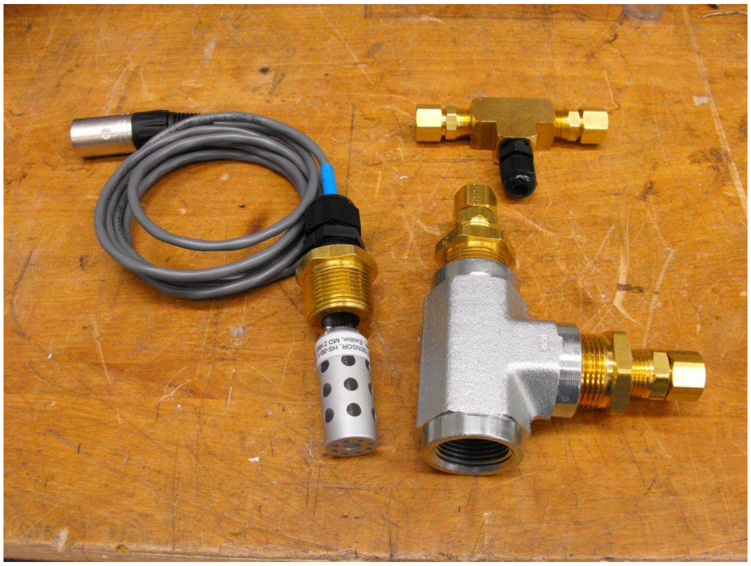
Pressure dew point conversion

One way to improve the performance of the 8072 (or other sensors) is to measure pressure dew point. Place the sensor at the output of the drying towers, prior to the pressure regulator. This will improve the operating range of the sensor. -28C dew point at 100PSI would be equal to -45C dew point at 3PSI. Other conversions can be done using PhyCalc.

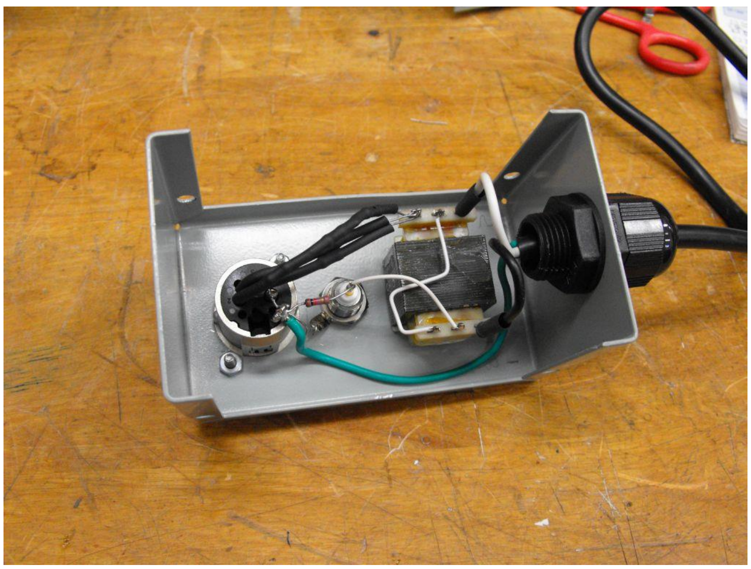
Pressure Dew Point Conversion

100PSI	3PSI	100PSI	3PSI
-15C	-33.8C	-28C	-45.0C
-16C	-34.6C	-29C	-45.9C
-17C	-35.5C	-30C	-46.7C
-18C	-36.4C	-31C	-47.6C
-19C	-37.2C	-32C	-48.5C
-20C	-38.1C	-33C	-49.3C
-21C	-39.0C	-34C	-50.2C
-22C	-39.8C	-35C	-51.1C
-23C	-40.7C	-36C	-51.9C
-24C	-41.5C	-37C	-52.8C
-25C	-42.4C	-38C	-53.7C
-26C	-43.3C	-39C	-54.5C
-27C	-44.1C	-40C	-55.4C

30PSI	3PSI	30PSI	3PSI
-15C	-24.7C	-28C	-36.7C
-16C	-25.6C	-29C	-37.7C
-17C	-26.5C	-30C	-38.6C
-18C	-27.5C	-31C	-39.5C
-19C	-28.4C	-32C	-40.5C
-20C	-29.3C	-33C	-41.4C
-21C	-30.2C	-34C	-42.3C
-22C	-31.2C	-35C	-43.3C
-23C	-32.1C	-36C	-44.2C
-24C	-33.0C	-37C	-45.1C
-25C	-34.0C	-38C	-46.0C
-26C	-34.9C	-39C	-47.0C
-27C	-35.8C	-40C	-47.9C



The Dunmore sensor is shown connected to the coil of wire. It fits inside the large Tee fitting on the lower right. Above is a partially completed HIH4000 sensor assembly.



Inside the transformer box. Resistors connect between the transformer, XLR, and BNC connectors. The AC cord is seen to the right.

It really is this simple.

The sensor plugs into the transformer box via a XLR connector. The voltmeter connects via a BNC connector and coaxial cable. The picture is from an early 0-100mVAC prototype.

Air Drying Techniques

Compression / cooling drying principle

- The bulk of moisture removal can take place before the drying towers or membrane.
- Compressing air will increase its temperature. Water vapor concentration and %RH remain constant. Dew point temperature increases.
- Cooling the air will increase its %RH. Dew point is reached at 100%RH. Any temperature reduction below DP will cause condensation. Liquid water will form inside air lines and storage tank. It should be removed prior to reaching the drying towers or membrane filter. %RH of the air remains at 100%.
- Reducing air pressure will reduce %RH and dew point temperature.

Examples (using PhyCalc)
At 30C and 70%RH the dew point will be 24C. The air will have 30180ppm water vapour.
Compress to 95PSI, cool to 32C. After coalescing filter, 6323ppm water vapour remains
6323 / 30180 = 0.21 79% of original water vapour has been removed.
Release pressure to 3PSI, new dew point 3.2C

At 20C and 85%RH the dew point will be 17C. The air will have 19986ppm water vapour.
Compress to 95PSI, cool to 22C. After coalescing filter, 3504ppm water vapour remains.
3504 / 19986 = 0.175 82.5% of original water vapour has been removed.
Release pressure to 3PSI, new dew point -4.3C

22C 95PSI air at 100%RH will have 3504ppm water vapour. Unless the air temperature or pressure changes, this will be the maximum concentration entering the drying towers or membrane. The compression and cooling cycle will produce liquid water in the coalescing filter if the room air has a dew point above -6.5C. The water removed will reduce drying required in subsequent stages and help prevent the membrane or desiccant from becoming saturated.

Consider this analogy.
A sponge can hold a certain amount of water until it starts to drip out. Consider this to be 100%RH. If you start with a damp sponge the %RH will be considerably less. As you squeeze it the %RH will increase until water drips. Squeeze harder and more water will fall out. Now when you release pressure on the sponge the %RH will be considerably less than when you started. In fact, the maximum %RH at low pressure will remain the same regardless of the starting point. When you compress and cool the air water will condense in the tank. It must be purged. When the pressure is reduced the %RH of the air will be less than original. The higher the pressure, the more water will drop out. This will lessen the load on subsequent drying stages.

Air drying process

1. Air entering compressor should be filtered to remove dust and dirt particles.
2. A radiator cools warm air exiting compressor. As air cools its %RH increases until it reaches the dew point. As temperature continues to drop moisture will condense. Oil / water separator or coalescing filter removes oil, water, and other contaminants.
3. Optional storage tank supplies reservoir of air. Air may cool further during storage. Condensation and oil will collect at bottom of tank and should be removed.
4. Air leaving tank requires further filtering. 0.5 micron and 0.01 micron filters ensure the air is clean and prevent contamination of dryer. This is especially important when an oil type compressor is used.
5. Saturated air enters drying system. Typically a twin tower regenerative desiccant dryer or membrane dryer is used. Assuming 21C 100PSI, output air must be 4.2%RH or less to produce 0.7%RH / -40C dew point at 3PSI.
6. Air exiting twin tower system requires 1 micron filter to remove desiccant dust.
7. Air pressure regulated to desired pressure.

Membrane dryer
Water vapour in compressed air is removed by selective permeation through a membrane. The membrane module consists of bundles of hollow membrane fibers, each permeable to water vapour. As the compressed air passes through the center of these fibers water vapour permeates through the walls of the fiber. A small portion of the dry air (purge flow) is redirected along the outside of each hollow fiber, carrying away the moisture-laden air that is then exhausted to room atmosphere. The remainder of the dry air is sent to the transmission lines.

Twin towers regenerative desiccant dryer
(Pressure swing adsorption)
Four modes of operation (approx times)

1. Tower one drying air, tower two purging. (4 minutes)
2. Tower one drying air, tower two pressurized and in standby. (1 minute)
3. Tower two drying air, tower one purging. (4 minutes)
4. Tower two drying air, tower one pressurized and in standby. (1 minute)

High pressure 100%RH air flows over activated alumina desiccant. Moisture is adsorbed onto desiccant, greatly reducing %RH of air. Small amount of dried air feeds to output of other tower and flows backwards to open input valve. The low pressure air will regenerate desiccant by absorbing moisture from surface of desiccant and release into room air. Dry high pressure air is regulated to a lower pressure. This will further lower %RH and dew point before being sent to transmission lines.

Desiccant chamber
This is typically used in low volume systems. %RH and dew point reduction is not as great as with pressurized systems. Low pressure air is dried by passing it through a desiccant chamber. The desiccant adsorbs the moisture and slowly becomes saturated. It must be manually regenerated at regular intervals, difficult to do at a remote site. Desiccant color is a poor indication of %RH.

Some systems merely connect a desiccant chamber to a transmission line, but do not apply positive pressure. If an air leak developed water could infiltrate the cable and rapidly overwhelm the desiccant chamber. Positive pressure is essential to help prevent moisture from entering the line.

It would be a good idea to replace these systems with a pressurized active drying system where possible.

Andrew MT1000 (1scfm)
Compressed air flows through the cooler to the filters.
Filters connect to an automatic purge valve that opens for about 5 seconds at compressor start up and at 15-minute intervals if the compressor continues to run.
Saturated air flows through a check valve to the membrane dryer.
A needle valve at output of dryer keeps the internal pressure at approximately 90PSI.
Air flows past the HIH4000 humidity sensor to the output manifold.
Return air feeds the front panel pressure gauge, low pressure alarm, and pressure control switch.
Compressor on / off pressures can be adjusted as required.
A small amount of air flows backwards from transmission lines through the membrane filter to assist with purging.

Wilkerson filters
W18-02-BG00 (0.5 micron), W18-02-CG00 (0.01 micron)

Andrew MT300 (0.3scfm)
Compressed air flows through the cooler to the filters.
The first filter has a Wilkerson X10-02-000 (Watts 134-02C) adjustable relief valve at the bottom.
It keeps the system pressurized at 90PSI. Extra air purges moisture through bottom.
The second filter has a small orifice that will continually purge collected moisture.
Saturated air flows through a check valve to the membrane dryer.
Air flows through a small orifice at the output of the dryer and past (optional) HIH4000 humidity sensor to the output manifold.
A branch from the output air feeds the front panel pressure gauge, low pressure alarm, and pressure control switch.
Compressor on / off pressures can be adjusted as required.
A small amount of air flows backwards from the transmission lines through the membrane filter to assist with purging.
Original filters
Wilkerson filter F00-02-Q34
Domnick Hunter (Parker) AA-0003G-AWC, Element code E003AA/AWC

Rebuild kits – Watts 134-02C replaces Wilkerson X10-02-000.
Parker filters. 7300-004 7300-005

A small coil of 3/8" copper tubing will greatly reduce the air temperature. It is effective as an emergency radiator in an MT300 or MT1000 dehydrator or for installation in the 1920 series.

Check the filter bowls on a regular basis. Occasionally the purge valve will become blocked and the bowl will fill with water. Water droplets on the sides is normal and acceptable.

Andrew 1920 and 1930 (pictured)
Compressor and twin tower dryers only. A Wilkerson X10-02-000 adjustable relief valve maintains internal pressure at 60PSI. The remaining air is released to the output. The gauges, blue desiccant moisture indicator, and pressure control switch are at the output. One tower dries air while the other purges, 30 second timer for cycling between towers. There is no intermediate stage to pressurize the standby tower. (Ratings - 1920 1.3cfm, 1930 0.2cfm)

During hot wet days in the summer the output air %RH can increase greatly as the drying towers become saturated. Once the weather clears up and the source air %RH drops, the towers will purge their excess moisture and begin to supply dry air again. An air cooler and filter will greatly reduce this problem.

This series dehydrator does not take advantage of the compression / cooling technique described earlier. As a result, the drying towers are often exposed to liquid water. Condensation will form over the desiccant and control valve as the air cools, potentially leading to early failure. Performance and long term reliability could be improved by adding an air cooler and coalescing filter prior to the drying towers. A 1PSI relief valve at the purge air output will prevent moisture from finding its way onto the desiccant during rest periods. These simple additions would considerably improve drying ability.

Puregas 550HTL (Rating 0.38cfm) http://www.canadianpuregas.com/550.htm
Compressor and twin towers only. An adjustable relief valve keeps the drying system at 50PSI. The drying towers cycle every 30 seconds without an intermediate stage to pressurize the standby tower. Dry air is stored in a small reservoir. The reservoir pressure is maintained at 30-50PSI via a pressure switch controlling the compressor. A regulator maintains a selected output pressure. As with the Andrew 1920 series, there is no air cooler prior to the drying towers. Air entering the towers was measured up to 76C. I expect it will suffer from the same long term issues with the control valves and drying towers being exposed to liquid water and becoming saturated. When operated at a site with tight lines the output crystals turned pink, indicating the air was very wet. The HIH4000 sensor confirmed wet air. In order to keep the air dry an unused valve was opened to create a leak. This causes the dehydrator to cycle more often.
More information at http://members.rennlist.org/warren/puregas.pdf

In either of the Andrew or Puregas systems it is assumed that with a 30 second cycle time that any moisture will be quickly removed from the desiccant. I've also been told that the amount of liquid water is insignificant. Another argument is the water separator filter will require maintenance. This could easily be part of an annual checkup of the systems and is easily done on the ground, not several hundred feet in the air after an antenna has failed.

Let's consider 60%RH at 25C. Water vapor will be at about 20725ppm. (Use PhyCalc) Compress the air to 50PSI and cool to 25C. Water will condense and the air will be at 100%RH. It will now have 4634ppm water vapor. This is about 22% of the original water vapor content. The compression / cooling cycle has removed 78% of the original moisture. The drying towers will be supplied cooled 100%RH air. No further water should form within the system. Without the air cooler and water filter, depending on temperature the air will be up to 264%RH. As it cools water will form over the desiccant and valves leading to premature failures.

Given these systems are expected to last many years and due to the critical nature of keeping transmission lines dry, we should consider anything that can improve the drying capacity and long term reliability of all dehydrating systems. Adding an air cooler and water filter could save many thousands of dollars in rigging expenses, antenna repairs, and unwanted downtime from just a single failure.

Larger systems

Large drying systems often use an oil lubricated piston or rotary vane compressor. These must have oil / water separator filters at the compressor output and another filter at the input to the drying towers. For maximum protection install 5, 1, and 0.01 micron filters in series prior to the drying towers. The filters and storage tank should each have automatic float valves or timed purge valves to vent water and oil. Each filter needs an independent purge valve and should operate at different times. Do not connect the drains of each filter to a common purge valve. Doing so can cause contaminants from the first filter to enter the later filter stages. There should be another filter at the output of the drying towers to prevent dust from getting to the transmission lines. All filters should be changed at least annually. Inspect the 0.01 micron filter occasionally for contamination. If it is clean there is no reason to expect contamination of the desiccant.

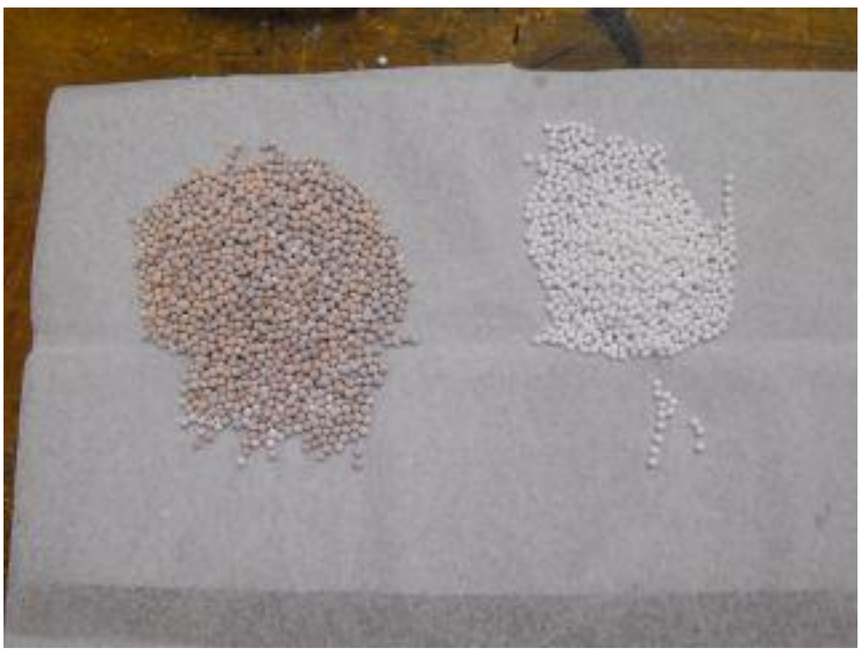
If the system has not been properly maintained lubricating oil may contaminate the desiccant, possibly even making its way to the plastic lines that provide air to the transmission lines. The desiccant must be replaced and the insides of the towers cleaned. All air hoses must be checked and replaced if contaminated. If the oil has made its way to the transmission lines they may need connectors removed for cleaning or possibly even the line replaced.

If it is kept clean from oil, the desiccant bed should last indefinitely. System failure may occur as the check valves or input air valve become worn and lose their ability to direct air flow properly. The prototype dew point monitor described is sensitive enough to detect failure in its very early stages. If one drying tower loses its drying ability earlier than the other suspect excessive valve wear. A rebuild may be needed.

The APPL AP-25 pictured is capable of producing air with dew point well in excess of -55C as measured using the pressure dew point at 100PSI. Twin tower systems such as this require about 15% air flow for purging the unused tower, regardless of air being supplied. The system pictured is rated 25CFM, so purge air is about 3.75CFM, even if it just supplies static pressure to the transmission lines. Include purge air from the pre filters, and there is a tremendous amount of wasted air from the compressor. Having a way to monitor the output dew point and switching towers only has required will greatly reduce air supply, limit contamination of air filters, and greatly extend life of the air valves. I've experimented with extending switching times, and limiting purge air. One tower was configured to supply air for 8 hours without switching and the relative humidity monitored. There was no noticeable change, dew point at 100PSI remained better than -40C. Compared to switching every 5 minutes, the purge air requirement dropped to less than 2%, and cycling reduced to less than 1%. I'm working on an automatic system to switch every 8 hours, or more often automatically based upon relative humidity measurement.

There is very little inside the drying towers. A metal grate prevents desiccant from escaping through the input and output connections.

Remove one end and the desiccant will pour out. Flush the tubes with alcohol to remove any residual oil or other contaminants. Refill with new desiccant and reassemble.



The desiccant on the left was contaminated with compressor oil. The original filtering was inadequate. Although the output air was still acceptably dry at a low flow rate, a large leak could have quickly overwhelmed its capacity. The new desiccant beads on the right are pure white with no discoloration.

Storage / regulating tanks

A regulating tank following a dehydrator will supply a constant pressure to the transmission lines and eliminate pressure fluctuations. Ensure the dehydrator will maintain tank air pressure in excess of that supplied to the lines. Repeated pressure changes place stress on the system, particularly at the connectors, joints, and waveguide windows. Such stress can result in unwanted failure and air leakage.

Some dehydrators maintain an external pressure between 1psi and 4psi. It doesn't quite work when the desired line pressure is 3psi. In this case connect the dehydrator to a regulating tank and adjust the pressure control switches to operate between 3psi and 7psi. This will keep the line pressure constant.

Some dehydrators can provide air that rivals that supplied from a tank of nitrogen in terms of moisture content. Perhaps a better system would use a dehydrator with automatic backup to a nitrogen tank. This would cover the site during an AC outage and supply dry air if the dehydrator was shut down remotely due to failure. A pair of check valves would perform this function.

Any oil contamination of relative humidity sensors will render them unusable. For this reason it is a good idea to include a small filter at the air input to help prevent contamination. The HIH4000 may be salvageable after cleaning with isopropyl alcohol. The Dunmore sensor cannot be cleaned and must be replaced. Clear tubing can provide a visual indication of presence of oil.

Air filters

Many air filters have an indicator at the top. As the filter becomes dirty a red indicator will become visible as a warning. This is not always a reliable method of confirming the filter is clean. With low air flow the differential pressure across the filter may not be enough to push up the indicator. A red indicator would require immediate filter replacement, but the only way to confirm the filter is clean is to inspect visually. Filters should be changed at least annually.

Proper air flow direction through the filters is important. There is usually an arrow on the housing to show recommended direction.

The standard flow for the coalescing effect is inside the element to outside for liquids, aerosols and vapours. Water and oil will flow to the bottom of the filter where it will drip into the bowl to be purged. Contaminants will be trapped in the filter element.

The standard flow for dust laden air is outside to inside the filter element to allow particles to drop off outside the filter element and to the bottom of the bowl.

Nitrogen vs dry air

Jampro TechTips has an article titled Protecting the Inside of Your Coax / Antenna. It continues the debate between nitrogen and dry air for transmission lines. The main point being made is that when Teflon is heated to 500C in the absence of oxygen it can create carbon soot. If the line is pressurized with dry air, the oxygen present can be used to create CO_2 gas instead. Clearly no one wants carbon soot inside the transmission lines.

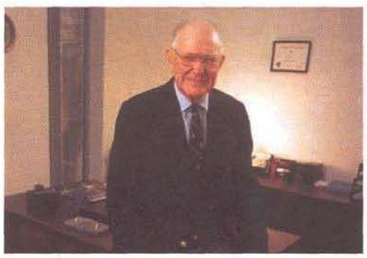
http://www.jampro.com/index.php?page=nitrogen-vs-dry-air-debate

Tech Tips

Protecting the Inside of Your Coax/Antenna

By Bob Groome

[SACRAMENTO, California - February 2004] Stations with antennas located in a lightning prone area or with antennas driven by transmitters that can sustain an arc for more than few seconds may find nitrogen is not the best way to safely keep the antenna interior dry. In fact, using nitrogen can lead to antenna or coax failure!



Manville "Whitey" Bro (Courtesy: DuPont Co.)

Sam Garfield, CEO of Technical Broadcast Consultants (and SBE VP) directed me to Dr. Manville "Whitey" Bro, a senior chemical design engineer at E.I. DuPont.

In a conversation with Bro, whose research made the copolymer Teflon® FEP (fluorinated ethylene propylene) from the precursor PTFE, he explained the problem with using the product with nitrogen.

CHEMICAL BACKGROUND

It turns out that when PTFE is heated to 500° C or so, hundreds of thousands molecules of Teflon react; CF_2 becomes double bonded CF_2. If nitrogen is used to pressurize the coax/antenna system, this double bonded CF_2 then will become CF_3 (a gas) and C (carbon), visible as soot. The chemical equation is:

$CF_2 + CF_2 + N$ + high heat = $HF + CF_2O$ (carbonate Fluoride) + C (*carbon*)

Clearly, no one wants carbon inside their coax or antenna. The results are, to put it mildly, potentially catastrophic.

A better way is to use dry air: $CF_2 + CF_2 + O_2$ + high heat = $HF + CF_2O + CO_2$ (a less damaging gas)

During an arc, the heated air expands quickly and possibly will open the pop-off value. This will allow more air to move through the system. Actually, this is good, as it will provide more oxygen molecules to bond with the CF_2 and make more CO_2. When the oxygen is depleted, C is the by-product.

Carbon Deposits (Courtesy: Sam Garfield)

So, depending on the duration of the flash over or arc, some carbon will still form in the presence of dry air, but not nearly as much as in the presence of nitrogen. In addition, the by-product of the arc itself may produce carbon.

It appears you cannot stop the production of carbon completely, but this recommended step will reduce the amount of its production in your antenna system, should it experience a sustained arc.

ANTENNA PRESSURIZATION

Antenna manufacturers like Jampro recommend that if nitrogen is used to test pressurization and/or used to purge moisture from an antenna, it should be replaced by dry air when the procedure is completed.

Here is a relatively easy way to replace nitrogen in a closed coax/antenna system: First, adjust the dehydrator to over 15 psi. This will cause the pop-off valve(s) in the antenna to purge the excess air. Then, the dehydrator will kick back in, adding more dry air as it attempts to maintain the 15 psi, blowing air through the entire system. You should maintain this mode of operation until all of the nitrogen is out of the system, and then reduce the dehydrator pressure to about 3 psi.

A reminder, though: If the pop-off valve has been removed, you will have to open and reseal this manually. Additionally, Garfield mentioned real caution should be taken when using the air dehydrators of today's design. The reason is poor input air filtration; additional filtration of the output dry air is highly suggested.

The bottom line: For long and reliable service from your antenna, it is best to use dry air for maintaining pressure in the system.

Teflon is registered trade mark of the DuPont Corporation.

Bob Groome is the Domestic Sales Manager for Jampro Antenna and RF Systems in Sacramento, CA. Contact him at BobG@jampro.com

JAMPRO ANTENNAS AND RF SYSTEMS, INC.

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Calibration for linear output sensors

Typical sensor coefficients will work in the majority of sites, but when operating near the upper and lower limits of any sensor specific calibration coefficients will improve readings. Ideally all sensors should be calibrated independently when installed.

The Davicom MAC seems to resolve in steps of 10mV and the Site Sentry Electralert in steps of about 20mV according to the remote control screen. Using the RTU voltages will factor ADC errors into the overall coefficients. This should provide better measurement than an external voltmeter for determining the offset reference and slope.

To ensure best accuracy, calibrate according to typical range of operation. For example, it is somewhat pointless to average the readings of a pressure sensor over 0-15PSI and have it measuring 1PSI maximum. Limiting the range of calibration will ensure best results within the range of normal operation.

A linear sensor response requires at least two measurement points to determine coefficients for B and C. Often the easiest points are zero reference and a normal operating point.

VTS uses a quadratic equation for calculating sensor values. $Ax^2 + Bx + C$
For a linear sensor the A coefficient is 0, leaving the equation Bx + C
Manual calculation using offset voltage and sensor output voltage can be performed.
Value $= (x – Z) / S$ where x = Voltage reading, Z = Zero offset, S = Slope
$= x/S – Z/S$
$= {}^{1}/_{S}\, x – {}^{Z}/_{S}$
From this equation, B = 1/S, C = -Z/S or C = -B x Z

Slope is volts per unit. The B coefficient uses the invert of this, units per volt.
The C coefficient is essentially an offset to compensate for the sensor output voltage at a zero level operating point, ie 0.5V @ 0PSI or 780mV @ 0%RH.

<u>MPX 5010 / 5050 / 5100 pressure sensor</u>
Install sensor and connect to Davicom.
A=0, B=1, C=0, D=0. 2 decimal places.

Do not apply pressure. Get voltage measurement with VTS.
This is the zero pressure (P0) voltage (V0)
Apply normal operating pressure. Get voltage measurement with VTS.
This is operating pressure (P1) voltage (V1)

A= 0. Assume the sensor is linear. D=0. Log function not needed.
B = (P1 – P0) / (V1 – V0)
C = - B x V0

The exact value of the C coefficient may need minor tweaking.
Change to 1 decimal place, set alarm points, proper labels, etc.
Confirm proper reading at normal operating pressure and at zero pressure.

<u>MPX5100 sample calculations</u>
B = (P1 – P0) / (V1 – V0)
= (3 - 0) / (1.28 – 0.31)
= 3.093

C = - B x V0
= -3.093 x 0.31
= -0.959

<u>MPX5010 sample calculations</u>
B = (P1 – P0) / (V1 – V0)
= (0.6875 - 0) / (2.39 – 0.30)
= 0.3289

C = - B x V0
= -0.3289 x 0.30
= -0.0987

Examples with Honeywell HIH4000 humidity sensor
Data sheet nominal offset 0.780V
Slope 29mV / %RH
B = 1 / 0.029 = 34.48
C = -34.48 x 0.780 = -26.90

Sample of measured zero output with nitrogen for 0%RH
Zero offset 0%RH = 860mV
Slope = 29mV / %RH
B = 1 / 0.029 = 34.48
C = -34.48 x 0.860 = -29.65

Alternate technique for determining C coefficient
The value for parameter C is not difficult to determine. Two measurements will find the slope and allow calculation for parameter B. Program A=0 and C=0 with the calculated B parameter. The VTS indication will be offset by the amount needed for parameter C. For line pressure, release pressure to 0PSI. The reading showing will be –C.
For temperature, C = Actual value - Measured value. Some minor tweaking may be needed.

Transmitter output power
$P = V^2/R$
Power = $Ax^2 + Bx + C$, where x = DC sample voltage
The square function uses the A coefficient in VTS
With transmitter power at 0W, the output voltage should be 0V.
Turn transmitter on at full rated power and measure the DC voltage at the sensor.
$A = P / V^2$, B=0, C=0

Example 1000W, 2.68V
$A = 1000 / 2.78^2 = 129.4$

Example 5kW, 2.11V
$A = 5 / 2.11^2 = 1.12$

Confirm DC sample voltage 71% at half power, 50% at quarter power. If the sensor input level is too high the output voltage will no longer follow the proper curve. Reduce the input level to bring it into a proper operating range.

When using a Scientel FMPM or TVPM, the output voltage is set at 5.0V at full power.
To indicate 0-100% output power, 5V = 100%
$A * 5^2 = 100$
A = 100 / 25 = 4

Note: Most transmitters RF output samples use a simple diode detector uses the $A = P / V^2$ equation. However, the Nautel VS series uses a linear output level for RF power. In this case only the B parameter is used as a multiplier. A=0 and C=0.

Variable relative humidity air for calibration

I am working on producing variable %RH reference air for sensor calibration and dew point monitor confirmation. The concept and math are easy, using a combination of pressure dew point and Boyle's gas law. The difficulty comes in accurately measuring the air pressure and keeping the temperature constant as the gas is expanded. Another problem is ensuring the moisture is thoroughly and equally mixed throughout the air. Unequal distribution throughout the gas will create unstable humidity and prevent accurate calibration. It is easier to plan and design than it is to implement accurate %RH calibration. Read the following articles for hurdles that must be overcome.

http://www.veriteq.com/humidity/index.htm

The Trouble with Humidity: Hidden Challenges of Humidity Calibration
http://www.veriteq.com/download/Trouble-with-Humidity.pdf

How hard could that be? Practical Humidity Calibration Experiences
http://www.veriteq.com/download/practical-rh-experiences.pdf

Here is a quick description of the concept.

Saturated 21C air at 100PSI will have a concentration of 3151.7ppm of water vapor. If pressure is released to 3PSI while maintaining temperature at 21C the air will be 15.43%RH. The dew point is -5.5C. This is a simple compression and cooling drying process. As long as the supply air from the room is higher this can be used as a calibration point.

We now have a source of 3PSI 3151.7ppm air. 15.43%RH, DP –5.5C.

Boyle's law describes the inversely proportional relationship between the absolute pressure and volume of a gas, if the temperature is kept constant within a closed system.
"For a fixed amount of an ideal gas kept at a fixed temperature, pressure and volume are inversely proportional."

We can calculate the new concentration of water vapor if we know the original concentrations of the gases being mixed. PhyCalc can be used to calculate the %RH and dew point.

Reduce the tank pressure to 0psig. Atmospheric pressure is 14.696psi. Use 10ppm nitrogen to increase pressure in the tank to two atmospheres or 14.696psig. The new water vapor concentration will be
(3151.7 + 10) / 2 = 1580.85ppm.
Maintain 21C and reduce pressure to 3psig. The resulting air will be 7.75 %RH, -13.3C dew point.

Start at 3151.7ppm water vapor and increase the tank to 8 atmospheres.
8x14.696psi = 117.5psi.
The new water vapor concentration will be (3151.7 + 8x10) / 9 = 359.1ppm.
Maintain 21C and reduce pressure to 0psi. The resulting air will be 1.76%RH, -28.6C dew point.

Assuming pure nitrogen, 0ppm water vapor, this calculation would create 3151.7/9 = 350.2ppm .This would result in 1.72%RH, dew point -28.9C. This error would be acceptable.

<u>Another test</u>

Consider that the absolute dew point measurement is not critical. We really have no way to confirm it anyhow. We can look at a digital readout on the Hygrodynamics dew point monitor, monitor the analog output of the HIH4000, or check the lookup table with the HS-00-1 sensor. Either way we are taking a relative humidity measurement and calculating an expected dew point of the sample air at an assumed temperature.

Let’s place the sensors in series and connect to a source of very dry air. Wait until all sensors are fully purged and indicate they are at the lower limits. This could take up to 30 minutes for the Hygrodynamics or HS-00-1 sensors if they are fully saturated. Now slowly introduce a very small amount of moist air from a second source. Starting with <-40C dew point air, water vapor will be less than 71ppm. 100%RH air at 100PSI will have 3157ppm water vapor. -40C dew point air will have 126ppm water vapor. A needle valve that can be opened very slowly will be needed. Ensure there is an inline particulate filter to prevent any water droplets, oil, or other contaminants from reaching the sensing elements. A rapid air flow will ensure the sensors each receive a good flow of air at essentially the same time.

You should see the %RH readings on all sensors increase and the dew point indication will increase. The sensor that detects the moisture first could be considered the most sensitive. If you’re looking for the earliest possible failure of a drying system, this is the sensor you should be using.

Closing

Air drying systems are an essential part of the broadcast systems infrastructure. They should be carefully monitored to ensure proper operation. The sensors mentioned provide cheap insurance against catastrophic antenna failure due to moisture. One comment I've encountered is that dehydrators have been in use for 30 years so do we don't need to monitor them in this manner. Unfortunately that doesn't guarantee they have been operating properly.

I've seen several antenna and cable failures that could be directly attributed to moisture. There were even splitter cables that needed to be disconnected for water to pour out! Fortunately transmitter power was not high enough to create arcing and catastrophic failure, but the moisture damage remains. Had the dehydrator been monitored the failure may have been avoided. Preventing a single failure could recover the cost of many humidity sensors and their installation. Wasted time purging transmission lines with nitrogen, expense for rigging, replacement parts and assembly, and extended downtime are easily avoided.

While the HIH4000 is not the ideal sensor for broadcast purposes it is the best I've found for direct connection to the Davicom or Site Sentry analog inputs. There is no reason to wait for a major antenna failure to detect a dehydrator failure. It's almost like destroying an expensive transistor to save its fuse. At $25 per sensor I can not think of a valid reason not to have one monitoring every dehydrator system in operation.

Any drying system can remove only a certain amount of moisture from the air. During winter the cold air will have less water vapour and thus a lower dew point than a rainy day in the summer. As a result, measuring the dew point at the output of a dehydrator during winter may not be an ideal indication of its drying capability. If the dehydrator supplies -40C dew point air during a wet summer day chances are it will also perform adequately during the coldest day of the winter. During high voltage leakage tests while assembling new splitter cables I require <0.1uA@5kV leakage for 7/8" cables. The test voltage is reduced to 4kV for 5/8" and 3kV for 1/2" cables. Even on a sunny summer day the water vapour in the room air can create leakage current inside the lines. The wet air must be purged before high voltage leakage tests are acceptable. This is much more noticeable during summer than it is during winter.

If you decide to measure %RH or dew point by letting air leak from the transmission line over the sensor you must know the air temperature. Cold air will have a higher %RH for a given moisture content. Most dew point monitors assume a sample temperature of 21C or 28C. Sampling cold air will give an incorrect reading of a much warmer dew point.

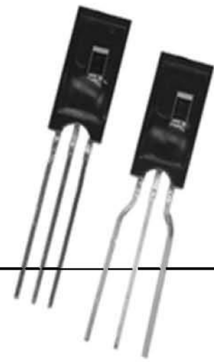
I routinely use the prototype dew point monitor for dehydrator confirmation. I prefer it over the Hygrodynamics 8072 dew point monitor unless it is already on the bench and the prototype model is packed away. For the price of a single Hygrodynamics dew point monitor, over 40 HIH4000 sensors could be assembled and installed and a more sensitive dew point monitor built for confirmation during maintenance visits.

I've attached a 9V battery to the HIH4000 sensor. Used with a multimeter it creates a very portable sensor for dehydrator confirmation. The 0%RH voltage is written on the side of the brass Tee to provide an easy reference. It travels as part of my multimeter kit along with temperature sensors, clamp on current probes, etc.

One of the prototype dew point monitors has become part of my personal test equipment for use while on the road. I'd like someone else to review my design and assess the other prototype dew point monitor. Please let me know if you are interested in helping out.

Contact information is supplied on the last page.

Honeywell



HIH-4000 Series

Humidity Sensors

DESCRIPTION

The HIH-4000 Series Humidity Sensors are designed specifically for high volume OEM (Original Equipment Manufacturer) users.

Direct input to a controller or other device is made possible by this sensor's near linear voltage output. With a typical current draw of only 200 μA, the HIH-4000 Series is often ideally suited for low drain, battery operated systems.

Tight sensor interchangeability reduces or eliminates OEM production calibration costs. Individual sensor calibration data is available.

The HIH-4000 Series delivers instrumentation-quality RH (Relative Humidity) sensing performance in a competitively priced, solderable SIP (Single In-line Package).

Available in two lead spacing configurations, the RH sensor is a laser trimmed, thermoset polymer capacitive sensing element with on-chip integrated signal conditioning.

The sensing element's multilayer construction provides excellent resistance to most application hazards such as wetting, dust, dirt, oils and common environmental chemicals.

FEATURES

- Molded thermoset plastic housing
- Near linear voltage output vs % RH
- Laser trimmed interchangeability
- Low power design
- Enhanced accuracy
- Fast response time
- Stable, low drift performance
- Chemically resistant

POTENTIAL APPLICATIONS

- Refrigeration equipment
- HVAC (Heating, Ventilation and Air Conditioning) equipment
- Medical equipment
- Drying
- Metrology
- Battery-powered systems
- OEM assemblies

HIH-4000 Series

TABLE 1. PERFORMANCE SPECIFICATIONS (At 5 Vdc supply and 25 °C [77 °F] unless otherwise noted.)

Parameter	Minimum	Typical	Maximum	Unit	Specific Note
Interchangeability (first order curve)	–	–	–	–	–
0% RH to 59% RH	-5	–	5	% RH	–
60% RH to 100% RH	-8	–	8	% RH	–
Accuracy (best fit straight line)	-3.5	–	+3.5	% RH	1
Hysterisis	–	3	–	% RH	–
Repeatability	–	±0.5	–	% RH	–
Settling time	–	–	70	ms	–
Response time (1/e in slow moving air)	–	15	–	s	–
Stability (at 50% RH)	–	1.2	–	% RH	–
Voltage supply	4	–	5.8	Vdc	2
Current supply	–	200	500	µA	–
Voltage output (1st order curve fit)	$V_{OUT}=(V_{SUPPLY})(0.0062(\text{sensor RH}) + 0.16)$, typical at 25 ºC				
Temperature compensation	True RH = (Sensor RH)/(1.0546 – 0.00216T), T in ºC				
Output voltage temperature, coefficient at 50% RH, 5 V	–	-4	–	mV/ºC	
Operating temperature	-40[-40]	See Figure 1.	85[185]	ºC[ºF]	–
Operating humidity	0	See Figure 1.	100	% RH	3
Storage temperature	-50[-58]	–	125[257]	ºC[ºF]	–
Storage humidity	See Figure 2.			% RH	3

Specific Notes:

1. Can only be achieved with the supplied slope and offset. For HIH-4000-003 and HIH-4000-004 catalog listings only.
2. Device is calibrated at 5 Vdc and 25 ºC.
3. Non-condensing environment.

General Notes:

- Sensor is ratiometric to supply voltage.
- Extended exposure to ≥90% RH causes a reversible shift of 3% RH.
- Sensor is light sensitive. For best performance, shield sensor from bright light.

FACTORY CALIBRATION DATA

HIH-4000 Sensors may be ordered with a calibration and data printout. See Table 2 and the order guide on the back page.

TABLE 2. EXAMPLE DATA PRINTOUT

Model	HIH-4000-003
Channel	92
Wafer	030996M
MRP	337313
Calculated values at 5 V V_{OUT} at 0% RH V_{OUT} at 75.3% RH	 0.826 V 3.198 V
Linear output for 3.5% RH accuracy at 25 °C Zero offset Slope RH	 0.826 V 31.483 mV/%RH (V_{OUT} - zero offset)/slope (V_{OUT} - 0.826)/0.0315
Ratiometric response for 0% RH to 100% RH V_{OUT}	 V_{SUPPLY} (0.1652 to 0.7952)

2 www.honeywell.com/sensing

HIH-4000 Series

FIGURE 3. TYPICAL OUTPUT VOLTAGE VS RELATIVE HUMIDITY (At 25 ºC and 5 V.)

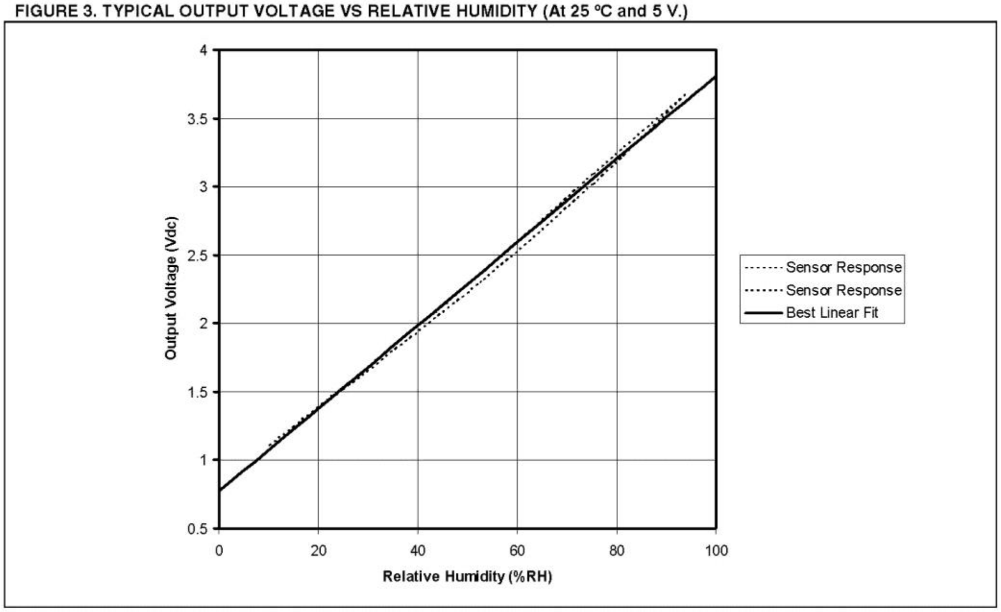
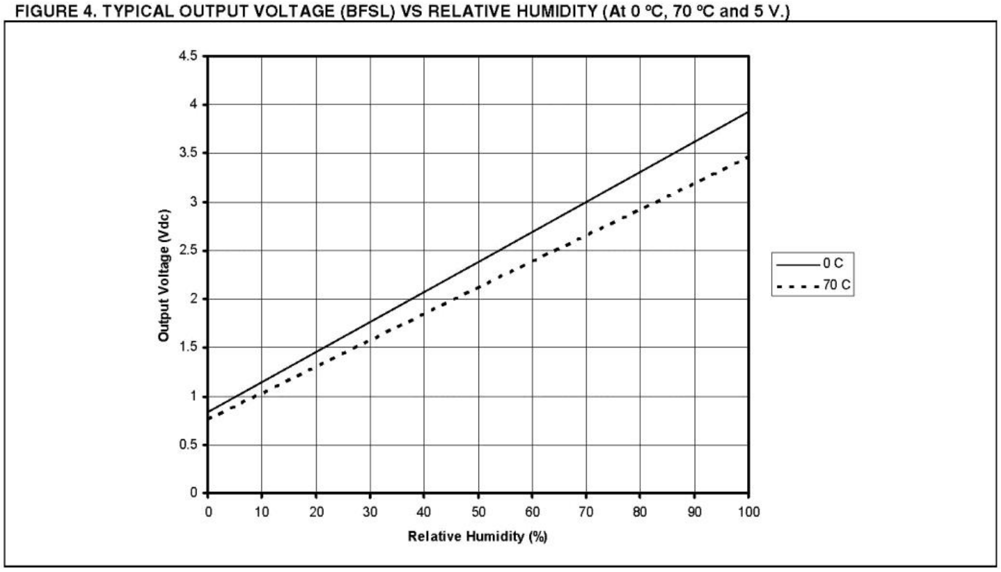
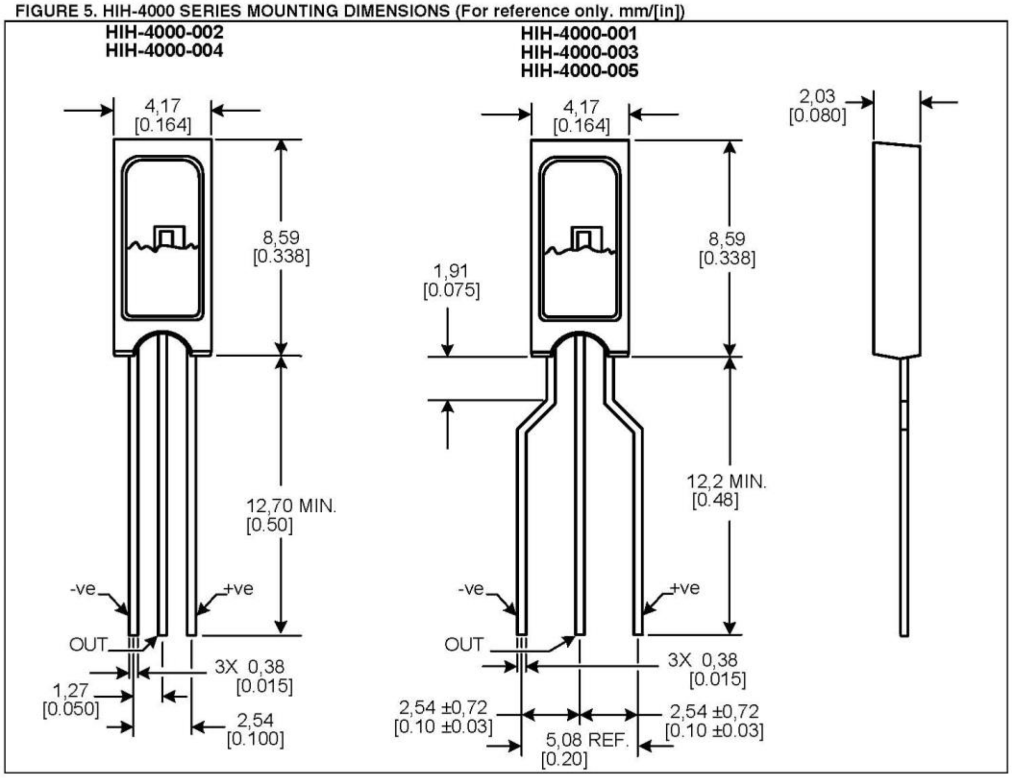


FIGURE 4. TYPICAL OUTPUT VOLTAGE (BFSL) VS RELATIVE HUMIDITY (At 0 ºC, 70 ºC and 5 V.)



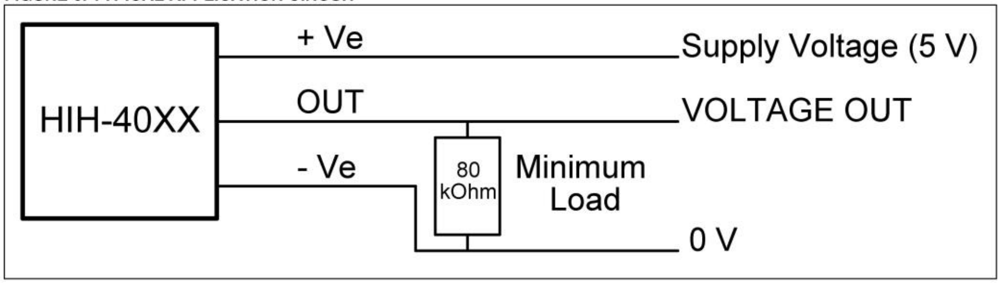
4 www.honeywell.com/sensing

FIGURE 5. HIH-4000 SERIES MOUNTING DIMENSIONS (For reference only. mm/[in])



HIH-4000 Series

FIGURE 6. TYPICAL APPLICATION CIRCUIT



ORDER GUIDE

Catalog Listing	Description
HIH-4000-001	Integrated circuit humidity sensor, 2,54 mm [0.100 in] lead pitch SIP
HIH-4000-002	Integrated circuit humidity sensor, 1,27 mm [0.050 in] lead pitch SIP
HIH-4000-003	Integrated circuit humidity sensor, 2,54 mm [0.100 in] lead pitch SIP, calibration and data printout
HIH-4000-004	Integrated circuit humidity sensor, 1,27 mm [0.050 in] lead pitch SIP, calibration and data printout
HIH-4000-005	Equivalent to HIH-4000-001

FURTHER HUMIDITY SENSOR INFORMATION

See the following associated literature at **www.honeywell.com/sensing**:

- Product installation instructions
- Application sheets:
  - Humidity Sensor Performance Characteristics
  - Humidity Sensor Theory and Behavior
  - Humidity Sensor Moisture and Psychrometrics
  - Thermoset Polymer-based Capacitive Sensors

6 www.honeywell.com/sensing

http://sensing.honeywell.com/index.cfm/ci_id/140570/la_id/1/document/1/re_id/0

Ohmic Instruments HS-00-1 Datasheets

RELATIVE HUMIDITY SENSORS
Model HS Series

OHMIC Company's **Model HS Series Relative Humidity Sensors** are a standard series of eleven improved Dunmore-type sensors designed to cover the 1% to 99% R.H. range. This type of humidity sensor, developed by the U.S. Bureau of Standards, is the most accurate and reliable relative humidity sensor available today and OHMIC Company is the world's largest manufacturer of Dunmore-type sensors. Millions of these sensors are in use today, some of which have been in normal service for over ten years.

The OHMIC relative humidity sensor offers many advantages over capacitive or polymer type sensors, such as ±1% NBS traceable accuracy, interchangeabllity with no recalibration requirements, clearly defined resistance vs. relative humidity response, no hysteresis shift errors after wide humidity changes, and low cost with a long life expectancy.

Each of the color-coded HS Series sensors responds to a specific humidity range and gives a resistance change from 1 kilohm to 10 Megohms. Figure 1 shows the HS Series model numbers, the identifying model color, and the corresponding relative humidity response over the full resistance change of 1 Kilohm to 10 Megohms. The Model HS-00-1 White sensor is a special shifted HS-00 white sensor used by many dryer manufacturers.

This databook gives curves and specifications for each sensor. The resistance vs. relative humidity response curves are given at operating temperatures of 40°, 80°, 80°, 100°, and 120° Fahrenheit. Each sensor specification sheet details the electrical and mechanical characteristics of the sensor and provides a general mathematical equation with specific sensor constants for use with computerized systems.

Model Number	Sensor Color	R.H. Range (10M to 1K)
HS-00-1	White	0.5% to 18%
HS-00	White	1.5% to 20%
HS-0	Black	3% to 25%
HS-1	Brown	5% to 35%
HS-2	Red	10% to 50%
HS-3	Orange	20% to 60%
HS-4	Yellow	30% to 70%
HS-5	Green	40% to 80%
HS-6	Blue	55% to 99%
HS-7	Violet	70% to 99%
HS-8	Grey	80% to 99%

Figure 1: The HS Series Humidity Sensors

FEATURES

- 11 sensors cover the 1% to 99% RH range
- NBS traceable ± 1% RH accuracy
- High resolution: ± 0.1% RH
- Complete interchangeability
- Long term stability
- Low temperature coefficient: ±0.15% per ±1°F
- Clearly defined Resistance vs. Humidity response
- Fast humidity response
- No hysteresis shift after large humidity changes
- No field calibrations required
- Operates at temperatures up to 160°F
- Low cost, long life

5

TECHNICAL INFORMATION

GENERAL CHARACTERISTICS AND CONSTRUCTION

The HS Series are humidity-sensitive variable conductance transducers which produce clearly defined resistance values over a narrow range of ambient relative humidity. The sensing element consists of two parallel palladium wires wound on a polystyrene bobbin and terminated at two male pins which are molded into the plastic bobbin. The palladium wires are then coated with a thin hygroscopic compound. When exposed to humidity conditions, the resistance between the coated palladium wires will decrease with humidity increases and vice versa. The response is repeatable and predictable with no hysteresis deviation over wide humidity changes. A resistance variation of 10 megohms to 1 kilohm will occur for an average relative humidity difference of about 30% R.H. To cover the entire 1% to 99% range, eleven narrow range sensors are manufactured, each with a different hygroscopic composition.

A perforated anodized aluminum shell is used to cover the sensor element for protection from damage due to handling. There are two styles of perforated shells available. The standard or room-type shell has perforated ventilation holes completely around and on the top of the shell for maximum sensor exposure to the ambient air flow. The other cover is a duct-type shell which has perforated ventilation holes only on the top of the shell to provide sensor element protection as well as sufficient air flow exposure when used in forced-air duct systems.

In high humidity applications, where water condensation may occur, or in HVAC applications where airborne particles may contaminate the surface of the sensor, a weatherproof protective porous teflon sleeve can be installed at an additional cost of $12. This protection will significantly lengthen sensor life during exposure to these damaging conditions. Weatherproofing can be ordered by specifying a "-W" suffix on the sensor model number.

All OHMIC sensors are aged and calibrated to a ±1% accuracy according to NBS traceable standards and each sensor is color-code labeled and marked with a computer-recorded serial number.

PRODUCING AN ANALOG OUTPUT

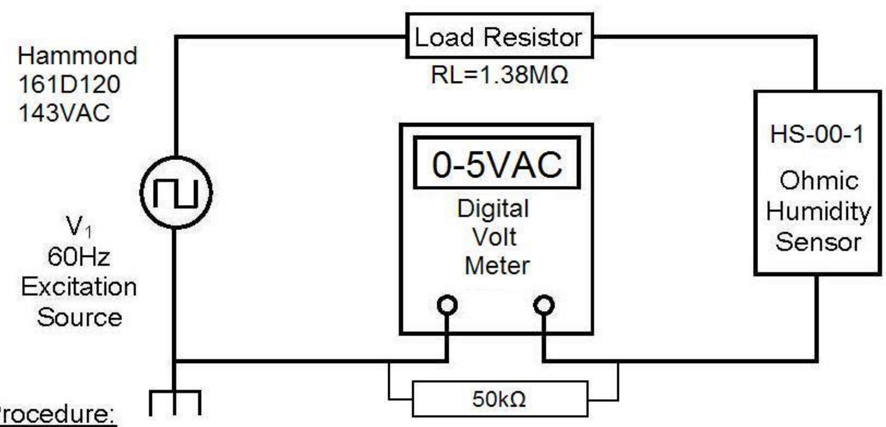
The humidity signal which is produced directly by the OHMIC Dunmore-type sensor is in the form of an ohmic resistance. Generally, current or voltage signals are preferred analog signals in electronic instrumentation systems. This requires that some type of signal conditioning be used with the humidity sensor. However, two factors must be considered during this signal conditioning process. First, the humidity sensor must never be connected to a voltage source which has a DC voltage component (i.e., pure DC, or DC mixed with AC). DC voltages will permanently polarize the moisture-sensitive compound and will significantly change the humidity vs. resistance response of the sensor. The sensor must therefore be driven (or "excited") by a pure AC sine or square source. RMS values will always be used to measure this AC excitation.

The second factor to be considered involves the maximum RMS current that should be allowed to flow through the sensor. To prevent permanent deterioration of the hygroscopic compound and to eliminate any "self-heating" effects, the maximum RMS AC current should not exceed 100 microamperes.

A SIMPLE SIGNAL CONDITIONING METHOD

A simple series circuit, as shown in Figure 2, can be used to measure humidity. The sensor is connected in series with a load resistor, an AC microammeter, and an AC sine or square wave voltage excitation source. The RMS current flowing through the sensor represents the percent relative humidity as interpreted using a particular sensor's response curves.

The load resistor value is chosen to be equal to the mid-range resistance value of the sensor response curve. Since the sensor resistance varies from 10 Megohms to 1 Kilohm, no single load resistance value will allow use of the full sensor response. Therefore, two different load resistance values are commonly used. A 909 Kilohm load resistor provides good sensor response over a resistance change of 10 Megohms to 50 Kilohms. This will be referred to as the "high dial" response. The other commonly used load resistor provides good sensor response over the lower portion of the curve from about 200 Kilohms to 1 Kilohm. This range will be referred to as the "low dial' response. Other load resistance values can be chosen for special applications; however, the 909K and 20K loads are the industry standards.



Procedure:

1. Choose load resistor R_L to be 20K or 909K, depending on the sensor resistance range. Use 20K load for sensor resistance changes between 1K and 200K, or use 909K load for sensor resistance changes between 50K and 10 Megohms.
2. Set the AC excitation source (V_1) for 2 volts RMS with 20K load or 91 volts RMS with 909K load.
3. Short across sensor. The maximum current should be 100μA. (5VAC)
4. Remove short, read current and find the sensor resistance using the following formula:

$$R_S = R_L \, [(100/\mu A \text{ Reading}) - 1]$$

5. Obtain the relative humidity by finding this resistance value on the response curve for the sensor and temperature being used.

Figure 2: A simple humidity measuring circuit

Note changes in Figure 2 from original document.

The AC excitation voltage is chosen so that the maximum sensor current of 100 microamps cannot be exceeded when the sensor resistance is at its minimum value with a particular load resistor in place. For the 909K load, the RMS excitation should be 91 volts RMS. For the 20K load, the RMS excitation should be 2 volts. This excitation voltage must be regulated for good circuit performance. A bilateral zener diode clamping circuit will work well for this purpose.

The RMS current signal is monitored by a conventional digital AC ammeter. This current will vary between 0 and 100 microamps when the correct load resistor and AC excitation are used. The 100 microamp value represents the full 100% output span of the circuit and will be referred to as "100 dial". This terminology avoids confusion between the use of percent (%) for both humidity and the output span reading. A dial reading (or span) of 50 will correspond to a sensor resistance equal to the value of the load resistor (909K or 20K). A zero (0) dial reading corresponds to a sensor resistance of infinity (open circuit). A reading of 100 dial corresponds to a sensor resistance of zero ohms (short circuit). Figures 3 and 4 (Page 9) show tables to convert dial readings to sensor resistance values. From these tables and the sensor curves, the humidity can be interpreted. For example, if a yellow sensor (HS-4) is being used with a 909K load and the current reading is 75 microamps (also called "75 dial"), the sensor resistance (from Figure 4) would be 303K. Using the 80°F. response curve for the HS-4 sensor, this 303K reading converts to a relative humidity of 36%.

More efficient electronic signal conditioning using operational amplifiers can be used to change the sensor resistance directly into an analog D.C. voltage signal. The non-linearity of a single sensor, the narrow R.H. range, and the dial vs. %R.H. offsets can be eliminated by combining two or more sensors into a multi-element resistive sensor network which is computer-designed for an optimum ±2% typical accuracy. Using these sensor networks, 0 to 100 microamps corresponds to 0% to 100% R.H. and each 1µA = 1% R.H. This eliminates a considerable amount of the "look-up table" work which is required when using a single sensor.

Ohmic Instruments Company manufactures a variety of humidity measurement and control products using the HS Series humidity sensors and also offers field-proven signal conditioning and humidity control cards for OEM applications. Many multi-element wide-range sensor networks, probes, and accessories are available to fit any humidity application. Call Ohmic toll-free at 1-800-626-7713 and ask for an applications engineer to discuss your humidity measurement application.

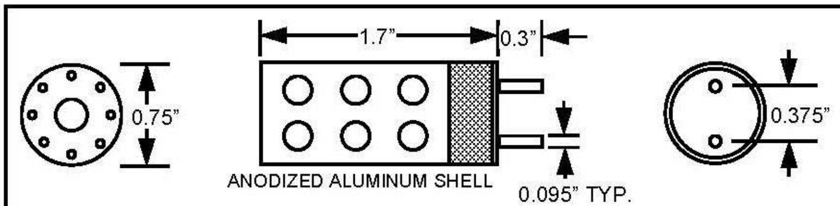
HUMIDITY SENSOR SPECIFICATIONS

Sensor Model No: HS-00-1 Color Code: WHITE

ELECTRICAL:

Dynamic Resistance Range (10-95 dial) w/ 909K Load:	8 Megohms to 50 Kilohms (0.7% to 4.4% RH @ 80°F)
Dynamic Resistance Range (10-95 dial) w/ 20K Load:	200 Kilohms to 1 Kilohm (2.7% to 17% RH @ 80°F)
Maximum RMS Operating Current:	100 Microamperes, A.C.
Operating Frequency Range:	10Hz to 400Hz (60Hz Typ.)
Accuracy:	± 1% R.H.
Resolution:	± 0.1% R.H.
Hysteresis:	None
Interchangeability:	Direct Replacement with No Calibration Required
Response Time:	5 seconds Max. for 63% of the Total Humidity Change
Long Term Stability:	±1% for One Year
Operating Temperature Range:	40° F to 160°F
Temperature Coefficient:	± 1% R.H. for ± 5° F Change
Operating Pressure:	No Effect

MECHANICAL:



Room-type shell (shown) is used in normal convection air flow applications.
Duct-type shell (not shown) does not have ventilation holes on side view and is used in forced-air duct applications.

GENERAL SENSOR EQUATION:

$$\%R.H. = A\{(CZ)^{\left[\frac{(t + 459.7)}{D(t + 459.7) + B}\right]}\}$$

Where:
A, B, C, D = CONSTANTS (See chart below) Z = SENSOR RESISTANCE IN MEGOHMS
t = TEMPERATURE IN °F

```
Computer Equation in BASIC:  %R.H. = A*(C*Z)^((t+459.7)/(D*(t+459.7)+B))
```

CONSTANTS FOR SPECIFIC RESISTANCE RANGES

Sensor Resistance Z	A	B	C	D
> 0.74 Megohm	52474.86	-988.8326	2.55773 E+12	-0.8993676
0.23 Meg to 0.74 Meg	239.5719	-2322.036	2214727	1.423486
< 0.23 Megohm	33.72195	-3549.287	4605.344	3.891261

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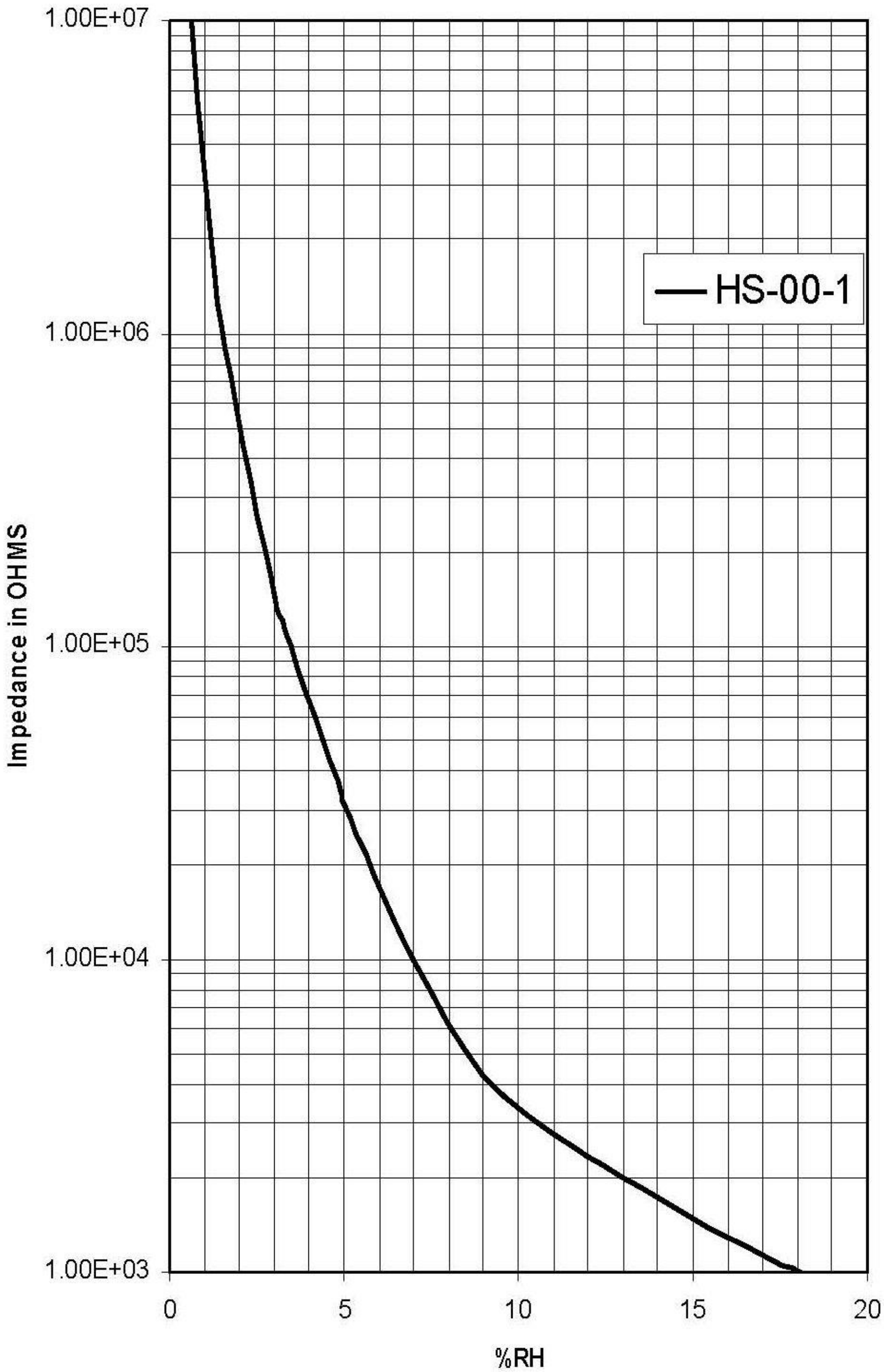
HS-00-1 Low White Sensor



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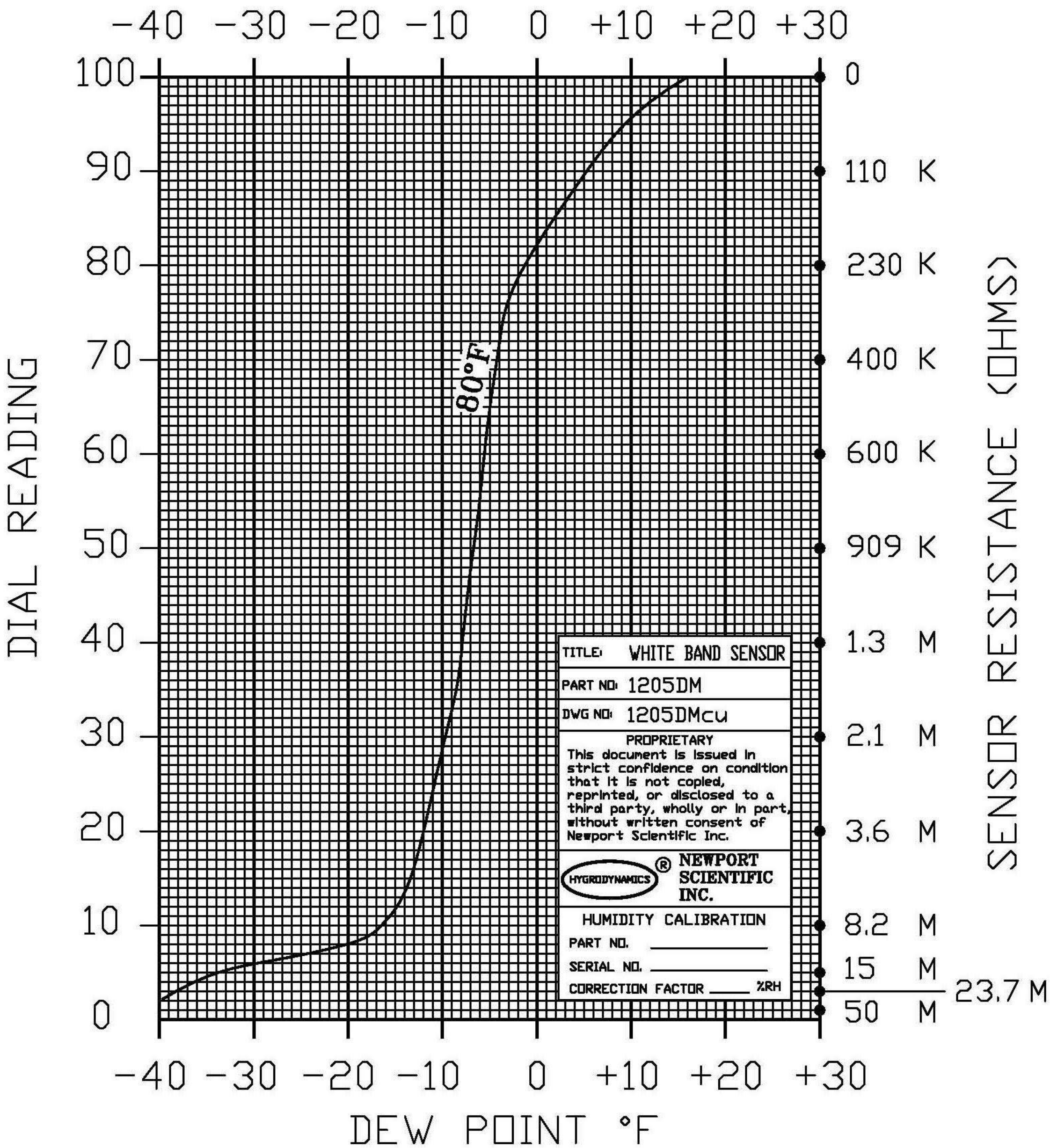
-40 -30 -20 -10 0 +10 +20 +30
100
90
80
70
60
50
40
30
20
10
0
DIAL READING
0
110 K
230 K
400 K
600 K
909 K
1.3 M
2.1 M
3.6 M
8.2 M
15 M
23.7 M
50 M
SENSOR RESISTANCE (OHMS)
80°F
TITLE: WHITE BAND SENSOR
PART NO: 1205DM
DWG NO: 1205DMcu
PROPRIETARY
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HYGRODYNAMICS ® NEWPORT SCIENTIFIC INC.
HUMIDITY CALIBRATION
PART NO.
SERIAL NO.
CORRECTION FACTOR %RH
-40 -30 -20 -10 0 +10 +20 +30
DEW POINT °F

Compressed Air Precautions

Compressed air is quite handy around a work area, but it can be dangerous if not used properly.

Dangers of Compressed Air:

1. A blast of air under 40 PSI from 4 inches away can rupture an eardrum or cause brain damage.
2. As little as 12 PSI can pop an eyeball from its socket.
3. Air can enter the navel, even through a layer of clothing, and inflate and rupture the intestines.
4. Directed at the mouth, compressed air can rupture the lungs.

The following guidelines will reduce the risk of injury when using compressed air:

1. Examine all hoses, connections, and equipment to see that they are in good condition before turning the pressure on.
2. Never point the air hose nozzle at any part of your body or at any other person.
3. Never look into the end of a compressed air device.
4. Never use compressed air to blow dust or dirt off clothing or body parts.
5. No horseplay with air hose.
6. Never kink the hose to stop airflow - turn it off at the control valve.
7. When using air for cleaning, make sure the pressure is no higher than 30 PSI.
8. Always wear eye protection when using compressed air.

Relative Humidity... Relative to What?
The Dew Point Temperature...a better approach
by Steve Horstmeyer, Meteorologist, Cincinnati, Ohio, USA
http://www.shorstmeyer.com/wxfaqs/humidity/humidity.html

A. THE CONCEPT

Humidity is a complicated concept. So complicated that most TV meteorologists I know cannot and do not explain it correctly - More on this in part "B".

Humidity refers to the amount of water vapor in the air (not liquid water drops or ice crystals or snowflakes).

For years you have seen RELATIVE HUMIDITY during TV weathercasts, and it seems to make sense but as I mentioned it is complicated and even the complications about humidity have complications.

But because the essence is very simple it is amazing There is SOOOO much confusion about humidity.

First when thinking about humidity - ALWAYS THINK ENERGY!

WHAT IS TEMPERATURE? - A definition you will need when reading this.

Temperature - The amount of thermal energy. In a gas like the atmosphere temperature is a measure of the average speed of the molecules. Scientists would say temperature is a measure of the average KINETIC ENERGY of the molecules. The faster air molecules move, the more kinetic energy and the higher the temperature.

B. HUMIDIMYTHS (Myths About Humidity)

Humidimyth #1. Warm air can hold more water vapor.

NO WAY! Since 1802 when John Dalton demonstrated that air is a mechanical mixture of gasses we have known that air in NO WAY "holds" water vapor. Being a mechanical mixture of gasses means the molecules (nitrogen, oxygen, carbon dioxide, water vapor and others) merely occupy the same space. In a large jar containing marbles of 5 different colors, the blue marbles do not hold the red marbles and the red the yellow, the marbles of different colors just coexist in the jar.

This is a bit misleading because in the jar the marbles are stacked on top of each other, in the atmosphere there is plenty of space between molecules SO MUCH SPACE THAT ait is mostly EMPTY SPACE. So if anyone asks you what the atmosphere is mostly - it is mostly empty space.

Oxygen and nitrogen alternately do not have "hook & loop" areas or little hands to grab and hold water vapor molecules.

It comes down to energy.

For the meteorologist the only factors that determine how much water vapor will be in the air are the availability of water and the amount of thermal energy to do the work of evaporation.

A liquid water molecule evaporates from a body of water or from the sweat on your skin if it gains enough energy to break free of the attractive forces holding the molecule to neighboring water molecules. The energy comes from collisions with neighbors and if a molecule gains enough energy it can rocket free of the water. The liberated molecule is then water vapor zipping around with zillions of other molecules in the air.

It has nothing to do with a magical power of the air molecules above. In science there is no magic, nearly everything when investigated at a fundamental level is elegantly simple, rational and quite amazing.

CORRECT TERMINOLOGY:
ON A WARM DAY MORE WATER CAN EVAPORATE BECAUSE
THERE IS MORE THERMAL ENERGY AVAILABLE TO DO THE WORK OF EVAPORATION.

Humidimyth #2. Warm air expands so there is more room for water molecules.

NO WAY AGAIN! There is always plenty of space between air molecules for water vapor molecules to fit. If we imagine oxygen and nitrogen molecules enlarged to about the size of two joined tennis balls at sea level and about 50°F (10°C) there is an average distance of about 4.75 feet (145cm) between air molecules.

It is important to realize that the molecules are zipping around in all directions at hundreds of miles per hour and many collisions are taking place all the time. If a "snap shot" is taken at an instant in time and all the distances measured the average inter-molecular distance between tennis ball size molecules at sea level will be 4.75 feet. (145cm).

Even at 50°F (10°C) there is plenty of room for more tennis balls to fit. When the air is heated to 80°F (27°C) the average distance between the tennis-ball size molecules increases to about 5.5' (168 cm), not a great increase in average inter-molecular distance.

Conclusion: The amount of water vapor in the air has nothing to do with distance between molecules.

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C. THINK ENERGY

When thinking of humidity always think in terms of energy and there is only so much energy to go around and not all of it is available to do the work of evaporation. The remainder goes to the other molecules in the air - each gas in the mechanical mixture gets its fair share.

There is a connection between humidity and air temperature, but the connection has nothing to do with warm air "holding" more water vapor. Think of air as a kinetic energy delivery system. Warmer air moving into a region has more thermal energy than the air it is replacing. At the molecular level we say the average kinetic energy of the molecules is greater in the warmer air and the thermal energy of the warmer air is transferred to water molecules as the faster moving air molecules collide with the slower molecules in the water. The faster moving air molecules lose energy and the slower moving water molecules gain energy and begin to move faster and collide with each other more violently. Some of the water molecules will gain enough kinetic energy (or speed or thermal energy - all three are the same) to escape the liquid and become a free moving gas molecule. If the newly arriving air is colder the opposite occurs.

Myth #3. Evaporation is precisely the opposite of condensation.

FOR A THIRD TIME - NO WAY! A liquid molecule of water is closely surrounded by many others, all moving about, twirling, swirling and gliding around each other in an incessant dance. Almost all the kinetic energy a liquid molecule needs to evaporate is gained from collisions with its surrounding liquid neighbors.

Air does deliver some thermal energy to the liquid, but because the number of molecules (molecular number density) in the air above the interface is about 1000 times less than the number of molecules in the liquid, by far most of energy for evaporation will come from the liquid.

A molecule evaporates when sufficient kinetic energy is gained through collisions with its neighbors for it to overcome the attractive forces between the liquid molecules. These forces include hydrogen bonds and Van der Waals force. As the molecule escapes it takes with it kinetic energy, leaving the water surface with a diminished total kinetic energy.

A molecule condenses when it is moving slowly enough and is pulled back to the water surface by the attractive forces, i.e. its velocity is insufficient to resist the pull of the various forces of attraction. The molecule plunges into the water, transferring energy to the molecules near where it hit the surface and is once again liquid.

It is easy to see why evaporation cools a surface and condensation warms it - when you THINK ENERGY

So.....

CORRECT CONCEPT:
EVAPORATION IS PRIMARILY DEPENDENT ON THE TEMPERATURE OF THE WATER, AND CONDENSATION IS PRIMARILY DEPENDENT ON THE TEMPERATURE OF THE AIR. THE NET EXCHANGE OF ENERGY IS THE SAME BUT STRICTLY SPEAKING THE PROCESSES ARE FUNDAMENTALLY DIFFERENT.

Relative humidity expresses how much of the energy available for evaporation has been used to "free" liquid water molecules from hteir neighbors. A relative humidity of 50% means half the available energy has been used to evaporate water from the ground, streams, lakes anywhere else it is and 50% is still available to do more evaporation.

Relative to What?

On a sticky summer morning the temperature may be 75°F and the relative humidity 90%, a very sticky morning indeed.

As the temperature rises during the day the amount of available energy increases. If by early afternoon the amount of available energy doubles (and it does in summer very often) Without changing the number of water vapor molelcules in the air the relative humidity drops to 45% BECAUSE THERE IS TWICE THE AMOUNT OF ENERGY AVAILABLE - REMEMBER RELATIVE HUMIDITY IS WHAT PERCENT OF AVAILABLE ENERGY HAS BEEN USED AND BECAUSE IT DOUBLED DURING THE DAY THE PERCENT USED IS HALF THE ORIGINAL! RELATIVE HUMIDITY IS RELATIVE TO WHAT .... RELATIVE TO THE AMOUNT OF ENERGY AVAILABLE TO DO THE WORK OF EVAPORATION. Because the amount of energy increased as the sun warmed the atmosphere the percentage of the energy available that was used decreased, i.e. the relative humidity, all the while there was no change in the amount of vapor in the air.

So when you hear someone say its feels worse than 52% relative humidity today, they do not understand the concept of RELATIVE HUMIDITY because 92°F and 52% is a very humid afternoon. Because the concept is confusing (even many TV meteorologists do not understand it) a better measuer is the dew point temperature.

The Dew Point Temperature

Dew point temperature is a measure of humidity. If air is cooled eventually enough energy will be removed for water vapor to begin to condense. When we say condense it just means some of the molecules slow enough so that the attractive forces between liquid molecules are strong enough to make the molecules stick together.Remember the water vapor was originally liquid water and to get it to evaporate you had to add energy. As long as a molecule is moving fast enough (faster = warmer) it will remain vapor, but as a molecule cools (cooler = slower) at some point it will slow enough so it will stick to other water molecules. When that happens scientists say the molelcule condensed.

The temperature where condensation first begins is the dew point temperature.

In terms of relative humidity, as the parcel of air is cooled, the relative humidity increases, when the relative humidity reaches 100%, the air parcel has cooled to the dew point temperature. At a relative humidity of 100% the dew point temperature ALWAYS equals the temperature. The greater the difference between temperature and dew point the lower the relative humidity.

Dew Point vs. Relative Humidity

Unlike relative humidity if dew point increases, it is only because the amount of moisture in the air increases. If relative humidity changes it can be because of temperature changes or moisture changes, or both.

REMEMBER - THINK ENERGY - if the air cools less thermal energy is available so the proportion utilized for evaporation is greater. For example if the relative humidity is 45% and half the thermal energy is removed because the air cools at night the relative humidity will rise to 90%, without changing the amount of moisture in the air. When using dew point temperature as a measure of humidity any change is strictly due to moisture change.

Dew point can never be higher than the temperature. At saturation, i.e. 100% relative humidity the temperature and dew point are the same.

So How Does Dew Point Feel?

On a typical summer day the following apply:

Dew Point Temp. °F	Human Perception	Relative Humidity Air Temp 90°F
75°+	Extremely uncomfortable, oppressive	62%
70° - 74°	Very Humid, quite uncomfortable	52% - 60%
65° - 69°	Somewhat uncomfortable for most people at upper limit	44% - 52%
60° - 64°	OK for most, but everyone perceives the humidity at upper limit	37% - 46%
55° - 59°	Comfortable	31% - 41%
50° - 54°	Very comfortable	31% - 37%
49° or lower	Feels like the western US a bit dry to some	30%

A Common Misconception

One last thing if you ever hear someone say it was 90°F and the humidity was 90%, that has never happened in Cincinnati, (and unless the greenhouse effect goes into overdrive never will). 90°F/90% requires a dew point of 85.5°F. In Cincinnati the highest ever dew point was 81°F. for just a few minutes.

In August 1995 we had four hours of 78°F,79°F,78°F,77°F dew points, the highest persistent dew points I have seen in Cincinnati since working here as a meteorologist. For one hour I did see a dew point of 81°F, just after a thunderstorm.

World Record Dew Points

However many veterans of the Persian Gulf War know what 90°F/90% feels like. The Persian Gulf and Red Sea both attain sea water temperatures in the mid 90's when that happens there is plenty of energy available, along with the 115°F air temperatures, to evaporate water.

The dew point has been measured on the shore of Ethiopia, the area is now part of Eritrea, at 94°F. The highest known dew point temperature in the world. The relative humidity with a temperature of 115°F and a dew point of 94°F is 54% this doesn't tell you as much as the dew point when you consider the table above.

Further information
This article is the result of research started during Fall 2009 after being asked about my experience with dew point monitors and their operation. Subsequent research revealed two readily available sensors and their use. PDF documents referenced to in links are available via email.

These are my notes and thoughts from the past several years. My research and writing takes place after work hours, on personal time, and purely out of personal interest. I've done my best but can not guarantee 100% accuracy throughout. Do your homework and double check before using the information in any critical application. I appreciate constructive suggestions and ideas for improvement. Please let me know if you have found the information useful or if you find errors or typos.

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I'd like someone to assist with proof reading and translation to French. Please email if you are interested in helping out.

The latest changes and updates to this article are available on my personal web page.
http://members.rennlist.org/warren/RelativeHumidityAndDehydrators.pdf

Other items I've been working on.

FM Combiner tuning and testing. Signal flow, intermod calculations, pictures, etc.
http://members.rennlist.org/warren/FMCombinerTuningAndTesting.pdf

Antenna splitter cable replacement, power divider calculations, etc.
http://members.rennlist.org/warren/SplitterCableDesign.pdf

Construct a simple and inexpensive dew point monitor for monitoring dehydrator performance.
http://members.rennlist.org/warren/DewPointMonitor.pdf

Broadcast and RF related grounding ideas.
http://members.rennlist.org/warren/grounding.pdf

Please contact me with any feedback or questions.
VO1KS@eastlink.ca

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"The greatest enemy of knowledge is not ignorance, it is the illusion of knowledge."
Stephen Hawking