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Modeling Rain Polarization Effects to Millimeter Wave Frequencies

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MODELING RAIN POLARIZATION EFFECTS TO MILLIMETER WAVE FREQUENCIES

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The attenuation of a received signal on a millimeter wave (above 30 GHz) link probably will be considerably more sensitive to transmitted polarization of the signal than is the case on a microwave (below 30 GHz) link. The introduction of this report explains why this is the case, and the second section of the report gives some background on past theoretical developments in assessing rain polarization effects. Then, a model is developed to more readily assess the rain attenuation polarization dependency, and this new model is compared with an accepted theoretical model. It is concluded, based on three separate sets of comparisons, that the model gives results close enough to the theoretical model to warrant consideration for its future use.

Key words: microwaves; millimeter waves; models; oblate spheroids; polarization effects; rain attenuation

1. INTRODUCTION

Millimeter wave propagation through rain is likely to encounter different amounts of attenuation depending upon the transmitted-received polarization. If dual orthogonal polarizations are used to increase channel capacity, loss of isolation at both polarizations can be caused by rain as well. Figure 1 shows why the polarization-attenuation dependency is important to investigate at millimeter wave frequencies.

Figure 1 shows the "co-polar attenuation" (i.e., for the signal received on the same polarization as transmitted) per unit length using vertical polarization, CPA_V, and using horizontal polarization, CPA_H, in the presence of rain. Three paths representative of three climatic types, as indicated on Figure 1, are examined. The details of the derivation of the curves in Figure 1 are given in "A survey of rain effects on millimeter wave communications in tactical environments," by E. J. Dutton, NTIA Technical Memorandum 83-82 (limited distribution), January 1983. Figure 1 is the same as Figure 3 of that memorandum.

The most notable feature of Figure 1 is the lower attenuation of vertical polarization over horizontal polarization with increasing frequency during rainy conditions. In relative terms, however, the use of vertical polarization maintains about a 10 percent advantage over horizontal polarization throughout the 10 to 90 GHz range. As a consequence, the attenuation differential between horizontally

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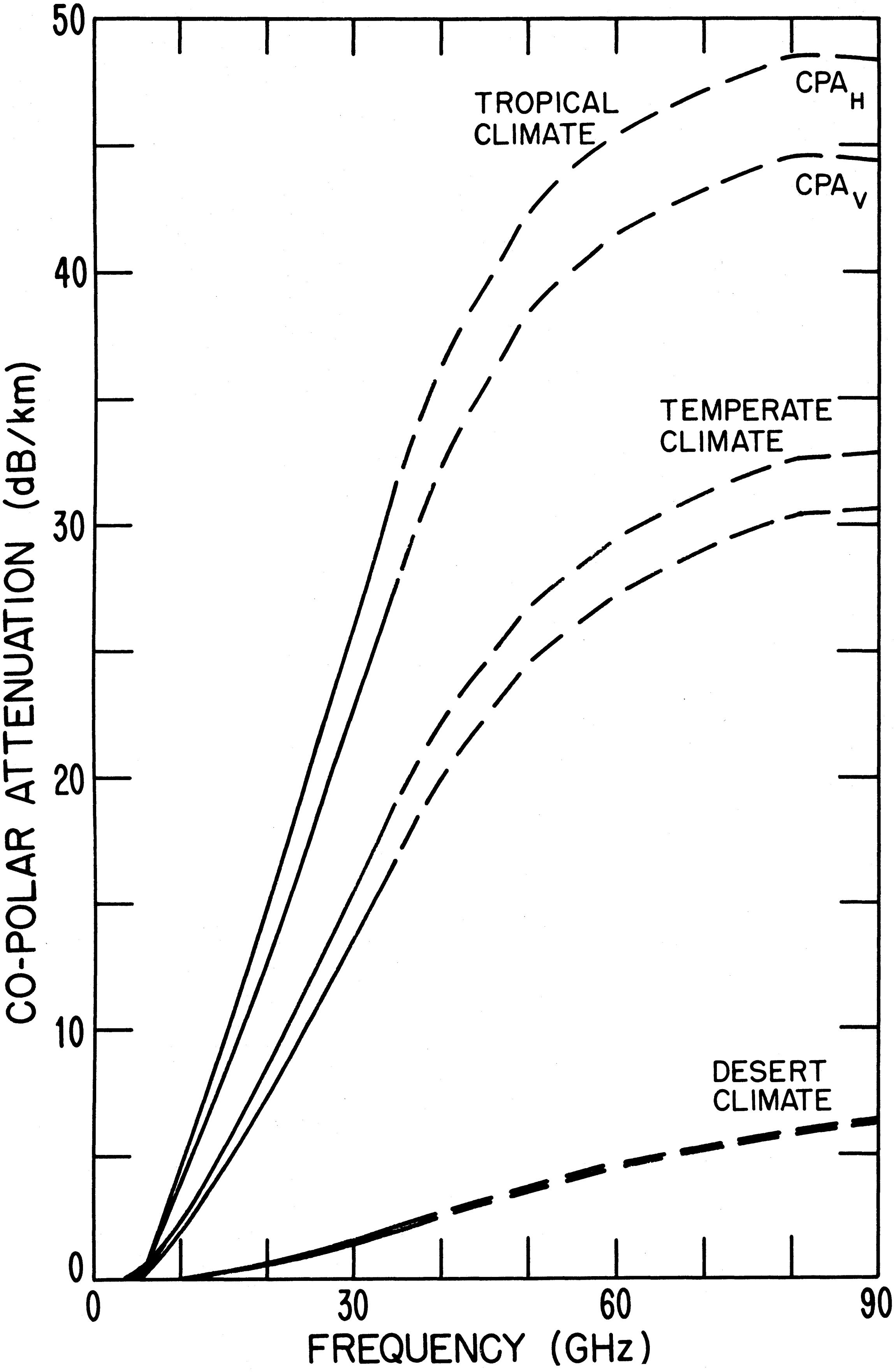

Figure 1. Variations of co-polar (specific) attenuation of transmitted horizontal (H) and vertical (V) linear polarizations for three different climatic types.

and vertically polarized attenuations at millimeter wave frequencies can be projected beyond the 90 GHz region to often be large enough to warrant modeling consideration, although it may not increase very much beyond this frequency.

2. POLARIZATON EFFECTS OF OBLATE SPHEROIDAL RAINDROPS

Co-polar attenuation, in decibels per unit length, can be expressed as follows (Ippolito et al., 1981):

$$CPA_V = \frac{1}{2}\left[(A_I' + A_{II}') + m_\theta (A_I' - A_{II}') \cos^2\varepsilon \cos^2 2\bar{\theta}\right] \tag{1a}$$

$$CPA_H = \frac{1}{2}\left[(A_I' + A_{II}') - m_\theta (A_I' - A_{II}') \cos^2\varepsilon \cos^2 2\bar{\theta}\right] . \tag{1b}$$

In (1a) and (1b), A_I' and A_{II}' are specific attenuations in dB/km oriented along the axes of an oblate spheroidal raindrop, with the signal direction incident perpendicular to the plane containing the axis of symmetry of the raindrop as in Figure 2. This results in an elliptical cross section of a raindrop canted at an angle θ, as shown in Figure 2. We shall denote the angle of incidence, as α (the angle that the incident Poynting vector makes with the vertical direction in Figure 2) where

$$\alpha = 90° - \varepsilon , \tag{2}$$

and ε is the transmitted signal's elevation angle. In the case of Figure 2, then, $\alpha = 90°$. Further in (1a) and (1b),

$$m_\theta = \exp(-2\sigma_\theta^2) , \tag{3}$$

with $\bar{\theta}$ and σ_θ^2 the mean and variance of the distribution of raindrop "canting angles" (see Figure 2). The field vectors, $\underline{E}_V$, of the vertically polarized field and $\underline{E}_H$, of the horizontally polarized field, shown in Figure 2 associated with that particular raindrop, are related to CPA_V and CPA_H by

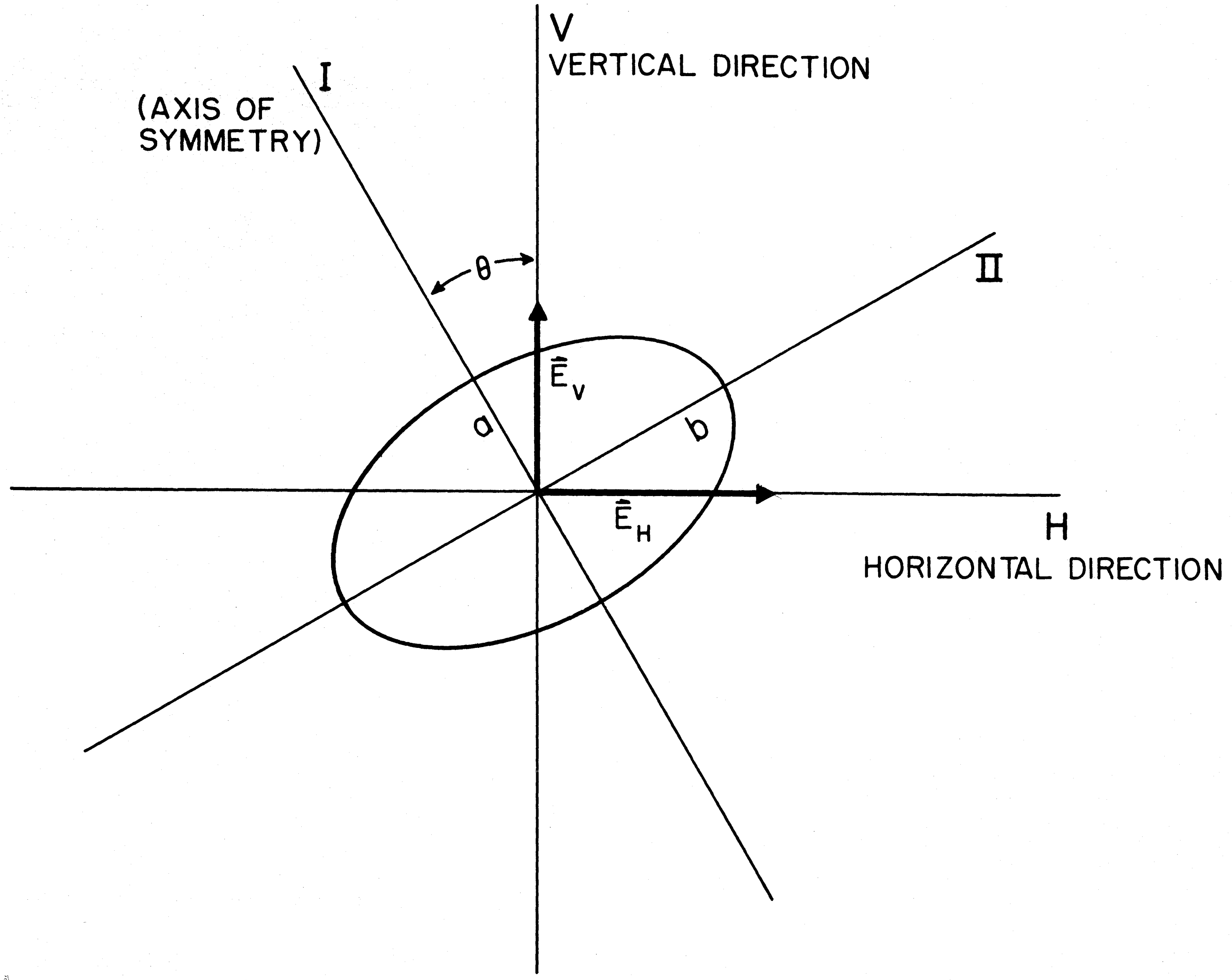

Figure 2. Elliptical cross section of an oblate spheroidal raindrop in a plane perpendicular to the direction of propagation, assumed to contain the axis of symmetry of the raindrop.

$$\mathrm{CPA}_V = -20 \log_{10} \frac{|\underline{E}_{Vs}|}{|\underline{E}_{Vi}|} \tag{4a}$$

and

$$\mathrm{CPA}_H = -20 \log_{10} \frac{|\underline{E}_{Hs}|}{|\underline{E}_{Hi}|} \quad . \tag{4b}$$

In (4a) and (4b), the s subscript refers to the scattered (i.e., attenuated) field and the i subscript to the incident field.

In the theoretical development of forward scattering by oblate spheroids, Oguchi (1983) presents a "forward scattering function," which we shall denote as $f_{V,H}$, for either f_V in the vertical polarization, or f_H in the horizontal polarization. He derives his forward scattering function by solution of the appropriate wave equation using three different approximate solution techniques. In another recent work, Yeh et al. (1981) discuss other solution techniques for another solid geometrical shape (Pruppacher-Pitter raindrops). For all these elaborate mathematics, however, they admit that "the scattering results for a Pruppacher-Pitter-shaped raindrop compared very closely to those for an equivalent oblate spheroidal shaped raindrop, even when their shapes are visibly different for large drops." This leads one to the immediate, though not absolutely confirmed, conclusion that changing drop shapes from, and solution techniques for, an oblate spheroid is largely nugatory. Hence, we shall continue to use the Oguchi theory, and concomitant oblate spheroidal shape, as a representative raindrop model at millimeter wave frequencies. However, we also believe that even the Oguchi theory is far too formidable for our modeling purposes, and in the next section will present a simpler, heuristic model.

The forward scatter function, $f_{V,H}$, for <u>any</u>* α, can be used to obtain corresponding propagation constants (wave numbers), as (Oguchi, 1983, page 1056)

$$k_{V,H} = \frac{2\pi}{k} \int_{r_{01}}^{r_{02}} f_{V,H}\, n(r_o) dr_o \quad , \tag{5}$$

where k is the free-space wave number, and $n(r_o)$ is the number of drops per unit

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*Symbols that are primed, as in (1a) or (1b) are for $\alpha = 90°$; otherwise, they represent any α, as presented here.

volume of atmosphere between r_0 and $r_0 + dr_0$, with r_0 the radius of a spherical raindrop equivalent in volume to a given oblate spheroidal raindrop (i.e., "equivolumetric" radius). The values r_{01} and r_{02} represent the minimum and maximum radii of drops in the unit volume of atmosphere. In turn, then, the attenuations $A_{I,II}$ (shorthand for A_I and A_{II}), in decibels per kilometer are given by

$$A_{I,II} = 10 \log_{10} \left\{ \exp \left[2\mathrm{Im}(k_{V,H}) \right] \right\} \quad . \tag{6}$$

At this point it should be noted that Oguchi theory obtains $f_{V,H}$, and thence $k_{V,H}$, for an ensemble of uncanted raindrops (i.e., $\theta = 0$ in Figure 2); thus, V and H coincide with the I and II axes, allowing the expression (6).

3. AN ALTERNATIVE ATTENUATION MODEL

Much of our present attenuation prediction material uses spherical drop theory (Mie theory, Rayleigh approximations) as its basis. It would therefore be desirable to develop a direct connection with this theory, in a relatively simple, straightforward manner, so as not to have to reprogram extensively to incorporate the Oguchi theory, which is inherently rather cumbersome. Using this as our rationale, we can postulate a heuristic model of the form

$$Q_{I,II}(a,b,\lambda) = W_{I,II}(a,b,r_0)\, Q(r_0,\lambda) \quad , \tag{7a}$$

where

$$Q_{I,II}(a,b,\lambda) = 2\lambda \mathrm{Im}(f_{V,H}) \quad , \tag{7b}$$

which separates the nonspherical variables from the spherical and electromagnetic variables. In other words, $Q_{I,II}(a,b,\lambda)$ in (7a), which represents the droplet attenuation cross section as a function of the semiminor axis, a, semimajor axis, b (see Figure 2), and the wavelength, λ, in both the I and II directions, is assumed expressible as the product of a weight, $W_{I,II}(a,b,r_0)$, which is a function of a, b, and the equivolumetric radius, r_0, and the spherical attenuation cross section $Q(r_0,\lambda)$. Since a sphere does not depolarize in the forward propagation direction, $Q(r_0,\lambda)$ is independent of the directions I or II.

Oguchi and Hosoya (1974) use the relationship

$$\frac{a}{b} = 1 - \frac{4.1}{4.5} r_o \tag{8}$$

where r_o is in centimeters to relate a, b, and r_o. Since we shall be comparing with their results in the next section, we shall also assume this relationship. If we now use (8) and abbreviate $W_{I,II}(a,b,r_o)$ to $W_{I,II}$, one pair of weights that can be used (see Appendix A), for r_o in centimeters, is

$$W_I' = \left(1 - \frac{4.1}{4.5} r_o\right)^{4/3} , \tag{9a}$$

and

$$W_{II}' = \left(1 - \frac{4.1}{4.5} r_o\right)^{-2/3} , \tag{9b}$$

where the primes again denote the angle of incidence, $\alpha = 90°$. For any elevation angle, ε, which is related to α by (2), we obtain, for r_o in centimeters (see Appendix A)

$$W_I = \frac{W_I'}{\left[\left(1 - \frac{4.1}{4.5} r_o\right)^2 \sin^2\varepsilon + \cos^2\varepsilon\right]^{2/3}} , \tag{10a}$$

and

$$W_{II} = W_{II}'\left[\left(1 - \frac{4.1}{4.5} r_o\right)^2 \sin^2\varepsilon + \cos^2\varepsilon\right]^{1/3} . \tag{10b}$$

The specific attenuations $A_{I,II}$, then, are given by

$$A_{I,II} = 10 \log_{10}\left\{\exp\left[\int_{r_{01}}^{r_{02}} W_{I,II} Q(r_o,\lambda) n(r_o) dr_o\right]\right\} . \tag{11}$$

All of the variables in (11) have been discussed. However, in order to evaluate the integral in (11), a representative distribution for $n(r_o)$ must be used. Oguchi and Hosoya (1974) use a Laws and Parsons (1943) distribution, but this form is not particularly facile for computer analysis. A preferred distribution is an exponential type of the form

$$n(r_o) = Ae^{-Br_o} , \tag{12}$$

first proposed by Marshall and Palmer (1948). For purposes of this report, we have used the Marshall-Palmer distribution specifically, with

$$A = 16{,}000 \text{ mm}^{-1}\text{m}^{-3} \tag{13a}$$

and

$$B = 8.2R^{-0.21} \text{ mm}^{-1} \tag{13b}$$

where R is the surface rain rate in millimeters per hour. At microwave frequencies, the choice of the Laws and Parsons or the Marshall-Palmer distribution should make little difference, but as frequency increases, a greater disparity develops between the two distributions. Since in the next section most of the comparison frequencies are microwave (<30 GHz) frequencies, this aspect of the analysis should not greatly influence the comparison results.

The values of $Q(r_o,\lambda)$ are obtained from standard Mie theory analysis (Kerr, 1951), using a specially tailored computer algorithm written by Zuffery (1972). The integral in (11) is then obtained using 24-point Gaussian quadrature (Abrahamowitz and Stegun, 1964) over the range r_{01} to r_{02}, in order to obtain sufficient accuracy in the results. In this integration $r_{01} = 0$, and r_{02} is set to 0.3 cm--roughly the upper limit of raindrop sizes.

4. COMPARISON OF MODELS

Since no analytic derivation is given to justify the use of (11), comparison is made of this model with other, better recognized, models. As a consequence, we have chosen to compare (11) with results from the largely theoretical modeling of Oguchi, as presented in tabular form in Oguchi and Hosoya (1974). There is a wide enough range of tabulated results here to allow, we believe, representative comparisons done in three different ways, but all using an rms error comparison.

Oguchi and Hosoya (1974) give 448 calculations of $A_{I,II}$, which, since they assume uncanted raindrops, are 224 calculations of vertical polarization specific attenuation, equivalent to A_I, and 224 calculations of horizontal polarization specific attenuation, equivalent to A_{II}. Their calculations cover a variety

(8 values) of rain rates up to 150 mm/hr, and a variety of frequencies (10 values) up to 50 GHz. A variety of angles of incidence, α, is also included, although more of the calculations (160 values) are for $\alpha = 90°$ than for other values of α (i.e., these represent calculations of $A'_{I,II}$).

As mentioned above, three different rms error comparisons were made of the Oguchi-Hosoya specific attenuation results and our modeled specific attenuations, always using the Oguchi-Hosoya results as "true" values. For our purposes, rms (root-mean-square) error, e, is given by

$$e = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left(\frac{m_i - t_i}{t_i} \right)^2} \quad , \tag{14}$$

where m_i is the modeled i^{th} value, t_i is the true (Oguchi-Hosoya) i^{th} value, and N is the number of observations. Table 1 shows the first set of rms error comparisons at each polarization and rain rate for an angle of incidence of $\alpha = 90°$. Hence, for each specific attenuation relative error tabulation, N = 10 for the 10 frequencies ranging from 4 to 50 GHz over which results are mean-square averaged. Table 2 shows the second set of rms error comparisons at each polarization and frequency for an angle of incidence $\alpha = 90°$. In this case for each specific attenuation relative error tabulation, N = 8 for the 8 rain rates ranging from 0.25 to 150 mm/hr over which results have been mean-square averaged. The third comparison is the rms value, e_{all}, taken over all frequencies and rain rates and for both polarizations (i.e., N = 448), which is, for e_{all} in percent,

$$e_{all} = 11.03\% \quad .$$

To our way of thinking, then, the relative error is sufficiently low, and is consistently sufficiently low, enough to justify the use of the model as expressed by (7) through (11) to calculate rain polarization, and, eventually, depolarization effects. It should be noted, however, that if one is using frequencies in excess of 50 GHz that the justification is diminished because of a) lack of comparative material above that frequency, and b) the use of two different dropsize distributions can have an impact of unknown proportions. It is recognized that the preceding error analysis does not always assist a user who is interested in a specific polarization, frequency, rain rate, and elevation angle. Therefore, in Appendix B we

Table 1. Relative rms Errors for the Modeled Versus Theoretical Specific Rain Attenuations at Given Rain Rates and Polarizations

	RMS ERROR (IN PERCENT) RELATIVE TO OGUCHI MODEL	
RAIN RATE (MM/HR)	VERTICAL POLARIZATION	HORIZONTAL POLARIZATION
.25	5.36	5.39
1.25	9.51	9.99
2.50	10.81	11.65
12.50	13.21	15.26
25.00	14.61	16.64
50.00	14.18	15.49
100.00	12.40	12.36
150.00	9.82	8.32

Table 2. Relative rms Errors for the Modeled Versus Theoretical Specific Rain Attenuations at Given Frequencies and Polarizations

	RMS ERROR (IN PERCENT) RELATIVE TO OGUCHI MODEL	
FREQUENCY (GHZ)	VERTICAL POLARIZATION	HORIZONTAL POLARIZATION
4.00	16.03	15.79
5.00	17.26	18.03
6.00	17.69	16.49
11.00	10.49	7.41
15.00	3.44	5.45
19.30	4.07	6.75
30.00	7.42	8.66
34.80	8.20	9.95
40.00	9.16	11.84
50.00	11.49	15.95

have included the complete table of our model's specific attenuation calculations vis-à-vis the Oguchi and Hosoya (1974) results for specific attenuation.

5. CONCLUSIONS

We have presented a model for quicker engineering-design assessment of microwave/millimeter wave link polarization effects of rain attenuation. We have compared this modeling with a well-known theoretical approach (Oguchi, 1983), and, specifically, a set of results from this approach given in Oguchi and Hosoya (1974). Relative errors between the two approaches were on the order of 10 to 15 percent, sufficiently low, we feel, to justify the use of our modeling, subject to the potential frequency constraint mentioned above. The reader is reminded, however, that there is nothing sacrosanct about the relative errors resulting from these comparisons. While the theoretical modeling was assumed to be true, for purposes of comparison, it is, nevertheless, modeling also. Hence, we have, in fact, compared two models. It is possible, therefore, that our results could, in some cases, even be closer to (and, of course, farther from) reality than the included comparison indicates.

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APPENDIX A: DERIVATIONS

Consider the oblate spheroid shown in Figure A1, which is really a three-dimensional representation of the cross-sectional geometry of Figure 2 (except that θ here represents a polar coordinate, not canting angle). Let us assume that the y coordinate corresponds to the direction of propagation*, the x coordinate to the "I" direction, and the z coordinate to the axis of symmetry direction, II. Then the equation of the spheroid can be written in rectangular coordinates as

$$\frac{x^2}{b^2} + \frac{y^2}{b^2} + \frac{z^2}{a^2} = 1 \quad , \tag{A1}$$

where a is the minor semiaxis of the spheroid and b is the major semiaxis, as well as the rotational radius, of the spheroid. If we change to the spherical coordinates (r,θ,ϕ) as shown in Figure A1, Equation (A1) becomes

$$\frac{r^2\sin^2\theta\sin^2\phi}{b^2} + \frac{r^2\sin^2\theta\cos^2\phi}{b^2} + \frac{r^2\cos^2\theta}{a^2} = 1 \quad , \tag{A2}$$

or, since $\sin^2\phi + \cos^2\phi = 1$,

$$r^2 = \left(\frac{\sin^2\theta}{b^2} + \frac{\cos^2\theta}{a^2}\right)^{-1} \quad . \tag{A3}$$

Now let us consider an "equivolumetric" sphere of radius, r_o, centered at the origin; whence

$$\frac{4}{3}\pi ab^2 = \frac{4}{3}\pi r_o{}^3 \quad . \tag{A4}$$

Further, let us use the relationship (8) with (A4) from which we obtain, after some manipulation

$$a = r_o\left(1 - \frac{4.1}{4.5}\, r_o\right)^{2/3} \quad , \tag{A5}$$

and

$$b = r_o\left(1 - \frac{4.1}{4.5}\, r_o\right)^{-1/3} \quad . \tag{A6}$$

Now consider that the attenuations $Q_{I,II}(a,b,\lambda)$ and $Q(r_o,\lambda)$ in (7) have the units of cross-sectional area. Hence, a first relation of the two via the weights $W_{I,II}$

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[*] Note that this implies an angle of arrival, $\alpha = 90°$.

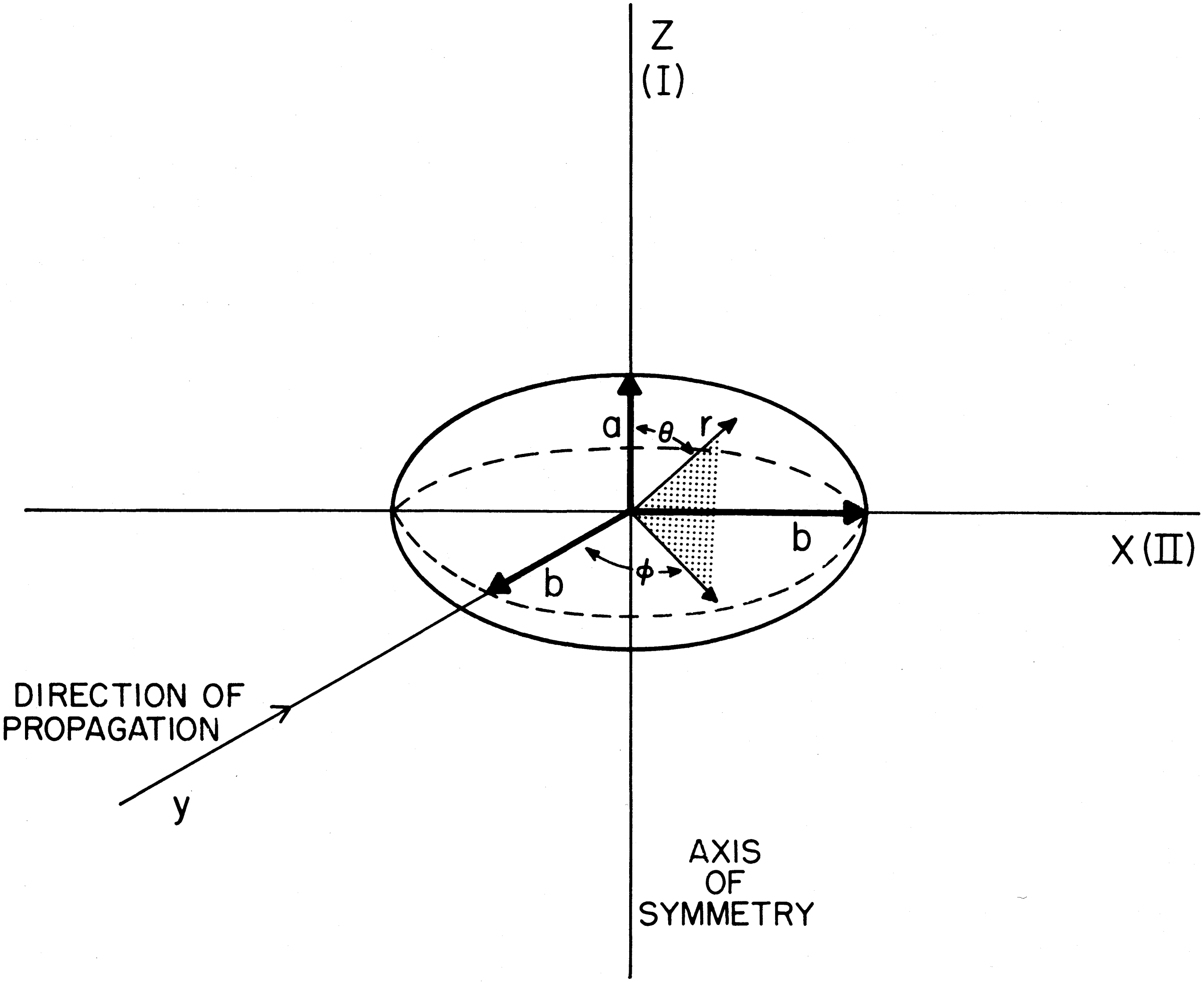

Figure A1. Geometry for the derivation of the weights $W'_{I,II}$.

of (7) could be a ratio of a representative modeled circular cross-sectional area to the corresponding circular cross-sectional area of the equivolumetric sphere, or, using (A3)

$$W'(\theta) = \frac{r^2}{r_o^2} = \left(r_o^2 \frac{\sin^2\theta}{b^2} + r_o^2 \frac{\cos^2\theta}{a^2} \right)^{-1} \quad . \tag{A7}$$

where the prime reminds us that the angle of incidence, $\alpha = 90°$.

In the use of (A7) we assume that the polarization vector is in the same direction as r, and therefore only "sees" an equivalent sphere of radius, r (i.e., the polarization is only obstructed by water extending to a length r, which we choose to interpret as a circular cross section of radius, r). As an example, consider a most unusual water "droplet" extending only in the horizontal direction. Then, incident vertical polarization on this droplet would encounter (essentially) no water at all, which we would therefore interpret as zero cross section in that direction, as well as in all other directions except the horizontal.

Using (A5) and (A6), (A7) becomes

$$W'(\theta) = \left[\sin^2\theta \left(1 - \frac{4.1}{4.5} r_o\right)^{2/3} + \cos^2\theta \left(1 - \frac{4.1}{4.5} r_o\right)^{-4/3} \right]^{-1} \quad . \tag{A8}$$

In the direction I, $\theta = 0°$, and in the direction II, $\theta = 90°$; thus,

$$W'_I = \left(1 - \frac{4.1}{4.5} r_o\right)^{4/3} \quad , \tag{A9}$$

and

$$W'_{II} = \left(1 - \frac{4.1}{4.5} r_o\right)^{-2/3} \quad , \tag{A10}$$

as per (9a) and (9b) of the main text.

Now consider Figure A2, which shows the propagation incident on an oblate spheroidal raindrop at some arbitrary angle of incidence, α, other than 90°, as was the case above. In this situation, the direction of propagation is assumed to be in the yz plane, so that the angle ϕ in Figure A1 is such that $\phi = 0$. Further, the direction is now normal to an elliptical cross section of the spheroid whose minor semiaxis is a_1, and major semiaxis is b. Therefore, we can set

$$r = a_1 \quad , \tag{A11}$$

and

$$\theta = 90° - \alpha \quad . \tag{A12}$$

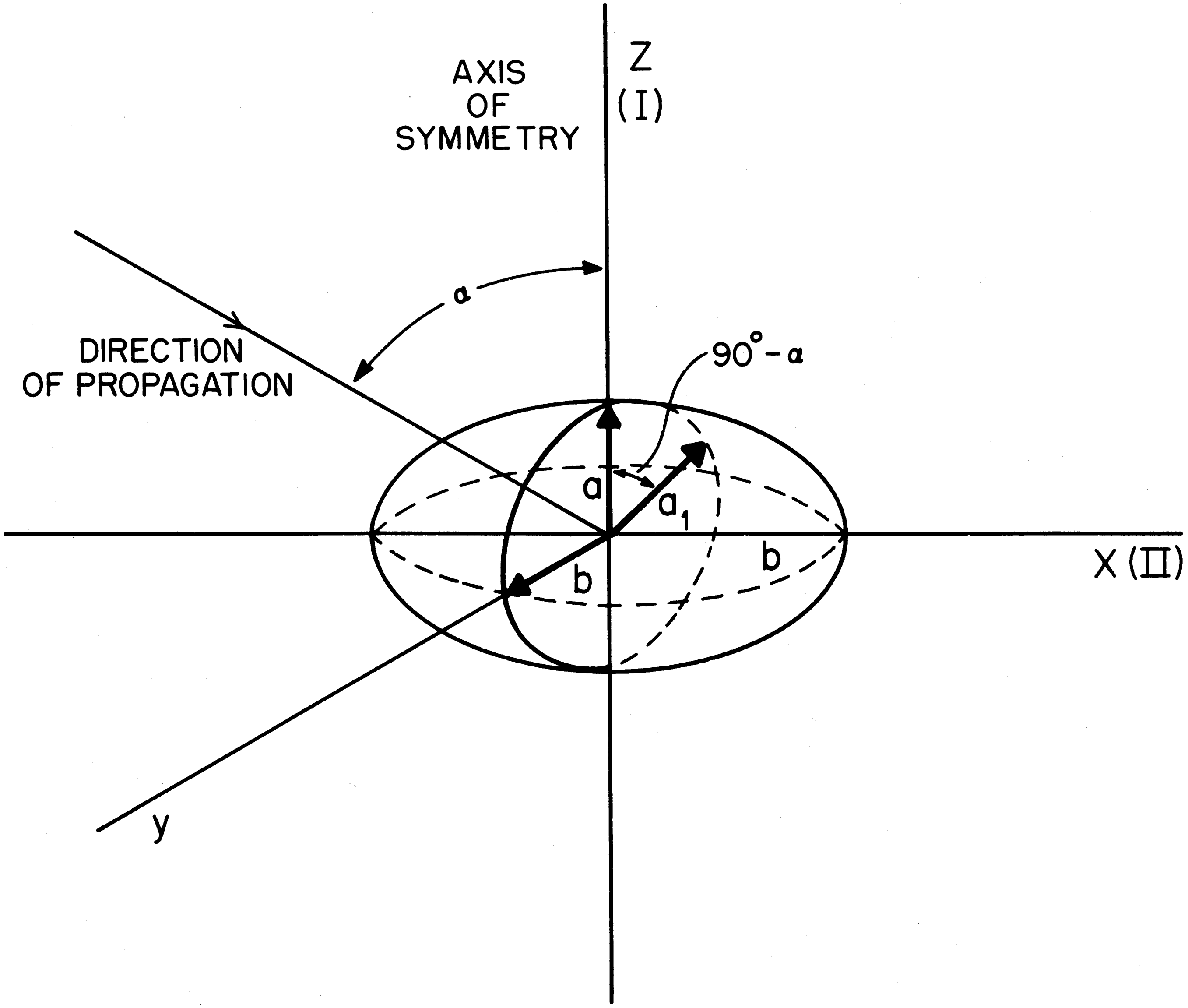

Figure A2. Geometry of arbitrary angle of incidence, α, on an oblate spheroid.

Substituting (A11), (A12), and $\phi = 0$ into (A2) eventually yields

$$a_1 = \left(\frac{a^2b^2}{a^2\cos^2\alpha + b^2\sin^2\alpha} \right)^{1/2} . \tag{A13}$$

Note that from (A13), when $\alpha = 0°$, $a_1 = b$, and when $\alpha = 90°$, $a_1 = a$, as it should. Now let us assume that a relationship similar to (A9) and (A10) is true if a is replaced by a_1; i.e.,

$$W_I = \left(\frac{a_1}{b} \right)^{4/3} , \tag{A14}$$

and

$$W_{II} = \left(\frac{a_1}{b} \right)^{-2/3} . \tag{A15}$$

Thus, knowing that the elevation angle, $\varepsilon = 90° - \alpha$, it is not difficult, using (A13), to obtain

$$W_I = \frac{\left(\frac{a}{b} \right)^{4/3}}{\left[\left(\frac{a}{b} \right)^2 \sin^2\varepsilon + \cos^2\varepsilon \right]^{2/3}} , \tag{A16}$$

and

$$W_{II} = \left(\frac{a}{b} \right)^{-2/3} \left[\left(\frac{a}{b} \right)^2 \sin^2\varepsilon + \cos^2\varepsilon \right]^{1/3} . \tag{A17}$$

Using (8), (9a), and (9b) of the main text in (A16) and (A17), then, we arrive at

$$W_I = \frac{W_I'}{\left[\left(1 - \frac{4.1}{4.5} r_o \right)^2 \sin^2\varepsilon + \cos^2\varepsilon \right]^{2/3}} , \tag{A18}$$

and

$$W_{II} = W_{II}' \left[\left(1 - \frac{4.1}{4.5} r_o \right)^2 \sin^2\varepsilon + \cos^2\varepsilon \right]^{1/3} , \tag{A19}$$

which are the same as (10a) and (10b) of the main text.

APPENDIX B: TABLES OF ATTENUATION CALCULATIONS

Tables B1 to B10 show the comparison between our modeled specific attenuations calculated at 4, 5, 6, 11, 15, 19.3, 30, 34.8, 40, and 50 GHz ("FREQ") for various values of "RAIN RATE" with those of Oguchi and Hosoya (1974). At 4, 6, 11, 19.3, 30, and 34.8 GHz, the specific attenuations were computed for the angles of incidence, "ALPHA," of 90, 70, 50, and 30 degrees. At 5, 15, 40, and 50 GHz, however, the specific attenuations were computed only for the angle of incidence of 90 degrees. This corresponds with the Oguchi and Hosoya (1974) calculations.

Table B1. Modeled Versus Theoretical Specific Attenuations for Given Angles of Incidence and Rain Rates Calculated at 4 GHz

ALPHA = 90 DEGREES

RAIN RATE (MM/HR)	FREQ (GHZ)	MODEL VERTICAL ATTENUATION (DB/KM)	OGUCHI VERTICAL ATTENUATION (DB/KM)	MODEL HORIZONTAL ATTENUATION (DB/KM)	OGUCHI HORIZONTAL ATTENUATION (DB/KM)	SPHERICAL ATTENUATION (DB/KM)
.25	4.0	.0002092	.0002042	.0002240	.0002230	.0002189
1.25	4.0	.0008584	.0008684	.0009485	.0009808	.0009172
2.50	4.0	.0016044	.0016740	.0018059	.0019270	.0017354
12.50	4.0	.0073395	.0084400	.0087935	.0102800	.0082725
25.00	4.0	.0147611	.0179600	.0184003	.0227000	.0170766
50.00	4.0	.0308996	.0395400	.0405659	.0522000	.0369821
100.00	4.0	.0685861	.0905000	.0966239	.1259000	.0859648
150.00	4.0	.1141144	.1461000	.1699207	.2083000	.1482993
ALPHA = 70 DEGREES						
.25	4.0	.0002103	.0002062	.0002234	.0002229	.0002189
1.25	4.0	.0008647	.0008797	.0009449	.0009790	.0009172
2.50	4.0	.0016182	.0016980	.0017980	.0019210	.0017354
12.50	4.0	.0074324	.0085820	.0087364	.0102000	.0082725
25.00	4.0	.0149839	.0182800	.0182571	.0224600	.0170766
50.00	4.0	.0314597	.0402500	.0401848	.0514300	.0369821
100.00	4.0	.0700957	.0921100	.0955162	.1234000	.0859648
150.00	4.0	.1169535	.1487000	.1577124	.2036000	.1482993
ALPHA = 50 DEGREES						
.25	4.0	.0002130	.0002114	.0002219	.0002225	.0002189
1.25	4.0	.0008813	.0009083	.0009359	.0009742	.0009172
2.50	4.0	.0016548	.0017590	.0017776	.0019070	.0017354
12.50	4.0	.0076844	.0089420	.0085875	.0100200	.0082725
25.00	4.0	.0155963	.0190700	.0178820	.0218600	.0170766
50.00	4.0	.0330244	.0420400	.0391800	.0494700	.0369821
100.00	4.0	.0743997	.0962000	.0925700	.1170000	.0859648
150.00	4.0	.1251695	.1553000	.1618021	.1918000	.1482993
ALPHA = 30 DEGREES						
.25	4.0	.0002164	.0002174	.0002202	.0002221	.0002189
1.25	4.0	.0009014	.0009408	.0009253	.0009689	.0009172
2.50	4.0	.0016996	.0018280	.0017537	.0018910	.0017354
12.50	4.0	.0080053	.0093520	.0084103	.0098120	.0082725
25.00	4.0	.0163945	.0199800	.0174310	.0211700	.0170766
50.00	4.0	.0351248	.0440700	.0379569	.0472400	.0369821
100.00	4.0	.0804027	.1008000	.0889258	.1097000	.0859648
150.00	4.0	.1369636	.1628000	.1544029	.1783000	.1482993

Table B2. Modeled Versus Theoretical Specific Attenuations for the Angle of Incidence at 90 Degrees and Given Rain Rates Calculated at 5 GHz

ALPHA = 90 DEGREES

RAIN RATE (MM/HR)	FREQ (GHZ)	MODEL VERTICAL ATTENUATION (DB/KM)	OGUCHI VERTICAL ATTENUATION (DB/KM)	MODEL HORIZONTAL ATTENUATION (DB/KM)	OGUCHI HORIZONTAL ATTENUATION (DB/KM)	SPHERICAL ATTENUATION (DB/KM)
.25	5.0	.0003409	.0003380	.0003654	.0003689	.0003570
1.25	5.0	.0014552	.0015180	.0016128	.0017140	.0015580
2.50	5.0	.0027923	.0030370	.0031577	.0035000	.0030297
12.50	5.0	.0140887	.0173000	.0170868	.0214400	.0160083
25.00	5.0	.0303647	.0400200	.0385736	.0526300	.0355702
50.00	5.0	.0705773	.0965400	.0956198	.1343000	.0862481
100.00	5.0	.1889780	.2450000	.2823571	.3620000	.2462734
150.00	5.0	.3677600	.4144000	.5919856	.6267000	.5034060

Table B3. Modeled Versus Theoretical Specific Attenuations for Given Angles of Incidence and Rain Rates Calculated at 6 GHz

ALPHA = 90 DEGREES

RAIN RATE (MM/HR)	FREQ (GHZ)	MODEL VERTICAL ATTENUATION (DB/KM)	OGUCHI VERTICAL ATTENUATION (DB/KM)	MODEL HORIZONTAL ATTENUATION (DB/KM)	OGUCHI HORIZONTAL ATTENUATION (DB/KM)	SPHERICAL ATTENUATION (DB/KM)
.25	6.0	.0005153	.0005194	.0005531	.0005663	.0005402
1.25	6.0	.0023007	.0024840	.0025587	.0028080	.0024690
2.50	6.0	.0045494	.0051860	.0051715	.0060110	.0049532
12.50	6.0	.0258108	.0341800	.0317438	.0431600	.0296004
25.00	6.0	.0611730	.0852000	.0795440	.1109000	.0727763
50.00	6.0	.1664543	.2175000	.2346878	.2911000	.2088791
100.00	6.0	.4860358	.5704000	.7457102	.7760000	.6450585
150.00	6.0	.8674795	.9814000	1.3783871	1.3480000	1.1785068

ALPHA = 70 DEGREES

RAIN RATE (MM/HR)	FREQ (GHZ)	MODEL VERTICAL ATTENUATION (DB/KM)	OGUCHI VERTICAL ATTENUATION (DB/KM)	MODEL HORIZONTAL ATTENUATION (DB/KM)	OGUCHI HORIZONTAL ATTENUATION (DB/KM)	SPHERICAL ATTENUATION (DB/KM)
.25	6.0	.0005180	.0005241	.0005517	.0005655	.0005402
1.25	6.0	.0023186	.0025100	.0025486	.0027960	.0024690
2.50	6.0	.0045915	.0052430	.0051471	.0059710	.0049532
12.50	6.0	.0261809	.0345500	.0315105	.0424700	.0296004
25.00	6.0	.0622561	.0860400	.0788202	.1088000	.0727763
50.00	6.0	.1701741	.2194000	.2319930	.2845000	.2088791
100.00	6.0	.4991654	.5752000	.7354330	.7567000	.6450585
150.00	6.0	.8925671	.9892000	1.3581510	1.3130000	1.1785068

ALPHA = 50 DEGREES

RAIN RATE (MM/HR)	FREQ (GHZ)	MODEL VERTICAL ATTENUATION (DB/KM)	OGUCHI VERTICAL ATTENUATION (DB/KM)	MODEL HORIZONTAL ATTENUATION (DB/KM)	OGUCHI HORIZONTAL ATTENUATION (DB/KM)	SPHERICAL ATTENUATION (DB/KM)
.25	6.0	.0005251	.0005360	.0005479	.0005635	.0005402
1.25	6.0	.0023659	.0025770	.0025226	.0027670	.0024690
2.50	6.0	.0047037	.0053880	.0050840	.0056720	.0049532
12.50	6.0	.0271927	.0354700	.0309009	.0407300	.0296004
25.00	6.0	.0652683	.0881700	.0769157	.1032000	.0727763
50.00	6.0	.1807558	.2244000	.2248366	.2677000	.2088791
100.00	6.0	.5373004	.5872000	.7079131	.7078000	.6450585
150.00	6.0	.9660072	1.0090000	1.3037969	1.2240000	1.1785068

ALPHA = 30 DEGREES

RAIN RATE (MM/HR)	FREQ (GHZ)	MODEL VERTICAL ATTENUATION (DB/KM)	OGUCHI VERTICAL ATTENUATION (DB/KM)	MODEL HORIZONTAL ATTENUATION (DB/KM)	OGUCHI HORIZONTAL ATTENUATION (DB/KM)	SPHERICAL ATTENUATION (DB/KM)
.25	6.0	.0005336	.0005495	.0005435	.0005613	.0005402
1.25	6.0	.0024234	.0026530	.0024921	.0027340	.0024690
2.50	6.0	.0048421	.0055530	.0050100	.0057590	.0049532
12.50	6.0	.0284982	.0365100	.0301711	.0387600	.0296004
25.00	6.0	.0692753	.0905600	.0746070	.0970300	.0727763
50.00	6.0	.1954267	.2301000	.2160137	.2485000	.2088791
100.00	6.0	.5922598	.6007000	.6734535	.6523000	.6450585
150.00	6.0	1.0734214	1.0310000	1.2353350	1.1230000	1.1785068

Table B4. Modeled Versus Theoretical Specific Attenuations for Given Angles of Incidence and Rain Rates Calculated at 11 GHz

ALPHA = 90 DEGREES

RAIN RATE (MM/HR)	FREQ (GHZ)	MODEL VERTICAL ATTENUATION (DB/KM)	OGUCHI VERTICAL ATTENUATION (DB/KM)	MODEL HORIZONTAL ATTENUATION (DB/KM)	OGUCHI HORIZONTAL ATTENUATION (DB/KM)	SPHERICAL ATTENUATION (DB/KM)
.25	11.0	.0023334	.0025070	.0025240	.0027310	.0024584
1.25	11.0	.0137012	.0160400	.0155343	.0180900	.0148926
2.50	11.0	.0325746	.0378100	.0380844	.0432600	.0361349
12.50	11.0	.2716353	.2852000	.3434792	.3349000	.3174153
25.00	11.0	.6400276	.6745000	.8323924	.7983000	.7619843
50.00	11.0	1.4392884	1.5540000	1.9245178	1.8550000	1.7452218
100.00	11.0	3.0869952	3.5040000	4.2544013	4.2300000	3.8180769
150.00	11.0	4.7286054	5.4670000	6.6511087	6.6370000	5.9265917
ALPHA = 70 DEGREES						
.25	11.0	.0023471	.0025240	.0025165	.0027210	.0024584
1.25	11.0	.0138262	.0161400	.0154624	.0179600	.0148926
2.50	11.0	.0329390	.0380500	.0378682	.0428700	.0361349
12.50	11.0	.2760572	.2873000	.3406525	.3312000	.3174153
25.00	11.0	.6515669	.6801000	.8248175	.7895000	.7619843
50.00	11.0	1.4676095	1.5690000	1.9053937	1.8350000	1.7452218
100.00	11.0	3.1529453	3.5470000	4.2083446	4.1890000	3.8180769
150.00	11.0	4.8346954	5.5430000	6.5752087	6.5800000	5.9265917
ALPHA = 50 DEGREES						
.25	11.0	.0023827	.0025670	.0024974	.0026980	.0024584
1.25	11.0	.0141583	.0164100	.0152769	.0176200	.0148926
2.50	11.0	.0339171	.0386800	.0373075	.0418800	.0361349
12.50	11.0	.2882041	.2925000	.3332552	.3217000	.3174153
25.00	11.0	.6835159	.6944000	.8049302	.7673000	.7619843
50.00	11.0	1.5466541	1.6090000	1.8550160	1.7860000	1.7452218
100.00	11.0	3.3386868	3.6580000	4.0865412	4.0870000	3.8180769
150.00	11.0	5.1353426	5.7400000	6.3739222	6.4320000	5.9265917
ALPHA = 30 DEGREES						
.25	11.0	.0024253	.0026160	.0024752	.0026720	.0024584
1.25	11.0	.0145661	.0167200	.0150592	.0172300	.0148926
2.50	11.0	.0351392	.0393900	.0366453	.0407600	.0361349
12.50	11.0	.3039941	.2985000	.3243759	.3110000	.3174153
25.00	11.0	.7256289	.7109000	.7809230	.7420000	.7619843
50.00	11.0	1.6523799	1.6540000	1.7938301	1.7300000	1.7452218
100.00	11.0	3.5914140	3.7870000	3.9375164	3.9710000	3.8180769
150.00	11.0	5.5493904	5.9680000	6.1263409	6.2650000	5.9265917

Table B5. Modeled Versus Theoretical Specific Attenuations for the Angle of Incidence of 90 Degrees and Given Rain Rates Calculated at 15 GHz

ALPHA = 90 DEGREES

RAIN RATE (MM/HR)	FREQ (GHZ)	MODEL VERTICAL ATTENUATION (DB/KM)	OGUCHI VERTICAL ATTENUATION (DB/KM)	MODEL HORIZONTAL ATTENUATION (DB/KM)	OGUCHI HORIZONTAL ATTENUATION (DB/KM)	SPHERICAL ATTENUATION (DB/KM)
.25	15.0	.0055520	.0059280	.0060394	.0064430	.0058715
1.25	15.0	.0382315	.0394100	.0437055	.0439700	.0417860
2.50	15.0	.0909425	.0907300	.1064844	.1023000	.1009916
12.50	15.0	.6140200	.6023000	.7575324	.6989000	.7059161
25.00	15.0	1.3192828	1.3120000	1.6679491	1.5500000	1.5413956
50.00	15.0	2.7406821	2.7910000	3.5655370	3.3760000	3.2627175
100.00	15.0	5.5218218	5.7450000	7.4354210	7.1690000	6.7229249
150.00	15.0	8.2071593	8.6230000	11.3091506	11.0000000	10.1432672

Table B6. Modeled Versus Theoretical Specfic Attenuation for Given Angles of Incidence and Rain Rates Calculated at 19.3 GHz

ALPHA = 90 DEGREES

RAIN RATE (MM/HR)	FREQ (GHZ)	MODEL VERTICAL ATTENUATION (DB/KM)	OGUCHI VERTICAL ATTENUATION (DB/KM)	MODEL HORIZONTAL ATTENUATION (DB/KM)	OGUCHI HORIZONTAL ATTENUATION (DB/KM)	SPHERICAL ATTENUATION (DB/KM)
.25	19.3	.0113795	.0115200	.0124250	.0124900	.0120644
1.25	19.3	.0775040	.0738000	.0882977	.0820700	.0845204
2.50	19.3	.1743361	.1639000	.2023468	.1847000	.1924823
12.50	19.3	1.0388577	.9822000	1.2655879	1.1520000	1.1843024
25.00	19.3	2.1435606	2.0550000	2.6801853	2.4720000	2.4858136
50.00	19.3	4.3072629	4.2220000	5.5499276	5.2310000	5.0944169
100.00	19.3	8.4233692	8.4830000	11.2273292	10.8900000	10.1858394
150.00	19.3	12.3123921	12.6900000	16.7665346	16.6300000	15.0984240
ALPHA = 70 DEGREES						
.25	19.3	.0114538	.0115800	.0123841	.0124400	.0120644
1.25	19.3	.0782402	.0743300	.0878746	.0816400	.0845204
2.50	19.3	.1762130	.1653000	.2012479	.1838000	.1924823
12.50	19.3	1.0533061	.9969000	1.2566778	1.1470000	1.1843024
25.00	19.3	2.1767823	2.0940000	2.6590770	2.4640000	2.4858136
50.00	19.3	4.3816402	4.3260000	5.5009905	5.2200000	5.0944169
100.00	19.3	8.5849885	8.7500000	11.1167755	10.8800000	10.1858394
150.00	19.3	12.5631337	13.1400000	16.5907912	16.6300000	15.0984240
ALPHA = 50 DEGREES						
.25	19.3	.0116483	.0117400	.0122790	.0123100	.0120644
1.25	19.3	.0801962	.0757000	.0867821	.0805700	.0845204
2.50	19.3	.1812296	.1690000	.1984042	.1813000	.1924823
12.50	19.3	1.0925523	1.0340000	1.2334632	1.1350000	1.1843024
25.00	19.3	2.2678243	2.1960000	2.6038723	2.4430000	2.4858136
50.00	19.3	4.5875112	4.5940000	5.3724641	5.1930000	5.0944169
100.00	19.3	9.0371736	9.4370000	10.8250763	10.8700000	10.1858394
150.00	19.3	13.2692633	14.3000000	16.1257743	16.6500000	15.0984240
ALPHA = 30 DEGREES						
.25	19.3	.0118818	.0119300	.0121559	.0121700	.0120644
1.25	19.3	.0825983	.0772700	.0855007	.0793500	.0845204
2.50	19.3	.1874520	.1733000	.1950550	.1785000	.1924823
12.50	19.3	1.1426054	1.0780000	1.2058081	1.1210000	1.1843024
25.00	19.3	2.3857815	2.3140000	2.5376722	2.4200000	2.4858136
50.00	19.3	4.8591385	4.9050000	5.2171520	5.1620000	5.0944169
100.00	19.3	9.6458254	10.2400000	10.4695835	10.8500000	10.1858394
150.00	19.3	14.2315325	15.6600000	15.5560623	16.6700000	15.0984240

Table B7. Modeled Versus Theoretical Specific Attenuations for Given Angles of Incidence and Rain Rates Calculated at 30 GHz

ALPHA = 90 DEGREES

RAIN RATE (MM/HR)	FREQ (GHZ)	MODEL VERTICAL ATTENUATION (DB/KM)	OGUCHI VERTICAL ATTENUATION (DB/KM)	MODEL HORIZONTAL ATTENUATION (DB/KM)	OGUCHI HORIZONTAL ATTENUATION (DB/KM)	SPHERICAL ATTENUATION (DB/KM)
.25	30.0	.0348731	.0328800	.0380658	.0357100	.0369655
1.25	30.0	.2118814	.1922000	.2393396	.2158000	.2297595
2.50	30.0	.4505013	.4055000	.5177326	.4632000	.4941244
12.50	30.0	2.3768389	2.1660000	2.8616731	2.5780000	2.6884059
25.00	30.0	4.6420342	4.3160000	5.7156215	5.2200000	5.3286969
50.00	30.0	8.7912566	8.4290000	11.0875020	10.3400000	10.2523161
100.00	30.0	16.1374368	16.0600000	20.8919968	19.9300000	19.1448181
150.00	30.0	22.6904670	23.1900000	29.8667972	28.8700000	27.2119420
			ALPHA = 70 DEGREES			
.25	30.0	.0351004	.0331100	.0379409	.0356100	.0369655
1.25	30.0	.2137703	.1944000	.2382635	.2153000	.2297595
2.50	30.0	.4550439	.4112000	.5150960	.4623000	.4941244
12.50	30.0	2.4080215	2.2130000	2.8426259	2.5770000	2.6884059
25.00	30.0	4.7094574	4.4230000	5.6734100	5.2240000	5.3236969
50.00	30.0	8.9317831	8.6690000	10.9971395	10.3600000	10.2523161
100.00	30.0	16.4201041	16.5700000	20.7047181	19.9900000	19.1448181
150.00	30.0	23.1091552	23.9600000	29.5839582	28.9900000	27.2119420
			ALPHA = 50 DEGREES			
.25	30.0	.0356953	.0336800	.0376202	.0353400	.0369655
1.25	30.0	.2187741	.1999000	.2354885	.2139000	.2297595
2.50	30.0	.4671506	.4258000	.5082802	.4599000	.4941244
12.50	30.0	2.4924668	2.3320000	2.7930598	2.5760000	2.6884059
25.00	30.0	4.8934066	4.6990000	5.5632218	5.2350000	5.3286969
50.00	30.0	9.3181879	9.2810000	10.7604763	10.4100000	10.2523161
100.00	30.0	17.2039211	17.8700000	20.2124393	20.1600000	19.1448181
150.00	30.0	24.2762906	25.9100000	28.8387601	29.2800000	27.2119420
			ALPHA = 30 DEGREES			
.25	30.0	.0364085	.0343400	.0372477	.0350500	.0369655
1.25	30.0	.2248898	.2063000	.2322398	.2123000	.2297595
2.50	30.0	.4820974	.4426000	.5002579	.4571000	.4941244
12.50	30.0	2.5996177	2.4690000	2.7341323	2.5740000	2.6884059
25.00	30.0	5.1298847	5.0180000	5.4315104	5.2480000	5.3286969
50.00	30.0	9.8219501	9.9910000	10.4759161	10.4700000	10.2523161
100.00	30.0	18.2417399	19.3600000	19.6166098	20.3600000	19.1448181
150.00	30.0	25.8370685	28.1900000	27.9329172	29.6300000	27.2119420

Table B3. Modeled Versus Theoretical Specific Attenuations for Given Angles of Incidence and Rain Rates Calculated at 34.8 GHz

RAIN RATE (MM/HR)	FREQ (GHZ)	MODEL VERTICAL ATTENUATION (DB/KM)	OGUCHI VERTICAL ATTENUATION (DB/KM)	MODEL HORIZONTAL ATTENUATION (DB/KM)	OGUCHI HORIZONTAL ATTENUATION (DB/KM)	SPHERICAL ATTENUATION (DB/KM)
ALPHA = 90 DEGREES						
.25	34.8	.0490193	.0459400	.0534613	.0500500	.0519310
1.25	34.8	.2908354	.2613000	.3280129	.2944000	.3150476
2.50	34.8	.6097825	.5429000	.6992719	.6209000	.6678694
12.50	34.8	3.0680719	2.7740000	3.6717463	3.2750000	3.4565092
25.00	34.8	5.8449030	5.3940000	7.1378930	6.4340000	6.6733186
50.00	34.8	10.7835001	10.2500000	13.4613353	12.3300000	12.4908324
100.00	34.8	19.2710345	18.9100000	24.6482218	22.8500000	22.6799533
150.00	34.8	26.6783847	26.8600000	34.6589055	32.5100000	31.7184502
ALPHA = 70 DEGREES						
.25	34.8	.0493358	.0463000	.0532874	.0499300	.0519310
1.25	34.8	.2933961	.2646000	.3265560	.2939000	.3150476
2.50	34.8	.6158407	.5512000	.6957627	.6202000	.6678694
12.50	34.8	3.1071532	2.8340000	3.6480359	3.2770000	3.4565092
25.00	34.8	5.9268171	5.5240000	7.0870702	6.4450000	6.6733186
50.00	34.8	10.9490855	10.5200000	13.3559928	12.3600000	12.4908324
100.00	34.8	19.5944267	19.4500000	24.4364970	22.9400000	22.6799533
150.00	34.8	27.1496359	27.6600000	34.3444919	32.6500000	31.7184502
ALPHA = 50 DEGREES						
.25	34.8	.0501641	.0472100	.0528413	.0496300	.0519310
1.25	34.8	.3001768	.2731000	.3227995	.2926000	.3150476
2.50	34.8	.6319763	.5724000	.6866934	.6184000	.6678694
12.50	34.8	3.2127687	2.9870000	3.5863879	3.2830000	3.4565092
25.00	34.8	6.1496913	5.8560000	6.9545528	6.4720000	6.6733186
50.00	34.8	11.4029338	11.2100000	13.0804565	12.4400000	12.4908324
100.00	34.8	20.4880030	20.8300000	23.8807484	23.1500000	22.6799533
150.00	34.8	28.4584886	29.6700000	33.5173066	32.9900000	31.7184502
ALPHA = 30 DEGREES						
.25	34.8	.0511565	.0482500	.0523233	.0492800	.0519310
1.25	34.8	.3084581	.2828000	.3184033	.2911000	.3150476
2.50	34.8	.6518753	.5967000	.6760367	.6164000	.6678694
12.50	34.8	3.3462978	3.1630000	3.5132058	3.2900000	3.4565092
25.00	34.8	6.4348420	6.2400000	6.7964611	6.5030000	6.6733185
50.00	34.8	11.9912989	12.0100000	12.7499132	12.5400000	12.4908324
100.00	34.8	21.6638132	22.4100000	23.2097755	23.4000000	22.6799533
150.00	34.8	30.1975146	31.9800000	32.5143903	33.3900000	31.7184502

Table B9. Modeled Versus Theoretical Specific Attenuations for the Angles of Incidence at 90 Degrees and Given Rain Rates Calculated at 40 GHz

ALPHA = 90 DEGREES

RAIN RATE (MM/HR)	FREQ (GHZ)	MODEL VERTICAL ATTENUATION (DB/KM)	OGUCHI VERTICAL ATTENUATION (DB/KM)	MODEL HORIZONTAL ATTENUATION (DB/KM)	OGUCHI HORIZONTAL ATTENUATION (DB/KM)	SPHERICAL ATTENUATION (DB/KM)
.25	40.0	.0671784	.0628400	.0732238	.0686800	.0711416
1.25	40.0	.3896852	.3471000	.4387723	.3908000	.4216637
2.50	40.0	.8028698	.7077000	.9180595	.8066000	.8776832
12.50	40.0	3.8267070	3.4240000	4.5480677	3.9870000	4.2915298
25.00	40.0	7.1030331	6.4760000	8.6004156	7.5890000	8.0639935
50.00	40.0	12.7630971	11.9500000	15.7738463	14.0700000	14.6861870
100.00	40.0	22.2292212	21.4500000	28.1147953	25.2900000	25.9676153
150.00	40.0	30.3376437	30.1400000	38.9526975	35.5900000	35.7889853

Table B10. Modeled Versus Theoretical Specific Attenuations for the Angles of Incidence at 90 Degrees and Given Rain Rates Calculated at 50 GHz

ALPHA = 90 DEGREES

RAIN RATE (MM/HR)	FREQ (GHZ)	MODEL VERTICAL ATTENUATION (DB/KM)	OGUCHI VERTICAL ATTENUATION (DB/KM)	MODEL HORIZONTAL ATTENUATION (DB/KM)	OGUCHI HORIZONTAL ATTENUATION (DB/KM)	SPHERICAL ATTENUATION (DB/KM)
.25	50.0	.1110663	.1030000	.1209613	.1127000	.1175545
1.25	50.0	.6082953	.5326000	.6818220	.5944000	.6562422
2.50	50.0	1.2061734	1.0420000	1.3696332	1.1710000	1.3124930
12.50	50.0	5.1974296	4.5190000	6.1019974	5.1210000	5.7816311
25.00	50.0	9.2298666	8.1570000	11.0201158	9.2600000	10.3815888
50.00	50.0	15.8997133	14.4100000	19.3506694	16.3700000	18.1095431
100.00	50.0	26.6419367	25.1300000	33.1531268	28.5900000	30.7880023
150.00	50.0	35.6145617	35.0200000	44.9775197	39.8700000	41.5535901

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15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The attenuation of a received signal on a millimeter wave (above 30 GHz) link probably will be considerably more sensitive to transmitted polarization of the signal than is the case on a microwave (below 30 GHz) link. The introduction of this report gives some background on past theoretical developments in assessing rain polarization effects. Then, a model is developed to more readily assess the rain attenuation polarization dependency, and this new model is compared with an accepted theoretical model. It is concluded, base on three separate sets of comparisons, that the model gives results close enough to the theoretical model to warrant consideration for its future use.

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microwaves; millimeter waves; models; oblate spheroids; polarization effects; rain attenuation

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