1.3 **1680 MHZ RADIOSONDE**

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1. INTRODUCTION

In 1999, the U.S. National Weather Service initiated a program to upgrade its existing network of upper air observation stations with a new generation system employing GPS radiosondes transmitting in the 1680 MHz band. This system, called the Radiosonde Replacement System (RRS), is the first to use GPS technology in the frequency band that had previously been used only by RDF systems. The RRS radiosonde has PTU sensors and wind-finding performance better than any that is currently available. Developing a 1680 MHz GPS radiosonde with improved performance has presented numerous challenges in design and testing.

As part of the RRS program, the National Weather Service (NWS) is upgrading its network of 102 upper air observation stations with new tracking antennas that will track the new GPS 1680 MHz radiosondes. To address the challenges of developing this radiosonde, InterMet put together an international team of meteorological systems engineers and sensor manufacturers. This paper describes key issues in the development of the new sonde and how they have been addressed.

The development team consists of InterMet, Modem, Inc. in France, and InterMet Africa. The design is a modified 403 MHz Modem GL98 with a 1680 transmitter and a circularly polarized antenna. A pressure sensor was added and the overall accuracy and resolution was increased.

2. INTERMET 3010 RADIOSONDE

Figure 1 shows the 3010 radiosonde. It has top and bottom polystyrene cases, a non-hygroscopic wrapper, a temperature-humidity probe and elastic strings for attachment to the balloon. It has three electronics boards and uses 8 AA dry-cell batteries, which provide power for 3 hours. The first electronics board consists of the pressure sensor and the PTU sensor electronics. The second board is the GPS receiver, LNA and GPS antenna. The third board is the 1680 MHz transmitter with its antenna.

The solid bottom polystyrene case has two holes. The first houses the circularly polarized antenna in a vertical position and the second (see Figure 1) stores the mailing bag horizontally.

Figure 1: InterMet 3010 Radiosonde

There are two doors in the upper case. The left door is used to insert the 8 AA cell battery pack. The right door provides access to dip switches for setting the transmitter to one of four frequencies in the 1668.4 to 1700 MHz range. The size of the radiosonde is 112 mm wide by 145 mm deep by 249 mm high and its weight is 426 grams.

While in storage, the temperature-humidity probe is bent down over the top of the radiosonde and protected by a piece of polystyrene.

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3. GPS RECEIVER

The receiver is a Trimble low power miniature Lassen LP C/A code model. It has 8 channels with continuous tracking using 32 correlators. C/A code receivers use the L1 frequency (1575.42 MHz). A cold start of the receiver is done in less than 130 seconds (90%) and the update rate is 1 Hz. The GPS antenna is a shaped dipole array with right-hand circular polarization.

The manufacturer's stated accuracy is 25 m CEP and 0.1 m/s with selective availability (SA) off and 2 m CEP and 0.05 m/s when operated in the differential GPS mode. The NWS TRS stations will be operated in the differential GPS mode with a base station providing the differential corrections.

4. 1680 MHZ TRANSMITTER

Modem, Inc. in France designed the 1680 MHz transmitter. It has a crystal controlled oscillator that controls the selected channel frequency to better than ±100 kHz. It has a left-hand circularly polarized antenna and transmits FM modulated signal containing digital PTU and GPS data. It has low susceptibility to AM noise due to antenna scanning, ground reflections and the atmosphere. A-to-D conversion minimizes these effects. During non-data transmission times, an FM modulated square wave is transmitted to improve tracking by the ground antenna (TRS).

5. TEMPERATURE-HUMIDITY PROBE

The temperature-humidity probe is shown in Figure 2. It is a one-piece assembly. A highly reflective coating covers the thermistor and surrounding mounting structure. The humidity sensor is under the white cap that protects it.

6. TEMPERATURE SENSOR

The temperature sensor is a very small glass bead. Its small size allows a fast response time (<3.6 sec at sea level and 5 m/s ventilation). The white coating is a highly stable, ultra-pure barium sulfate to minimize solar heating. The coating has an extremely high diffuse reflectance of 0.936 to 0.993 over the UV, visible and part of the near infrared ranges (200 nm to 1300+ nm).

7. HUMIDITY SENSOR

The humidity sensor is a variable capacitance device. It has a polymer dielectric insulator with a permittivity that varies with relative humidity. Due to its small size it has a fast response time (2 seconds at sea level and 20 deg C and 60 seconds at sea level and –35 deg C). There is very little performance degradation after long-term saturation with nearly instantaneous de-saturation. There is no performance degradation after immersion and thawing.

Figure 2: Temperature-Humidity Probe

8. PRESSURE SENSOR

The pressure sensor is a compensated piezo-resistive silicon device. It is very small and has excellent long-term stability. It is an outgrowth of the medical and automotive instrumentation industries and is very low cost. It has a resolution of 1 part in 100,000.

9. DATA PROCESSING

The radiosonde microprocessor manages the PTU and GPS data. The PTU data is A-to-D converted and the PTU and GPS data are transmitted in digital format. The ground station Signal Processing System (SPS) down converts the telemetered data to a baseband signal. The SPS performs calculations to recover the PTU and GPS data. A base station GPS receiver is used to correct the position and velocity measured by the GPS receiver in the radiosonde. Once these computations are performed the data is sent to the NWS workstation.

10. PERFORMANCE REQUIREMENTS

A summary of the performance requirements is given in Table 1. The NWS requirement is that 98.5% of the test results are within the listed accuracies (2.5 sigma level).

11. PERFORMANCE CHALLENGES

The NWS requires that the absolute accuracies of the sensors be demonstrated. Clearly, the best way to demonstrate accuracy is under real flight conditions. The problem is that there is no way to measure the true PTU parameters under real flight conditions. Repeatability and the differences between radiosondes are often used as measures of accuracy. The NWS requires extensive chamber testing to determine accuracy relative to precision reference sensors.

Although the reference sensors are much more accurate than the radiosonde sensors being tested, the chambers present a special set of problems. The accuracies of commercially available chambers are not good enough, resulting in stabilities of pressure, temperature and humidity that are not adequate for the testing. Gradients across chambers require that reference sensors be very close to the unit under test. Humidity reference sensor accuracies and time responses of all reference sensors require long test times. The combined errors of the chamber conditions and reference sensors must be 3 to 10 times better than the radiosonde sensors being tested.

12. PRESSURE TEST

InterMet designed and built a test chamber to meet the required pressure and temperature accuracy and stability. The reference pressure sensor maximum error is 0.1 hPa. The pressure stability of the test setup is 0.02 hPa and the temperature stability is 0.1 deg C. We use 7 pressure set points over the operational range of 1060 hPa to 2 hPa and 3 temperature set points over the temperature range of –5 deg C to +45 deg C. At each set point, the radiosonde pressure and reference pressure and temperature are recorded for 5 minutes. The mean and standard deviation of the pressure errors are computed. 99.5% of 230 points must meet the requirement.

Table 1: Performance Requirements

Pressure		
	Range	2 to 1070 hPa
	Resolution	0.01 hPa (may be 0.1 for > 100 hPa)
	Accuracy	1.8 hPa > 400 hPa 0.5 hPa < 400 hPa
	Response Time	1 sec
Temperature		
	Range	-95 to +50 deg C
	Resolution	0.01 deg C
	Accuracy	0.3 deg C (-80 deg C to 40 deg C)
	Response Time	3.6 sec at 1013.4 ±20 hPa between –80 to 40 deg C with ventilation speed 4.5 to 5.0 m/s
Humidity		
	Range	0 to 100% RH
	Resolution	0.1%
	Accuracy	5% (-35 to 40 deg C) 10% - following near saturation
	Response Time	5 m/s, 1013 hPa +25 deg C (40 – 90% RH) 2 s -35 deg C (40 – 70% RH) 60 s
GPS		
	Range – wind Range – position Range - altitude	0 – 164 m/s Any lat, lon -50 to 42 Km, MSL
	Wind Velocity	0.1 m/s res, 1 m/s smoothed error
	Position	100 m resolution
	Altitude	0.1 m resolution

13. TEMPERATURE TEST

Commercially available temperature controllers and chambers have ±2 deg C accuracy and stability. InterMet designed and built a special test fixture which is placed inside a commercial chamber. The test fixture isolates the chamber air from the test air inside the fixture. The reference temperature accuracy is 0.05 deg C. A thermally integrating mass is used to meet the stability requirements of 0.03 deg C.

In the temperature test, 13 temperature set points are used over a –80 to +40 deg C range. At each set point, the radiosonde and reference temperatures are recorded for 5 minutes. The mean and standard deviation of the temperature errors are computed. 98.5% of 300 points must meet the requirement.

14. HUMIDITY

Relative humidity (RH) is a measure of the amount of water vapor in the air relative to the maximum amount that the air can hold at a temperature. In the chamber testing, it is necessary to accurately control the temperature as well as the amount of water vapor in the air. A two-pressure, two-temperature humidity generator developed by NIST and built by Thunder Scientific is used to generate the test conditions.

At a test temperature of 20 deg C, RH of 5 to 96% and back to 5% are used. At a test temperature of -10 deg C, RH of 5 to 88% and back to 5% are used. At a test temperature of -35 deg C, RH of 5 to 68% and back to 5% are used.

The accuracy of the reference equipment is 2% RH at –35 Deg C, and better as temperature increases, which is also dependent on the temperature/pressure sensor accuracies and stabilities. At each set point, radiosonde RH is recorded for 5 minutes. The reference RH is computed from pressure and temperature and thermodynamic properties of water. The mean and standard deviation of the RH errors are computed. 98.5% of 300 points must meet the requirement.

15. CONCLUSIONS

The test equipment challenges have been met and the radiosonde is in pre-production testing. Preliminary test results show that the radiosonde meets all requirements. Full production and field-testing will be done over the next several months.