THE EFFECTS OF RAIN ON MICROWAVE LANDING SYSTEM ANTENNA RADOMES

By

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ABSTRACT

Testing has indicated the sensitivity of the performance of Microwave Landing System antennas to the presence of water on the antenna radomes. Effects include degradation of system accuracy, effective radiated power, and system monitoring. Research has also been conducted in an attempt to find suitable radome materials with water shedding (hydrophobic) properties that would eliminate the problem. Test results and a discussion of candidate radome materials are presented.

INTRODUCTION

The Microwave Landing System (MLS) is in the process of being implemented worldwide as the new all weather landing system for aircraft. It will replace the existing Instrument Landing System (ILS). One of the operational requirements for the system is to guide aircraft to runway touchdown in all weather conditions (termed Category III). Testing conducted in recent years has demonstrated the sensitivity of the performance of the microwave antennas to the presence of water on the antenna radome. The effects can include not only degradation of the radiated signal but also degradation of system monitoring. Research has been conducted to find a radome material with hydrophobic (water shedding) properties sufficient to prevent the accumulation of water on the radomes and thereby eliminate its effects. The radome material also needs to have a sufficient lifetime that it does not create a maintenance problem. This paper describes the effects of rain on the antenna radomes and summarizes the research that has been accomplished on hydrophobic radome materials as applied to MLS antennas.

The susceptibility of problems caused by rain are directly related to the frequency of the radio waves. Problems with transmission loss through rain are greatly accentuated as the wavelength gets close to the size of water droplets. For this reason satellite links which typically operate in the 18-30 GHz frequency range are susceptible to significant transmission loss. Radar surveillance systems that typically operate in the 1000 MHz frequency range are much less affected by rain attenuation. MLS operates at C-Band from 5030-5090 MHz and is marginally affected.

There is a different aspect in which MLS is much more susceptible to problems caused by water on the radome surface than are satellite ground station antennas. That is in the accuracy of the pointing angle of the antenna. MLS is a highly accurate position determining system. The accuracy is superior to surveillance radars and all other navigation systems. Angular accuracies on the order of one milliradian are typical. Great care has been taken in the design of MLS antennas to ensure as much protection as possible from multipath and other error sources.

THE EFFECTS OF WATER ON MLS RADOMES

There are three ways in which the performance of MLS scanning beam antennas can be degraded by the presence of water on the radomes. These are accuracy, effective radiated power, and system monitoring.

ACCURACY

The performance of MLS depends upon very accurate electronic scanning of a narrow beam through space (horizontally for azimuth and vertically for elevation). Total system errors, termed Path Following Error (PFE), including all factors are limited to 0.133^o (2?) in elevation and to approximately 0.10^o (2?) in azimuth, depending upon runway length. When allocating error tolerances to the various factors generally no allowance is made for errors induced by water on the radomes. And since there is usually little margin in the accuracy budgets, this means that the allowance for radome effects has to be extremely small. However field measurements have found that, under certain rain conditions, errors on the order of 0.1^o can occur. The exact nature of the cause of the errors has not been determined, but it probably involves a combination of signal blockage and diffraction of the RF as it is

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transmitted through the water on the radome surface. Testing has determined that the most severe effects on accuracy occur when the water is running down the radome surface either in sheets or rivulets. When water is on the surface only in the form of beads and not sheets or rivulets the beam pointing errors are much smaller.

Controlled tests have been difficult to design. However some testing has been accomplished under realistic conditions and rain rates. One such test was conducted at the U.S. Federal Aviation Administration (FAA) Technical Center in Atlantic City, New Jersey on June 6-7, 1988. The system tested was a Bendix 1.5° beamwidth elevation antenna. The outer surface of the radome consists of a Teflon film bonded to Tedlar. There will be more discussion later concerning radome materials. A hose from a fire engine was used to spray water on the radome and a rain gauge at the bottom was used to estimate rain rates. Data was collected from the system monitors (integral and field), a test van in the far field, and flight data. Rain rates measured varied from 1 to 40 in/hr. With the higher rain rates, peak errors between ±0.1° and ±0.2° were measured. With more realistic rain rates of 2 in/hr or less, peak errors varied from ±0.05° to ±0.10°. Figure 1 shows the errors measured on a flight test with a rain rate between 1 and 2 in/hr. Reasonable correlation was found between the occurrence of rivulets and the maximum errors. Generally good agreement was found between the field monitor (located at a distance of 200 feet), test van (at 560 feet), and aircraft flight data.

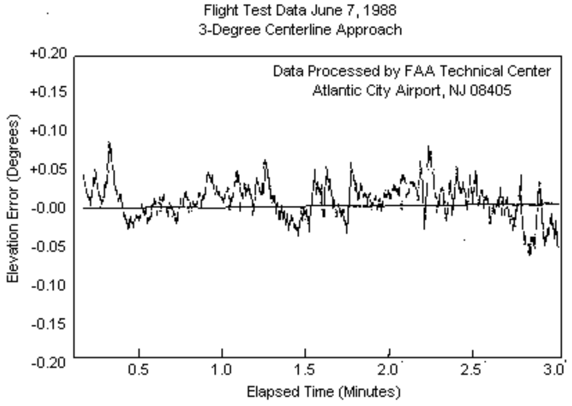

Figure 1. Elevation Error in Simulated Rain Test (1-2 in./hr.)

Similar tests were conducted with the same antenna on May 22, 1990. Again peak angle errors of approximately ±0.1° were measured under varying rain rates. During these tests more control over rain rate was achieved by placing a pipe with shower nozzles at the top of the antenna and varying the flow rate. Figure 2 is a plot of the error as measured by the test van, with a rain rate of approximately 2 in./hr.

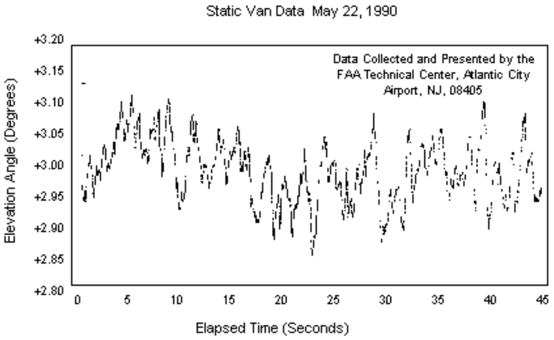

Figure 2. Elevation Error in Simulated Rain Test (approx. 2 in./hr.)

Tests conducted with Hazeltine (Model 2600) antennas yield similar results. The Hazeltine radome is a Teflon/fiberglass fabric. Factory tests were conducted under a controlled rain rate of 1 in./hr. The PFE on the 1.5° beamwidth elevation antenna increased as much as 0.05°. Field data was collected on the same elevation antenna at the FAA Technical Center on May 23, 1990. Peak errors in excess of 0.10° were measured.

The azimuth antennas appear to be less susceptible to these problems. Data collected on the Bendix 2.0° beamwidth azimuth antenna at the FAA Technical Center have shown peak errors to be less than 0.030°, although this is still large enough to be of concern. Factory tests on the Hazeltine 2.0° azimuth antenna found little effect on accuracy with a 1 in./hr. rain rate.

EFFECTIVE RADIATED POWER

Signals transmitted at the MLS frequency (5000 MHz) will be attenuated by water. In recognition of this an allowance is made in the MLS power budget for transmission loss due to rain. The loss allowed is 2.2 dB [1]. This allows for a 2 in/hr rain cell of 5 nautical miles and 1 in/hr for 15 nautical miles [2]. These allowances do not take into account the losses that can occur due to water on the radomes. Field measurements from the experiments described above and other tests have found decreases in Effective Radiated Power (ERP) in excess of 3 dB. Additional measurements [3] have also found transmission losses of 1-2 dB through radome materials sprayed with water.

SYSTEM MONITORING

The performance of MLS scanning beam antennas is primarily monitored through two different RF monitors. One is a field monitor generally located 100-300 feet in front of the antennas. The other is an integral monitor which samples the radiated signals in close proximity to the aperture of the scanning beam antenna. Based on the sampled signal the integral monitor is able to form the scanning beam and measure its accuracy and power.

Field Monitor

Some of the problems discussed above relative to the presence of water on the scanning beam antenna radomes are also applicable to the field monitor antennas. Most field monitor antennas designed for use with MLS consist of either a horn antenna, a waveguide array, or a dipole array. The most significant problem caused by water on the surface of the monitor radome is related to transmission loss. Transmission losses similar to those seen for the scanning beam antennas (3 dB and higher) have been measured. Effects on the measured angle accuracy have not been a problem with the field monitor antennas. Monitoring of the ERP by the field monitor is not required by MLS specifications. This can be accomplished by the integral monitor. However even in the case where the ERP is not monitored by the field monitor, a decrease in signal level could have an effect on the monitor's performance.

One aspect of field monitor antenna design that has been evaluated concerns the distance between the antenna element and the radome. The two basic designs can be classified as being either conformal or suspended. In the conformal design the radome material is bonded directly to the antenna element, usually a waveguide or dipole array. In the suspended design the radome is physically separated from the antenna element, by at least one quarter wavelength. Measurements [3] have found that when coated with water the conformal design results in more transmission loss than the suspended design. The conformal design resulted in approximately 3.5 dB loss while the suspended design generally showed 1.5-2.0 dB loss.

Integral Monitor

The physical design of the integral monitors is significantly different between azimuth and elevation. They are not equally susceptible to problems with interference from the environment such as that caused by water on the radomes. The azimuth integral monitor normally is a waveguide (commonly called a manifold) that is bolted directly onto either the top or bottom of the scanning beam array. The detected RF is coupled directly into holes in the waveguide. Therefore it will not receive any RF interference that might be coming in through the antenna radome or elsewhere.

On the other hand the elevation integral monitor is normally a slotted waveguide that is located to one side of the scanning beam array (see Figure 3). Unlike azimuth, it can't be coupled directly to the array, and is therefore space coupled. As a result it will receive RF interference that comes back into the antenna through the radome. Experiments have shown that when water is present on the radome the transmitted RF will be reflected off the water and back into the integral monitor causing an error in the signal detected. Changes in the angle decoded by the integral monitor as large as 0.10^{o} have been measured. It has even been found that the presence of streams of water in front of the aperture and not on the radome at all will cause a reflection. This is not that surprising, since water has a high dielectric constant of approximately 76 at 5000 MHz [6], and thus will have a nearly unity reflection coefficient. Similar effects were found by placing a metal rod in front of the aperture. Again, as with the effects on accuracy and ERP, normally it is only when the water is in sheets or rivulets that a significant reflection occurs.

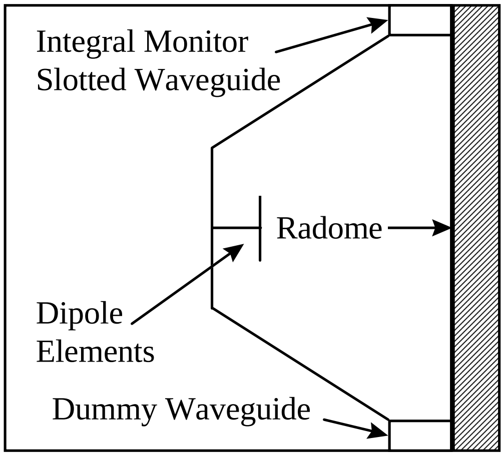

Figure 3. Elevation Antenna Aperture

POSSIBLE SOLUTIONS

The obvious solution to the various problems caused by the presence of water on the radome is to use a radome material which will not allow water to accumulate on the surface. The typical radome used

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for antennas does not have this property. The material property of being able to shed water is called hydrophobicity.

HYDROPHOBICITY

Figure 4 shows the various ways in which water can adhere to a surface. In order to be able to classify materials in terms of their hydrophobicity a standard measurement technique was developed and is generally accepted in the industry. The parameter used is the water contact angle. Contact angle is a measurement of the angle between the tangent of the edge of the water droplet and the surface. Low contact angles (less than 90°) indicate that the surface has high wettability and thus low hydrophobicity. High contact angles (greater than 130°) indicate low wettability and thus very high hydrophobicity. Materials with contact angles in this range are classified as superhydrophobic. Water droplets generally will not even adhere to such surfaces. On the other hand, materials with low contact angles will allow water to adhere in films. Materials with medium contact angles normally do not allow films to form, but will allow rivulets to form in rain conditions. Superhydrophobic materials will not allow this to occur.

CANDIDATE MATERIALS

There are materials available which exhibit hydrophobic properties to varying degrees. Among these are Teflon, fumed silicon dioxide, and HMOD-4. Prior testing [3] had found that Teflon and fumed silicon dioxide were both possible candidates for use with MLS.

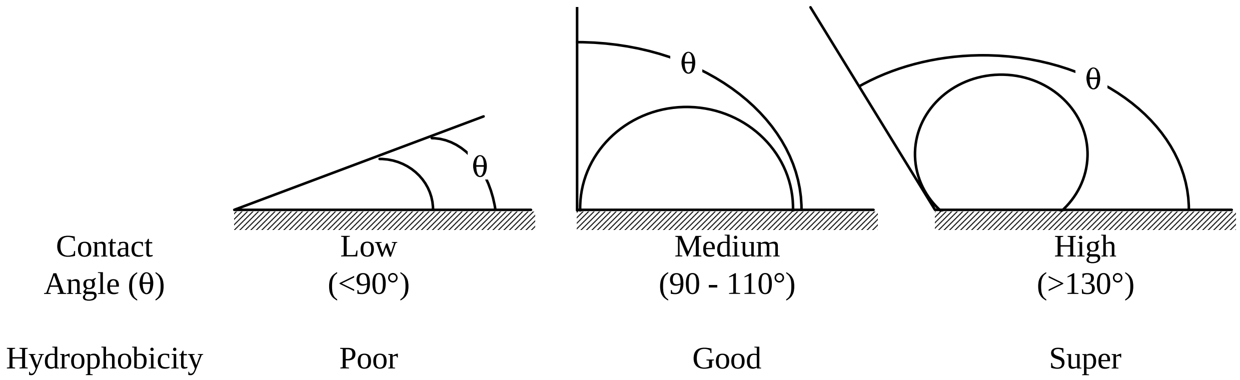

Figure 4. Water Droplet Contact Angle and Hydrophobicity

HMOD-4

HMOD-4 is a material that was developed for use on aircraft windshields to improve visibility in rain. Measurements [3,5] have found that HMOD-4 exhibits a low amount of hydrophobicity. Contact angles measured upon initial application range from 40-70°. In addition, it was found that its performance will degrade over time due to weathering. For the above reasons it has not been considered a suitable material for use with MLS.

Fumed Silicon Dioxide

Fumed silicon dioxide is a white powder which is usually either sprayed or brushed on a base coat material. It is marketed under various names by different manufacturers. Among those tested have been Vellox and Silibond. Fumed silicon dioxide is classified as a superhydrophobic material. Measurements [3,5] have generally found contact angles to be 130-150° upon initial coating. Laboratory and field testing have consistently shown excellent performance in keeping the radome free of water. This results in rain having little or no effect on accuracy and transmission loss. An example is shown in Figure 5. As part of the testing at the FAA Technical Center on May 22, a temporary radome coated with Vellox was mounted to the Bendix elevation antenna. In all test conditions no errors were detected due to the presence of water on the radome. This included extremely high rain rates. Even then the superhydrophobicity of the material would not allow any water to adhere to the radome surface and form rivulets.

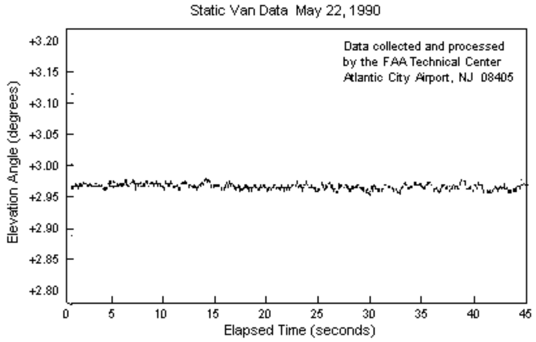

Figure 5. Elevation Error in Simulated Rain Test (heavy rain rate) with Vellox Coated Radome

The problems associated with fumed silicon dioxide are in application and life expectancy. The application with current materials is difficult, especially when done in the field environment. A base coat must be applied, followed by the top coating of fumed silicon dioxide. Field tests have also found that recoating can only be done a limited number of times before the old material must be stripped and a new application made. Because of these problems there is a concern about the life expectancy. Field tests to date have found a maximum life expectancy of about one year. After this period of time the coating loses its hydrophobic properties. This presents maintenance difficulties in having to reapply the material on a yearly basis.

Teflon

Teflon (tetrafluoroethylene) is a material well known for its non-stick and non-wettability properties. Like fumed silicon dioxide it is marketed under various names by different manufacturers. Those tested include Teflon TFE, Tefzel, Teflon FEP film, and Teflon 100-20R fabric. Teflon has good hydrophobicity. Measurements [3] generally find contact angles of approximately 90^o. Testing has also found life expectancy to be very good. Very little deterioration of the radome material has been found.

The problem with Teflon is that it has been found that it is not hydrophobic enough for use with MLS. The testing of antenna performance previously described was done on antennas with Teflon based radomes. Because MLS can tolerate only very small amounts of deterioration in accuracy performance, Teflon does not appear to be suitable as a hydrophobic radome material.

FIELD MONITOR ANTENNA DESIGN

In the previous discussion mention was made of significant transmission losses measured through field monitor radomes. This data is for materials made of either Tedlar or Teflon. The same measurements on radomes coated with fumed silicon dioxide resulted in insignificant loss. The conclusions that can be reached concerning field monitor antenna design are the following. First, the radome should be the suspended type rather than conformal. Regardless of the hydrophobic material used this will result in lower loss. Second, the radome should be hydrophobic. As discussed previously, the ERP of the antenna should be monitored by the integral monitor. Although a reduction in received power should not result in erroneous angle measurements at the field monitor, it is not desirable to allow this to occur.

CONCLUSIONS

Research has determined that the performance of MLS can be significantly affected due to the presence of rain on the antenna radomes. Of greatest concern is the performance of the MLS in Category III conditions. In that case it is imperative that the system be essentially immune to shutdowns due to environmental effects.

The ultimate solution to the problem is to develop a radome material with sufficient hydrophobic properties. This probably will involve the integration of Fumed Silicon Dioxide with a base radome material during the manufacturing process. This should improve the life expectancy and eliminate the maintenance problems with standard coatings. More research is needed to determine the feasibility of this approach.

More research is also needed concerning the electromagnetics of the phenomena that causes angular errors to occur in the presence of water on the radome. More knowledge about this will assist in developing the optimum solution.

ACKNOWLEDGEMENTS

I wish to thank Dave Huntington of Bendix Communications Division for his assistance in the collection and analysis of much the data referenced in the paper. I also wish to thank Cliff Mackin and his coworkers from the FAA Technical Center, who were responsible for gathering and providing most of the data referenced.

Presented at the Symposium on Antenna Technology and Applied Electromagnetics, Winnipeg, Canada, August 15-17, 1990.

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Presented at the Symposium on Antenna Technology and Applied Electromagnetics, Winnipeg, Canada, August 15-17, 1990.