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Attenuation of Microwaves by Rain Drops

By

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Abstract:

In connection to microwave interaction with the rain drops, characterizing equations of microwave attenuation by the rain drops were derived. The attenuation constant was found to be an increasing function with rain rate when the rain drop is at resonance. The results support the previously reported experimental results.

Keywords:

Attenuation, Rain rate and Resonance frequency.

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1. Introduction:

Presence of rain in the atmosphere affects the performance of a Microwave communication link. When rain falls over portions of the terrestrial air link, large variations in received power can be expected depending upon the rain rate and the diameter of the raindrops [7]. The microwave energy transfer to the rain drops is monitored by observing the attenuation constant of microwave propagating through the Atmosphere [2]-[3]. The studies showed that the behavior of microwave propagation is greatly dependent upon the attenuation constant, which in actual is dependent on the media used [7]. It has been known that a rain drop absorb more microwave energy if the frequency of microwave equals the resonance frequency of the oscillating raindrop than the case of off–resonance [4]-[7]. However it has not been well investigated as to the effect of raindrop pressure (on the surrounding atmosphere) on this microwave energy absorption. For the initial thinking, the microwave absorption is considered proportional to the raindrop pressure. But some experimental results reported indicated that under a certain condition, the amount of absorption decreases with the increasing pressure [1]-[6]. This paper is to characterize the pressure effect on microwave energy transfer to the raindrops when rain rate is increases.

2. Attenuation by Rain Drops:

A conceptual model to explain the behavior of microwave attenuation constant vs. raindrop pressure is presented. The model is a cubical model and says that when each oscillator mass **M** in the system is oscillating at a frequency **f,** the amplitude of oscillations of each oscillator is the same in each of the three orthogonal directions. The oscillator is then said to have cubical oscillations of amplitude **(X/2)** in each of the six directions. Now suppose that the oscillator exerts a pressure **P** on any one of the sides of the cube having an area **A**. The total force **F** exerted by the oscillator on that side is:

$$\mathbf{F = M\ a = PA} \qquad (1)$$

where,

$$\mathbf{A = X}^2 \qquad (2)$$

and acceleration 'a' is given by

$$\mathbf{a = \omega^2 (X/2) = 2\pi^2 f^2 X} \qquad \mathbf{(3)}$$

Substituting both Equations (2) and (3) in Equation (1), we obtain

$$\frac{\mathbf{M}}{\mathbf{(X/2)}} = \frac{\mathbf{P}}{\pi^2 \mathbf{f}^2} \qquad (4)$$

Since the microwave attenuation in the atmosphere is proportional to the mass of the oscillator and inversely proportional to the amplitude (X/2) of the oscillator, it can be stated that attenuation constant ***á***

$$\acute{a} = \frac{\mathbf{kM}}{\mathbf{(X/2)}} \qquad (5)$$

Where, 'k' is proportionality constant. Each oscillator of mass **M** is assumed to be composed of a rain drop or a group of rain drops which take part in the transition process.

Let us choose another constant k' such that

$$\mathbf{k} = \frac{\mathbf{k'}}{\mathbf{M}} \qquad \mathbf{(6)}$$

Substituting Equation (6) and Equation (4) in Equation (5), we obtain,

$$\alpha = \frac{\mathbf{k'}}{\pi^2 \mathbf{f}^2} \frac{\mathbf{P}}{\mathbf{M}} \qquad (7)$$

It should be emphasized in Equation (7) that the attenuation constant **α** is proportional to the (P/M) ratio. When the pressure is increased, the mass M increases as well. But (P/M) ratio is not necessarily constant. It is postulated that at resonance frequency due to synchronization effect of rain drops, the (P/M) *r*atio is dominated

by M. The majority of the mass of the oscillator oscillates in the same direction at the same time in this case. Hence attenuation constant decreases as pressure increases. It is further postulated that at off-resonance frequency, due to randomness of particle motion, the (P/M) ratio is dominated by P. In this case only a part of the mass of the oscillator oscillates in one direction at the same time. Moreover, not all the mass takes part in the transition process. Based

upon this conceptual model following results have been found.

$$\boldsymbol{\alpha[dB] = 150(1/LP)} \qquad \text{(at resonance)} \qquad \textbf{(8)}$$

$$\boldsymbol{\alpha[dB] = 5.69 \text{ x } 10^{-3}\left(\frac{\sqrt{P}}{L}\right)} \qquad \text{(at off-resonance)} \qquad \textbf{(9)}$$

Where P is the pressure exerted by a rain drop(s) oscillator mass
M on its surrounding atmosphere in “torr” and “L” is the path
Length of microwave link in “Km”.

3. Attenuation Constant:

Calculations have been made using a terrestrial microwave link [7]. Microwaves in that link were propagating at resonance frequency through a rainy atmosphere, with an increasing rain rate and following results were found,

$$\mathbf{LP = \frac{10^4}{1.19r^b d}} \qquad (10)$$

Now substituting Equation (10) in the conceptual- model Equation(8),
we obtain,

$$\boldsymbol{\alpha[dB] = 0.018r^b d} \qquad (11)$$

4. Correlation to Experimental Results:

Both experimental results of Ref [7] and calculated results from Eq.(11) were plotted in the Figure. As seen from Figure, both experimental and calculated results agree reasonably well with each other. Comparing Equation (7) and Equation (11), we see that rain rate ‘r’ and mass of the oscillator ‘M’ are inversely proportional to each other. This result exactly matches the experimental observation [7], that by increase in the rain rate, rain cell diameter decreases and hence mass of the oscillator decreases. As postulated in the model in Equation (7) by decrease in the mass of the oscillator, attenuation constant increases. Although, rain cell diameter ‘d’ is also proportional to the attenuation constant, yet the rate of increases of rain rate is much higher than the rate of decrease of diameter of the rain drop [7].

5. Remarks and Discussion:

Although behavior of attenuation vs. rain rate in both of the curves in Figure. Agree considerably with each other, yet the lower values of attenuation constants of theoretical curve, for each corresponding value of the rain rate is due to the fact that the factors like atmospheric temperature, atmospheric pressure, humidity, canting angle, gravity, aerodynamic forces and other geographical conditions have not been included in the calculations.

Moreover, Equation (8) is not accurate for $P \rightarrow 0$. it is reasonable at low pressure. If $P \rightarrow 0$, then the attenuation observed is not zero dB. At $P \rightarrow 0$, the observed attenuation is a finite value which is equal to the attenuation of the non rainy atmosphere. Equation (8) is not accurate for $P \rightarrow \infty$ either. There will be an additional apparent attenuation at high pressure. The high density rainy atmosphere presents different impedance to the surrounding atmosphere when compared with the low density rainy atmosphere. This effect is also not considered in Equation (8).

Moreover, theoretical equation for the attenuation constant at off – resonance frequency had also been derived Equation (9) for further study of behavior of microwaves propagating through a rainy atmosphere at off-resonance frequency.

***Figure 1**: Attenuation vs Rain rate*

6. Conclusion:

As seen from the reviewed experimental data and presented analysis, a conclusion can be made that microwave absorption by rain drops increases as rain rate increases at resonance frequency. The dependency of microwave attenuation on raindrop pressure has been characterized. Thus the dependency of raindrop pressure on the effectiveness of microwave communication has been analytically characterized.

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Nomenclatures:

α …Attenuation constant in 'dB'
P …Pressure exerted by the rain drop on its surrounding atmosphere in 'torr'
r…. Rain rate in mm/hr.
d…. Diameter of rain drops in mm. [d **-** range from 10 mm to 2 mm] [7]
L…. Path length of microwave link in Km.
b…. Constant representing the order to which the attenuation varies with respect to rain rate. [**b** = 1.09] [7]