COMPLEMENTARY USE OF LASER-BEAM AND MILLIMETRIC-WAVE PROPAGATIONS

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Introduction

The fact that the losses for optical waves caused by rain are fairly small as compared with those for millimetric waves has scarecely been reported, except by Chu and Hogg [1], and has not been well exploited.

Through our simultaneous propagation tests at Nagoya, Japan of both laser beams (0.63µm) and millimetric waves (103GHz) on the same route, we verified that the losses for laser beams due to rain were low, confirmed that the relative attenuations between laser beams and millimetric waves coincide well with theoretical predictions, and further that rain, which causes the severe attenuation of millimetric waves, does not coexist with fog excepting in the case of light rains. Therefore, a complementary operation between optical and millimetric waves is suggested as a unique method to overcome severe meteorological conditions for such terrestrial applications as intracity communications.

Origin of Complementary Effects

The complementary effects are due to the following two reasons:

(1) The complex refractive indices n of liquid water are: n=1.33-j10⁻⁶ (λ =0.63 μ m), n=3.28-j1.84 (λ =3mm, f=100GHz). The total extinction Q_{ext}, consisting of the absorption and scattering of a raindrop, is about Q_{ext}=2 for a laser beam of λ =0.63 μ m, and Q_{ext}=2.7-3.0 at 100GHz for the raindrop radius a for the range of 2π a/ λ ≥1 [2].

(2) For laser beams, the next two conditions of a/ \gg l and | n-1| \ll l are satisfied and, therefore, an incident laser beam goes through raindrop particles with some phase delay according to the path length and scatters forward. This forward scattering decreases propagation losses and the power ratio against the total scattering power is denoted by $\beta(a)$.

According to the single scattering model given by Chu and Hogg, the propagation loss A is given by,

$$A_o = 4.343 \times 10^3 \int_0^\infty Q_{\text{ext}}(a, \lambda) \left\{ 1 - \beta(a) \right\}.$$

$$\pi a^2 \cdot n(a) \, da \qquad (1)$$

where, n(a) is the raindrop size distribution of radius a as a function of the rain rate. On the other hand, for millimetric waves, the incident waves reflect and refract on the spherical surface of raindrops, since $|n-1|\gg 1$, and the back scattering of incident power is dominant for a raindrop of $2\pi a/x \ll 1$.

Assuming that the forward scattering pattern of a raindrop is a Gaussian beam, $(2/\pi W_s^2) \exp(-2r^2/W_s^2)$, with an effective aperture area, $2\pi W_{os}^2 = \pi a^2$, equal to the geometrical cross section of a water sphere, we obtained the β in a simplified closed form,

$$\beta \simeq \frac{Q_{\text{scat}}}{Q_{\text{ext}}} \left(\frac{W_{\text{os}}}{W_{\text{ot}}} \right) \tan^{-1} \left(\frac{W_{\text{ot}}}{W_{\text{os}}} \right) \tag{2}$$

where, $Q_{\rm scat}/Q_{\rm ext}$ is the fraction of the intercepted energy available for forward scattering. The β is dependent on the ratio of raindrop radius a, $W_{\rm os} = a/\sqrt{2}$, to the minimum laser beam radius $W_{\rm ot}$, and is shown in Fig. 1. The accuracy of Eq.(2) is good as shown in Fig. 2, when $L\gg(\pi W_{\rm ot}^2/\lambda)$ and $(\pi W_{\rm os}^2/\lambda)$. Fig. 3 shows the calculated attenuations of Eq. (1) for the Laws and Parsons raindrop size distribution as a function of the rain rate.

2. Outline of Propagation Tests

We conducted the experimental tests on a 390m-long path at Atsuta-ku, Nagoya City, Japan from the end of March, 1983 to the middle of April, 1984.

The optical source was an He-Ne laser (GLD-5350 3mW, NEC) with focusing lenses (TOPCON) designed for a laser level meter

having a laser spot size of about 40mm at the distance of 390m. The millimetric wave CW source at 103GHz was a Klystron (100V11 70mW, OKI). The receiver was a double superheterodyne type with an auto-sweep AFC for the local source Klystron. The antenna was a Cassegrain reflector with a diameter of 45cm.

3. Experimental Discussions

The millimetric wave attenuations due to rain \mathbf{A}_{R} have been found by our former discussions [3] to be consistent with the predictions by Olsen, etal [4] in Eq. (3).

$$A_{R}(dB) = aR^{b} \cdot L$$
 (3)

where, R is the rain rate (mm/H) and L is the path length in Km and the constants are a=0.958 and b=0.774 at 100GHz and 20°C.

On the other hand, the laser beam attenuation due to rain, taking account of the forward scattering, is given by Eq. (4) by Chu and Hogg:

$$A_{O}(dB) = (\alpha R + \beta) \cdot L \tag{4}$$

where, the constants are $\alpha = 0.155$ and $\beta = 2.66$.

Fig. 4 shows the experimental attenuations as a function of the mean rain rate at the two locations as measured by a 10-second rain gauge during a thunderstorm on July 18, 1983. Some differences from the theoretical predictions above can be seen in Fig. 4. The reason for the differences, it seems, derives from a disparity between the actual rain rate and the measured rate, since a rain gauge which is set on the roof

of a building is unable to measure the correct rain rate because of the turbulence in the air flow surrounding the building, and from excessive radome losses owing to water film on the surface of the wet antenna radome.

In order to eliminate errors in the measurements of the rain rates, we turned our attention to the correlation of the two attenuations. Eliminating rain rate R from both equations (3) and (4), we obtained the next equation,

$$A_o = \alpha L \left(\frac{A_R}{aL}\right)^{\frac{1}{b}} + \beta L$$

=0.216 $A_R^{1.29} + 1.037$ (5)

Fig. 5 shows the measured correlations of the two attenuations at 10-second intervals. The excessive losses owing to the wet radome are cancelled by shifting the data on the axis by that amount. The good consistency with the theoretical prediction of Eq. (5) indicates that the results of Fig. 3 (Wot=2.5mm) and Eq. (4) are correct and that the optical losses in rain are really small, i.e. 18 dB/Km for R=100mm/H compared to 34 dB/Km for millimetric waves.

Fig. 6 shows the loss correlations for fog accompanied by a drizzle on April 19, 1983.

On some rain bursts in a typhoon, which present the worst propagation conditions for both waves, on September 28, 1983, the optical attenuation increased to about 40 dB/Km at the rain rate of lOOmm/H, while the millimetric attenuation became about 65 dB/Km, an excessive loss of

approximately 25 dB/Km.

4. Conclusions

Theoretically and experimentally, we ascertained that the propagation loss of laser beam in heavy rains was small as compared with that of millimetric This fact is applicable waves. to millimetric waves higher than The effects of loss re-40GHz. duction are more prominent as the laser beam becomes narrower. By complementary use of both optical beam and millimetric wave, we can expect the higher reliability and longer propagation path in a new range of electromagnetic wave communications.

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