Weather and Radar Interactions

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Abstract—This paper will discuss the effects of weather on radar system performance. This discussion will be based on computer simulations and climatological data. The relationships between frequency and range will be explored as they interact with the weather. This effort is being conducted in the RF Technology Division of the Applied Sensors, Guidance, and Electronics Directorate, US Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC) on the Redstone Arsenal in Huntsville, Alabama.

Although there is extensive work in this area this paper will present the background in a condensed form and go into greater detail of the attenuation due to rainfall rates and cloud water content. The ground work for this effort was performed in a paper titled “Weather Clutter and Effects on Radar Systems”, Joel P. Booth. This research is a continuation of that work. The goal is to uncover any data relating the attenuation or reflection from clouds verses the cloud liquid content. Another goal is to try and quantify attenuation due to rain fall rates.

The data obtained from this effort will be used in the selection of new radar system parameters. The effects of weather impact the selection of operating frequency and modes. The results also effect the combination of modes in seeker system design to achieve the mission.

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I. INTRODUCTION AND BACKGROUND

In today’s world it is becoming increasingly important to exploit any advantage in battle. To this end, the U.S. Army is researching the need to upgrade current missile seeker technology. The general trend is toward multi-mode type seeker systems in an attempt to overcome weather and other battlefield conditions. This paper will focus on the background of current missile technology and how weather affects it. This data will be used in decisions for future efforts in the seeker arena.

For completeness, the following is a short history of current missile systems including the Hellfire, TOW (Tube-launched, Optically tracked, Wire-guided missile), LOSAT (Line-Of Sight-Antitank-Missile) and Javelin. These systems represent the use of, along with combinations of, optical and radar technologies in the guidance and targeting schemes.

The LOSAT missile uses a second generation Forward Looking Infrared acquisition sensor (FLIR). The LOSAT has a range of around 4+ Km. The fire control system can track up to three targets at a time and guide weapons to each of these target in order of acquisition [1].

The TOW uses a command to line of sight guidance. After firing the missile, the gunner must keep the cross hairs of the sight centered on the target to ensure proper guidance. The TOW has a range of around 4-4.5 Km. The TOW has undergone several upgrades since it’s original fielding in 1970 [2].

The Javelin missile uses a long-wave IR seeker to engage its targets. The missile has a range of 2.5 Km. The Javelin has a fire and forget feature due to its target lock before launch guidance programming [3].

The HELLFIRE missile has two different seeker options. The first homes on a laser spot and the second is a Radio Frequency (RF) seeker. The laser seeker and the longbow (RF) are both currently fielded and are actively being used [4]. The Hellfire has an effective range of up to 8 Km with current guidance hardware. The range may be limited by the propulsion unit [5].
Each guidance type has its own limitations due to weather. Although the seekers employ different wavelengths of energy they are all forms of electromagnetic propagation. In this paper I will discuss the limitation due to weather. I will also mention the direction for the future of the Army’s missile seeker work.

II Weather Concerns

There are many different aspects of weather and each one can have a different effect on Electromagnetic propagation. Electromagnetic propagation is adversely affected or attenuated by different weather conditions. The attenuation is generally brought about by either dispersion or absorption [6]. The main attenuation components of weather are rain and suspended water vapor. Although the attenuation from other particles and gases can have a signification effect on electromagnetic propagation, the main concern is generally focused on rain and water vapor. Since the different wavelengths react differently to the weather the paper will look at the effects based on wavelength.

A. Scattering

Scattering describes the phenomenon that occurs when the electromagnetic energy is deflected or dispersed away from the intended target or the receiving antenna. The following illustration shows how scattering from a raindrop occurs.
This is a very straightforward example of the scattering from one droplet. Now, consider that each droplet can scatter a small amount of the radiated energy and that there are many droplets in a storm. The energy scattered from one droplet could collide with the scatter from another droplet, and so on. This leads to a very complicated picture of collisions and re-radiations.

B. Absorption

Absorption is a little more complex than dispersion in that there is true absorption and pseudo-absorption [6]. True absorption occurs when the electromagnetic energy passes through different regions of the atmosphere having different dielectric properties. As the electromagnetic energy passes from one region to another, such as the air to rain, a small amount of energy is lost due to the heating of the particles. This occurs because the water acts as a poor dielectric and absorbs some of the power from the electromagnetic radiation. Pseudo-absorption deals with the fact that there are magnetically charged particles in the air, such as water, that begin to rotate when electromagnetic radiation passes by [6]. The rotation is induced because a small portion of the electromagnetic energy is imparted to the particle. When a magnetically charged object rotates, it radiates random electromagnetic energy that can cause interference with the returning signal from the intended target. At the very least, this random energy will raise the background noise level. There is also an overall loss of power due to the small parts of energy transferred to each particle that is caused to rotate. The following section will identify the main particles and weather conditions that adversely effect electromagnetic propagation.

C. Rain

Rain is defined as water condensed from atmospheric vapor falling to earth in drops. In addition, the diameter of the drops must be greater than or equal to 0.5 millimeters [8]. Rain is usually described by the rainfall rate method. For example, 4mm per hour is a common specification for moderate rainfall [9]. The following chart shows the attenuation due to different rain rates over the 3 to 100 GHz range.

Figure 3. Attenuation due to Rainfall Rates [10]
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The attenuation due to rain is based on the rate of precipitation and the droplet size. The attenuation of electromagnetic energy is related to the apparent area of the raindrops. The area of a raindrop is a function of its diameter. As the wavelength of the operating frequency approaches this dimension, the system will experience greater attenuation due to the rain. A common misconception is that rain droplets are all the same size for a given rainfall rate. As it turns out, each rainfall rate has a range of different sized droplets, based on a statistical distribution. The follow chart is a graphical representation of the distribution for some common rainfall rates. This distribution is referred to as the Laws and Parsons (L-P) after the two gentlemen that developed it [11].

### Table 1. Drop Sizes per Rainfall Rate

<table>
<thead>
<tr>
<th>Rain Drop Distribution based on Rainfall Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
</tr>
<tr>
<td>0.25 mm/hr</td>
</tr>
<tr>
<td>Percentage of the total volume</td>
</tr>
</tbody>
</table>

In general terms, rain can be thought of as two types, convective (or thundershowers) and stratiform (or widespread). Convective rains are usually associated with approaching weather fronts [11]. Convective cells, as they are commonly known, are characterized by high rainfall rates exceeding 25 mm/hr. It is also common for convective cells to be localized to a specific area [8]. Convective cells are also typically very short in duration, usually less than an hour. Convective cells can possess vertical profiles that exceed the average freezing height of the atmosphere. Stratiform rainfall, on the other hand, is usually spread out over hundreds of kilometers. The duration of stratiform rainfall is typically greater than an hour and rainfall rates are less than 25 mm/hr. The stratiform cloud layers usually have a height of 4 to 6 km [11].

### D. Hail

Hail is defined as hard pellets of snow or ice that fall to earth, generally ranging from the size of raindrops to the size of golf balls [8]. Hailstones generally do not greatly attenuate the RF energy as long as they remain frozen.
However, as soon as the stones start to melt, they have the ability to be more disruptive than rain. As the stones melt, a thin covering of water forms on the outside of the stones. It is this covering of water that attenuates the RF. The hailstones act like large raindrops due to the frozen cores. The attenuation caused by the covering of water is attributed to the different dielectric constants of water and ice. The dielectric constant for water at 20ºC is 80.4. The dielectric constant for ice is 3.2 [12]. The dielectric constant is a measure of a material’s ability to concentrate the electrostatic lines of flux. This means the higher the number, the more conductive the material. Since good conductors are also good radiators it is easy to see why hail with a layer of water on the outside would cause a greater problem than the ice particles alone.

E. Snow

Dry snow is the least attenuator of RF energy, even at very high fall rates. For example, at the fall rate of 15 centimeters per hour only 0.01 to 0.04 dB per kilometer of attenuation was measured over the 18 to 100 GHz range [6]. Once again, this is supported by the lower dielectric constant of ice. In addition, the average density of snow is eight times less than the average density of rain. This would mean at the same fall rates there would be a lot less snow than rain [7].

Wet snow is snow with very high water content, often considered a mixture of rain and snow. Wet snow attenuates the electromagnetic energy much in the same way is rain. The attenuation due to wet snow can be estimated by Equation (1.7) [13]:

\[
Wet\_snow\_attenuation = \frac{0.00349r^{1.6}}{\lambda^4} + \frac{0.0022r}{\lambda}
\]

where

- $\lambda$ is the wavelength in centimeters, and
- $r$ is the water content of the wet snow in mm/hr.

Equation (1.7) produces results in dB/km as seen in Figure 4.
Taking a closer look at Figure 4, it can be seen that as the wavelength gets smaller the attenuation rises rapidly. This is illustrated by Figure 5.
150 GHz the attenuation by wet snow becomes a large problem and would render the system unusable. The attenuation would affect the IR and higher RF regions of the frequency spectrum.

**F. Fog and Clouds**

Fog is defined as condensed water vapor in cloud-like masses that lie close to the ground and limit visibility. The droplet size is generally up to 0.2 millimeters in diameter [4>8]. Fog is often considered just a cloud at very low elevation. Clouds are defined as a visible body of fine droplets of water or particles of ice dispersed in the atmosphere above the earth’s surface at various altitudes. Since clouds usually fall into one of two categories, either water or ice, the water clouds act like fog in attenuating electromagnetic radiation while the ice clouds usually have an attenuation that is two orders of magnitude lower than the water clouds.

**G. Other Scatterers**

There are many other scatterers that could be encountered in the atmosphere. Sand particles can be suspended in the air and offer large attenuation in the visible region of the electromagnetic region. Sand also attenuates RF but not as much as some of the other weather effects. The sand particles are on the same order of size as some raindrops [6]. There are parts of the world where sand is a problem in that the particles might have diameters comparable to raindrops, but the sand storms are generally close to the ground—only extending four meters off the ground. These particles will only offer some attenuation if the target of interest is on the ground or the radar system is ground-based.

**H. Atmospheric gases**

Atmospheric gases such as water vapor and oxygen attenuate the electromagnetic energy in certain frequencies. Water vapor has a significant effect in the 100 to 500 MHz range and oxygen has great effects at 22 GHz and several frequencies centered around 60 GHz. Figure 6 shows some of the peak areas of absorption in the millimeter wavelength spectrum.
III. Relationship of Operating Frequency and Propagation

Another very important relationship is the wavelength of the operating frequency and the atmosphere. Table 2 shows some frequencies and their corresponding wavelengths in meters and millimeters.

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Wavelength (m)</th>
<th>Wavelength (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>0.0375</td>
<td>37.50</td>
</tr>
<tr>
<td>12</td>
<td>0.0250</td>
<td>25.00</td>
</tr>
<tr>
<td>18</td>
<td>0.0167</td>
<td>16.67</td>
</tr>
<tr>
<td>27</td>
<td>0.0111</td>
<td>11.11</td>
</tr>
<tr>
<td>40</td>
<td>0.0075</td>
<td>7.50</td>
</tr>
<tr>
<td>75</td>
<td>0.0040</td>
<td>4.00</td>
</tr>
<tr>
<td>110</td>
<td>0.0027</td>
<td>2.73</td>
</tr>
<tr>
<td>300</td>
<td>0.0010</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Recalling from earlier in the paper, some of the raindrop diameters were on the same order as the wavelengths of interest. As the operating frequency approaches the diameter of the raindrops, the drops absorb a larger portion of the electromagnetic energy. Physics dictates that anything that absorbs electromagnetic energy will also radiate that energy. This reradiated energy is commonly referred to as sky noise or brightness temperature. The sky noise will raise the overall noise floor in the system. It can be easily seen in Figure 5 that a designer would be well advised to avoid the frequencies that correspond to the highest sky noise. It is also important to note that the curves vary not only in frequency, but also in angle of elevation of the radiated energy [14].

Figure 6. Atmospheric Absorption of Electromagnetic Energy [10]
After examining Figure 7, it becomes apparent why 60 GHz and 120 GHz would be poor choices for operating frequencies. These two frequency regions are areas of extreme sky noise and would cause the radar to have higher noise floors to deal with in the receiver [14]. Secondly, considering the relationship between frequency and range, Figure 6 will show that, if all other parameters are held constant, the maximum range will go down as frequency increases.
Figure 8 is a very simple look at the relationship between range and frequency. It does not take into account that as the frequency increases and the size of the aperture is held constant; a general increase in the gain of the antenna is experienced. In Figure 8, the horizontal black line, referred to as the threshold line, is set at 13 dB which is generally accepted as a good working goal for systems. The code for this plot can be found in the Appendix.

IV. General Weather Patterns

A major design question is, how often will a system operate in less than perfect weather conditions? Also, it is important to consider under what weather conditions the system must operate. For example, consider the general specification of 4mm/hr widespread rain that most systems are required to operate in. Based on past climatological data, this specification is only exceeded 1.2% of the time in the continental United States. In general, the rainfall rates worldwide only exceed this specification 1.7% of the time. The storms producing the high rainfall rate numbers also tend to be more localized and short-lived [15]. All other weather effects are seasonal at best and rarely last for an extended period of time.

V. Conclusion

In conclusion, the data in this report supports the use of multi-spectral or multi-mode seeker systems for the next generation missiles. The front runner in this field is the Joint Common Missile (JCM). The JCM is proposed to have a tri-mode seeker, combining millimeter wave, infrared, and semi active laser [16]. The tri-mode seeker will allow for the widest range of operational conditions as well as increased range and fire-and-forget [16].

References:


**BIOGRAPHY**

Joel P. Booth is a research engineer with the Applied Sensors, Guidance, and Electronics Directorate of the U.S. Army Aviation and Missile Command; Redstone Arsenal. He graduated with a B.S. in Electrical engineering from the university of Alabama in Huntsville.