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RESULTS OF EXPERIMENT OF LONG-DISTANCE OVERLAND PROPAGATION OF ULTRA-SHORT WAVES

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ABSTRACT

This paper explains the results of a VHF and UHF path loss test performed over a distance of 364 km between Tokyo and Osaka. Frequencies used were 159.49 Mc and 600.00 Mc. The measurement was made from November, 1956, to August, 1957. The data were statistically analyzed to investigate the temporal variation of field strength, the spatial correlation of field strength, and the relation between the transmission loss and meteorological condition.

1. Introduction

As the result of recent investigations of long-distance overland propagation of ultra-short waves, multiple diffraction by mountain ridges and atmospheric scattering are acquiring a great importance as mechanisms of propagation. In Japan, by reason of its mountainous configulation, at a long distance from the transmitting point, there is often found a zone where the field strength is very steady and strong on account of single diffraction of a high mountain. Generally, however, a diffraction wave over mountains weakens abruptly by multiple diffraction, but, on the other hand, an atmosphyeric scattering wave does not attenuate so much with the increase of propagation distance. For these reasons, it is considered that the mechanism of overland propagation of ultra-short waves over distances of several hundred kilometers is constructed of almost the same amounts of multiple diffraction by mountain ridges and atmospheric scattering. Many investigations on atmospheric scattering have been carried on in America, various characters of atmospheric scattering being discovered. But, those results are not always applicable to Japan where the meteorological conditions considerably differ from those in America. Moreover, as mentioned above, the mountainous configuration of Japan, it is considered, makes much difference between Japan and America in the propagation mode of ultra-short waves.

Therefore, this experiment aims at research into the propagation mechanism of ultra-short waves in Japan to develop the long-distance communication on ultra-short waves.

The experiment was conducted over a distance of 364 km between Kokubunji (Tokyo) and Mt. Ikoma (Osaka) for a period of about a half year from November, 1956, to August, 1957, to investigate a long term variation in transmission loss. Frequencies used were 159.49 Mc (VHF) and 600.00 Mc (UHF) for investigation of frequency characteristic of transmission loss. But, as the UHF signal was too weak to derive accurate information, this paper will, for the most part, deal with the data on VHF, the data on UHF being used as an auxiliary.

2. Summary of the Experiment

(1) Period of the experiment
From 9th November, 1956
To 4th August, 1957
(From 8th Dec., 1956, to 15th Mar., 1957, the experiment was suspended.)

(2) Transmitting and receiving points
Transmitting point: Kukubunji, Tokyo, (Radio Research Laboratories)
Receiving point: Mt. Ikoma, Osaka

(3) Map and profile of transmission path
The map and profile of transmission path are shown in Fig. 1.

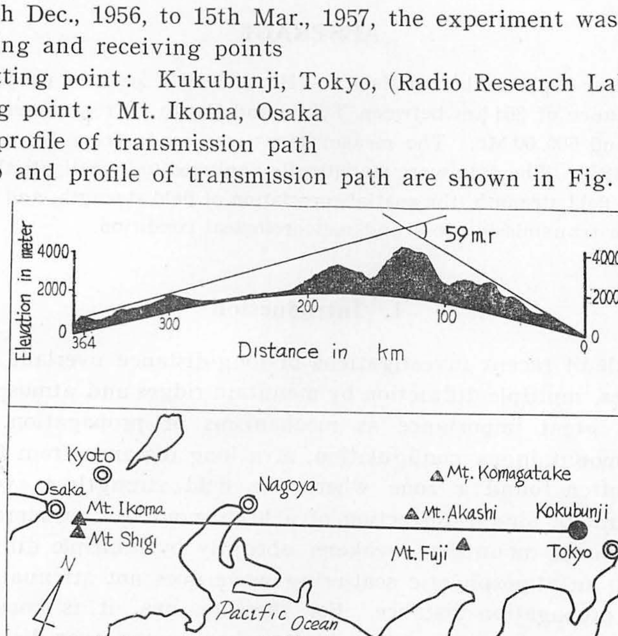


Fig. 1. Map and profile of transmission path.

(4) Transmitting and receiving equipments

The characters of transmitting and receiving equipments are indicated in Tables 1 and 2.

Table 1. Transmitting equipment

Frequency (Mc)	Transmitter Output (W)	Line Loss (db)	Type of Antenna	Antenna Gain* (db)	Antenna Height (m)	
					above ground level	above see level
159.49	300	2	2 stacks of a pair of 4 element Yagi antenna	13	80	155
600.00	200	3	Paraboric Antenna (Diameter is 2.3 meters)	20	45	120

* Referred to isotropic antenna

Table 2. Receiving equipment

Frequency (Mc)	Type of Antenna	Antenna Gain* (db)	Antenna Height (m)		Line Loss (db)	Band-width (c/s)
			above ground level	above sea level		
159.49	4 stacks of a pair of 8 element Yagi antenna	24	7	607	0	100
600.00	Paraboric Antenna (Diameter is 3 meters)	23	3	610	3	100

* Referred to isotropic antenna

3. Results of the Experiment and Considerations

(1) Median values of basic transmission loss

This section will deal with the relation between the observed median value and the theoretical value of basic transmission loss. Those values are shown in Table 3.

The observed median values shown in Table 3 mean the median values of 5-min. medians of basic transmission loss observed during the whole period of this experiment, and it is considered that these values are nearly equal to the annual median values, although the period of experiment was about half a year.

Table 3. Observed value and estimated value of basic transmission loss

Freguency (Mc)	Basic Transmission Loss (db)		
	Observed Value (Annual Median)	Theoretical Value	
		Scattering	Diffraction
159.49	209	196	206
600.00	227	213	235

We could obtain the anual median value of transmission loss on UHF by using the differences in basic transmission loss between UHF and VHF when both strengths were comparativery strong.

The theoretical values shown in Table 3 were computed on the assumption that the main propagation mode is only of atmospheric scattering, or of multiple diffraction by mountain ridges.

The theoretical values of basic transmission loss for atmospheric scattering waves were computed by the formula presented by K.A. Norton(1). That is:

$$L_b = 30\log_{10} f + 30\log_{10} d + 50\log_{10}\theta + bNs + a \tag{1}$$

where L_b: median value of basic transmission loss in db
f: frequency in Mc
d: distance in miles
θ: scattering angle in radian
Ns: median of the surface values of refractive index in N.U.
a: constant which is determined by the asymmetry of transmission path, the scale of turbulence, and wave length, etc.
b: regression coefficient of Ns for transmission loss in db/N.U.

In our case, $f=159.49$ or 600.00, $d=226$ and $\theta=0.059$.

Ns was calculated from the meteorological data obtained at Nagoyo Meteorological Observatory whose geographycal position was near to the middle point of the transmission path. We applied the value of a or b to the value pointed out in America, namely $a=174$, $b=-0.156$.

Equation (1) is considered as on empirical formula rather than a pure theoretical one. It may be applied to long-distance propagation except in the case where extremely high field strength is obtained by reflection from the inversion layer, etc. The constant a or b has to be determined empirically in consideration of meteorological or geographycal conditions.

The theoretical values of basic transmission loss for multiple diffraction waves were computed on the assumption that diffraction ridges are black bodies in knife-enged shapes(2).

The theoretical values of basic transmission loss in Table 3 show that the main propagation mode of this transmission path is of atmospheric scattering, because the theoretical values of basic transmission loss of scattering wave are smaller than those of diffraction wave. It is noticeable, however, that the observed median values of basic transmission loss are about 13 db greater than the theoretical values for atmospheric scattering. Next, in the frequency characteristic of basic transmission loss in Table 3, it is interesting that the observed values of difference in basic transmission loss between VHF and UHF is almost equal to the theoretical values for atmospheric scattering. This means that the basic transmission loss is proportional to the 3rd power of the frequency. This phenomenon of atmospheric scattering is of great importance and was pointed out theoretically by many investigaters, for example, by F. Villars and V. F. Weisskopf,[3] F. H. Friis,[4] and K. Takahashi[5].

It is very difficult to decide the main propagation mode of this transmission path only on the basis of comparison between the observed median values and the theoretical values, but it is acceptable that the received signals on VHF are composed of atmospheric scattering and multiple diffraction waves.

When the median values of basic transmission loss are dealt with, the local variation of the transmission loss must be considered. So, we examined the variation in the vicinity of the receiving point, and found that there was no wide variation due to locality.

(2) Long term variation in transmission loss

(i) Seasonal variation

Fig. 2 shows the long term variation in basic transmission loss. In the figure, both ends of each slender vertical line indicate the maximum and minimum of 5-min. medians of basic transmission loss on VHF during a day, black circles indicate monthly medians of 5-min. medians of basic transmission loss on VHF and crosses the minimum of 5-min. medians of basic transmission loss on UHF during a day on which the signals were comparatively strong.

The figure shows a tendency that the transmission loss decreases in summer. A rough estimation of seasonal variation of transmission loss may be made by the transition of Ns in the equation (1). In this experiment, the correlation between the

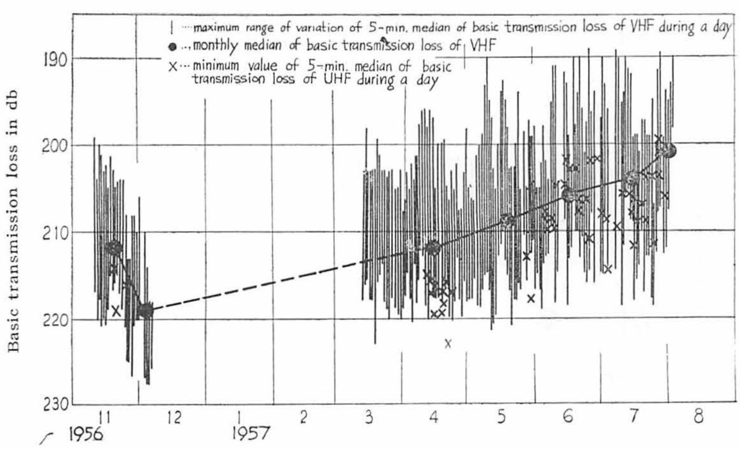


Fig. 2. Observed value of 5-min. median of basic transmission loss.

monthly median of transmission loss and Ns is very good, namely, the correlation coefficient is -0.93 and the regression coefficient is -0.162 (b in the equation (1)). The same phenomena were discovered by many investigators, such as B. R. Bean(7), G. W. Pickard(8), H. T. Sletson(8), D. L. Randall(9) and R. E. Gray(10). According to R. E. Gray, the regression coefficient between the transmission loss and Ns varies with latitudes. The value of the coefficient used in the preceding section ($b=-0.156$) was obtained in the experiment conducted in Texas, U.S.A. The fact that the correlation between the monthly median of transmission loss and Ns is good is very useful for engineering purposes. Though its exact physical meaning is not yet obvious, we may be able to imagine the relation between the transmisson loss and Ns. In other words, the correlation between Ns and refractivity gradient with height in the atmosphere is very good in a general sense, so a scattering angle is small when Ns is large and the height of important scattering volume is low when Ns is large. Futhermore, the unhomogeneity of refractivity in the scattering volume is great when the refractivity gradient is large. For these reasons, it may be imaginable that the transmission loss of atmospheric scattering waves is small when Ns is large. On the other hand, we can easily imagine that the transmission loss of diffraction wave also is small when the refractivity gradient is great.

We estimated the range of variation in monthly median of transmission loss on the assumption that the variation of transmission loss was caused only by the variation of k (ratio of the equivalent earth radius to the true radius). But the estimated range of variation in monthly median of transmission loss was only a few db for either scattering or diffraction waves.

In Fig. 3 are shown the estimated monthly medians of transmission loss computed from the regression coefficient, the observed monthly medians being added for ready comparison. It is noticeable in the figure that the observed monthly median in December appreciably differs from the estimated value. The reason is that the data for this month are considerably few and the field strength during this month was extremely weak because the transmission path was covered by the atmospheric

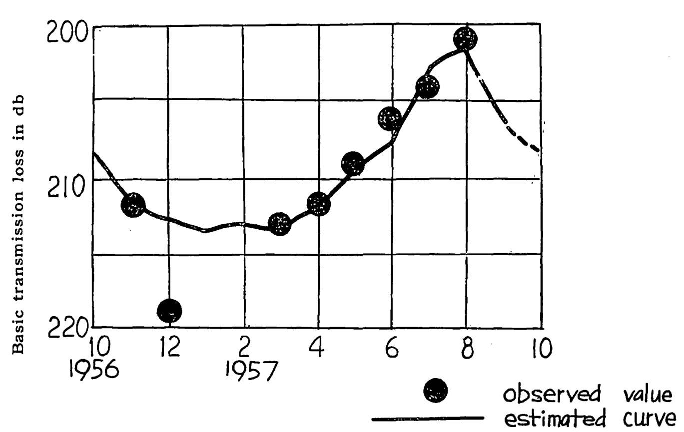


Fig. 3. Estimated annual variation of basic transmission loss (VHF)

depression. It has often been found in other experiment, too, that the transmission loss is large when the transmission path is covered by atmospheric depression. Therefore, the estimated values seem to be preferable as the range of variation in monthly median of transmission loss. The difference between the maximum and minimum of monthly medians of transmission loss is about 12 db. The ranges of variation in monthly median of transmission loss observed in America are shown in Table 4 including our data. It may be seen that the range in our experiment is considerably small as compared with those in America.

The values of a and b in the equation (1) obtained in this experiment are 189 and -0.162 respectively.

Table 4. Range of variation of monthly median of transmission loss

Transmitting and Receiving Points	Distance (Km)	Frequency (Mc)	Period of Experiment	Ratio of Monthly Median of Transmission Loss between Summer and Winter (db)	Data Unit	Reference Number
St. Anthony —Gander	278	505	1954 Mar.—Jun.	19.5	hourly median	(11)
St. Anthony —Gander	278	4090	Dec. 1953 —Jul. 1954	12.5	hourly median	(11)
Round Hill —Red Bank	296	385.5	Jan. 1954	12.0	hourly median	(12)
		399.5	Jul. 1954		15-min. median	
Crawfords Hill —Round Hill	303	3670	Dec. 1953 —Jul. 1954	26.0	hourly median	(12)
Scituate —Seal Harbor	312	200	1954 Jan.—Aug.	23.0	15-min. median	(13)
Kokubunji —Mt. Ikoma	364	159.49	Nov. 1956 —Aug. 1957	12.0	5-min. median	this paper

(ii) Diurnal variation

Fig. 4 shows the diurnal variations of transmission loss in each month. In each figure, the ordinate indicates the monthly median of 5-min. medians of basic transmission loss. It may be seen in the figures that in autumn (November) and spring (April, May) the transmission loss decreases slightly in the afternoon, but there is no marked tendency.

(iii) Distribution of transmission loss

The cumulative probability curves of 5-min. medians of transmission loss for each month and for the whole period of experiment are shown in Figs. 5 and 6.

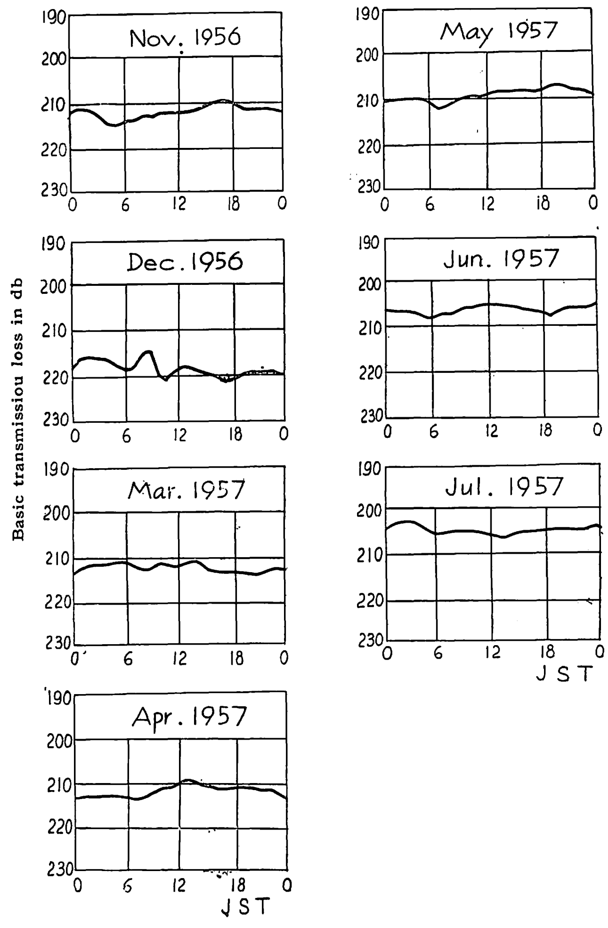


Fig. 4. Diurnal variation of transmission loss (VHF)

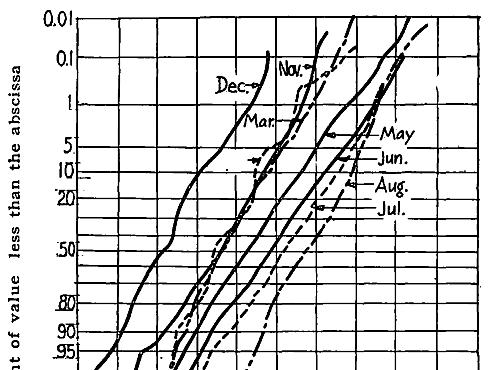


Fig. 5. Cumulative distribution of 5-min. median of basic transmission loss (VHF) (each month)

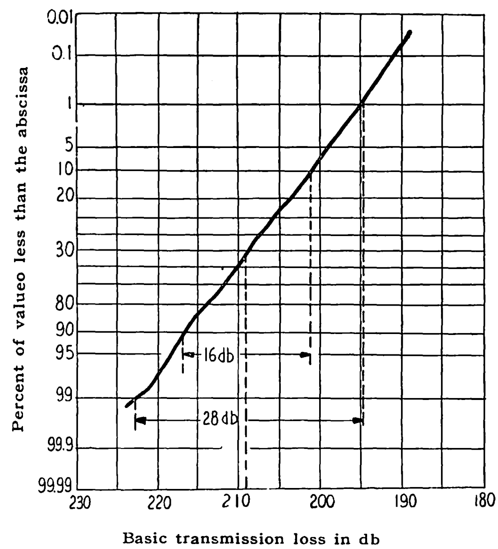


Fig. 6. Cumulative distribution of 5-min. median of basic transmission loss (VHF) (whole period of the experiment)

The result can be represented reasonably well by log-normal distribution. The ranges of variation, the ratios of the 10% value to the 90% value and of the 1% value to the 99% value, in each cumulative probability curves in Figs. 5 and 6 are shown in Table 5. In Table 6 are shown the ranges of variation in transmission loss obtained in America. In order to compare them with the data in America and to investigate the variation in 5-min. medians of transmission loss within an hour, we shall show in Table 5 also the ranges of variation of hourly median. Comparison of two sets of range of variation implies that the variation of 5-min. medians within an hour is negligibly small. Table 6 shows that the range of variation

Table 5. Range of variation of transmission loss

Definition of range of variation	Data Unit \ Year / Month	1956 Nov. and Dec.	1957 Mar.	Apr.	May	Jun.	July and Aug.	Whole period
10% to 90% ratio	5-min. median	14.7	10.0	10.2	12.5	13.7	13.5	15.5
	Hourly median	12.4	9.4	10.0	10.6	11.3	13.6	14.5
1% to 99% ratio	5-min. median	23.4	17.5	19.5	23.0	23.7	22.8	28.2
	Hourly median	24.4	18.0	19.3	19.1	19.7	22.1	27.3

Table 6. Range of variation of transmission loss during a year

Transmitting and Receiving Points	Distance (Km)	Frequency (Mc)	Period of Experiment	Range of Variation of Transmission Loss (10% to 90% ratio) (db)
Cheyenne Mt. —Garden City	365	1046	Feb. 1952 —Jan. 1953	16
Cedar Rapids —Quiney	216	418	Apr. 1951 —Dec. 1951	20
St. Anthony —Gander	278	505	Nov. 1953 —Oct. 1954	24
St. Anthony —Gander	278	4090	Nov. 1953 —Oct. 1954	20
Kokubunji —Mt. Ikoma	364	159	Nov. 1956 —Aug. 1957	16

during the experiment was comparativery small, but we have to consider that, according to the data in America, the range of variation decreases as the distance increases, so that at a distance of more than 300 km the range of variation (10% to 90% ratio) approaches about 14~16 db.

(iv) Relation between the transmission loss and meteorological condition

It is interesting to note that the relation between the transmission loss and the meteorological condition on the propagational path was considerably clarified in this experiment. Some explanations will be given in this connection as follows:

(a) Generally, the transmission loss is large when the transmission path is covered by atmospheric depression.

(b) When the transmission path is covered by anticyclone, the diurnal variation of transmission loss has a tendency that the loss is largest in early morning and decreases gradually with the increase of atmospheric temperature as shown in Fig. 7.

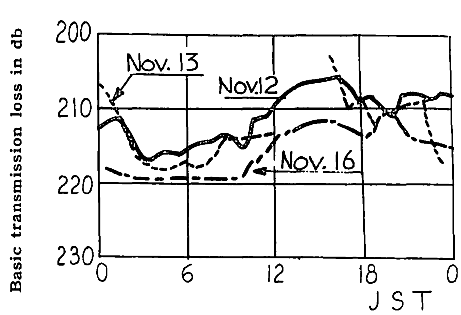


Fig. 7. Variation of hourly median of transmission loss when the transmission path was covered by anticyclone (VHF).

(c) In autumn, the influence of anticyclon upon the transmission loss is considerably active. The reascn may be that the scale of anticyclone is relatively large in this season in Japan.

(d) Fig. 8 gives a correlation diagram between the hourly median of transmission loss and the atmospheric temperature measured at the top of Mt. Fuji at midnight and noon. From the figure, there is found a negative correlation between them. The data used in the figure were obtained when the transmission path was covered by anticyclone or atmospheric depression in autumn, because the whole transmission path was expected to be in similar meteorological conditions. The reason why we used the data at the top of Mt. Fuji is that Mt. Fuji is located near the transmission path as shown

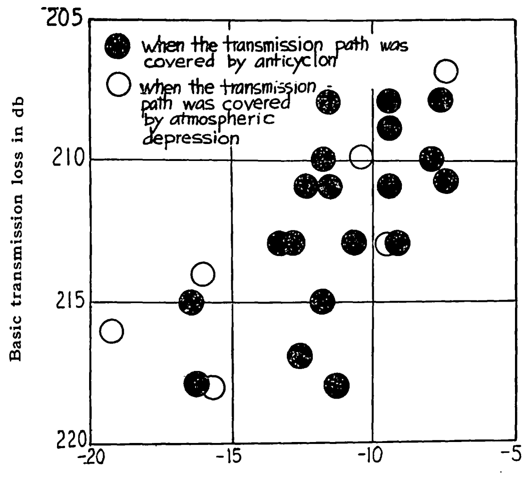
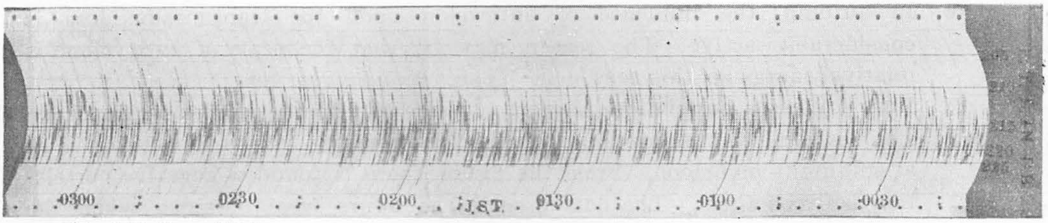


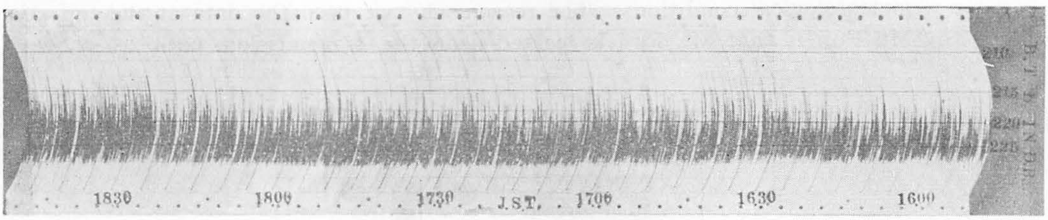
Fig. 8. Correlation diagram between the transmission less and the atmospheric temperature.

in Fig. 1 and its height is nearly equal to the height of important scattering volume. Futhermore, in like manner, we drew a diagram for the correlation between the transmission loss and the atmospheric temperature observed by radiosonde at Tateno Aerological Observatory, and there was also found a negative correlation between the transmission loss and the atmospheric temperature at a height below about 4,000 m. From the phenomena mentioned above and the tendency referred to in (b) of this section, it may be imagined that there is some relation between the atmospheric temperature and scattering parameters if the main propagational mode in this experiment is of atmospheric scattering. Also, a number of direct measurements(14)(15)(16) of atmospheric turbulence suggest the same results.

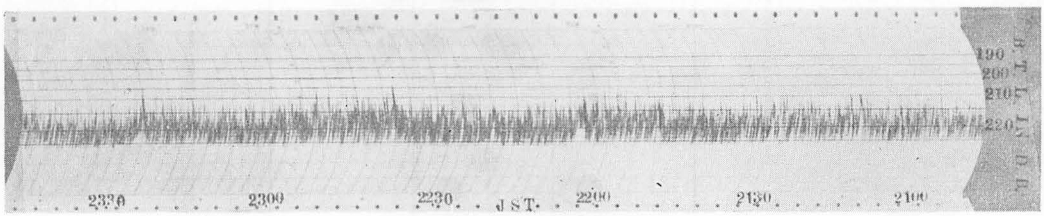
(e) In autumn when the meteorogical conditions changed abruptly, especially when the atmospheric depression took the place of the anticyclone, the rapid decrease of transmission loss, say, by more than 10 db, was found often. Its duration ranged from a few hours to several ten hours.



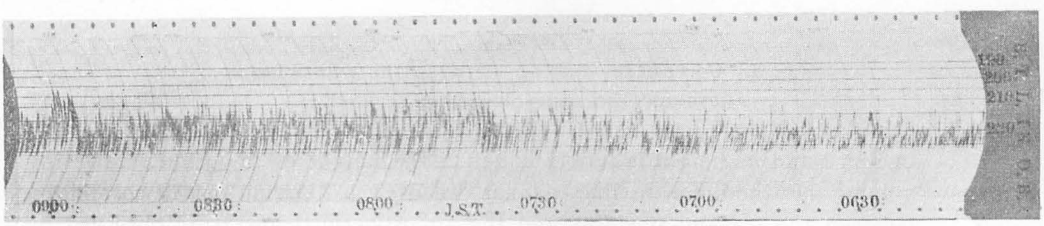
(a) 14th Nov., 1956



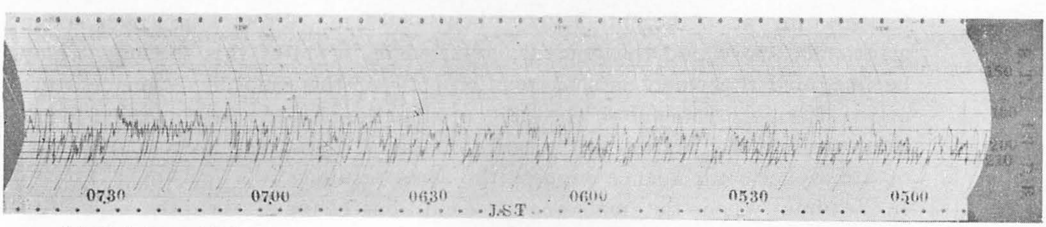
(b) 4th Dec. 1956



(c) 19th Mar., 1957



(d) 20 th Mar., 1957



(e) 3rd Aug., 1957

Fig. 9. Example of automatic recording of transmission loss (VHF)

(3) Short term variation in transmission loss

(i) Fading type and fading rate

A few examples of automatic recording of transmission loss on VHF are shown in Fig. 9, in which (a) and (b) exemplify the autumn data, (c) and (d) the spring, and (e) the summer. In summer, the transmission loss is small and the fading rate is also as small as about 1 times/min.

Moreover, (a) and (d) are examples in the case where the transmission path is covered by anticyclone, and (b) and (c) where the transmission path is covered by atmospheric depression. Generally, in the case of anticyclone, the fading rate is small (about 5 times/min.), and in the case of atmospheric depression, rate is large (about 10~15 times/min.).

(ii) Distribution of transmission Loss

A few samples of distribution of transmission loss (relative value) during 5 min. are shown in Fig. 10. From the figure, it is found that the fading range is slightly smaller than that of Rayleigh distribution.

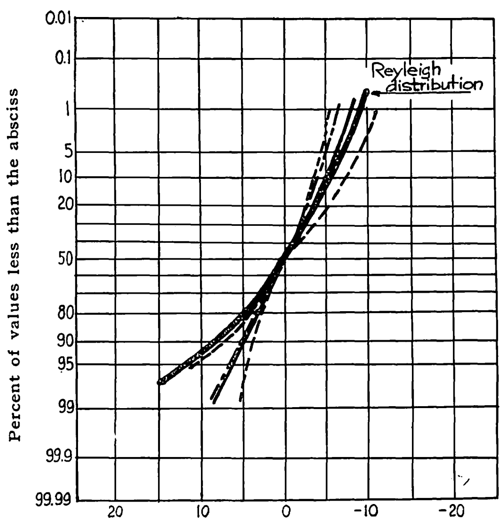


Fig. 10. Short term distribution of transmission loss during 5 min. (VHF)

(iii) Spatial correlation of transmission loss

Fig. 11 indicates the spatial correlation of transmission loss. In the figure, the ordinate indicates correlation coefficients between the instantaneous output of two VHF receiving antennas separated normal to the transmission path, and the duration of measurement is 5 minutes. For ready comparison, the data in America are also shown in the figure. As seen in the figure, it is remarkable that the spatial correlation measured in this experiment is very good, namely, when the antenna separation is about hundred wave-length, the correlation coefficient is about 0.4, while the corresponding values in America are almost zero. The high spatial correlation

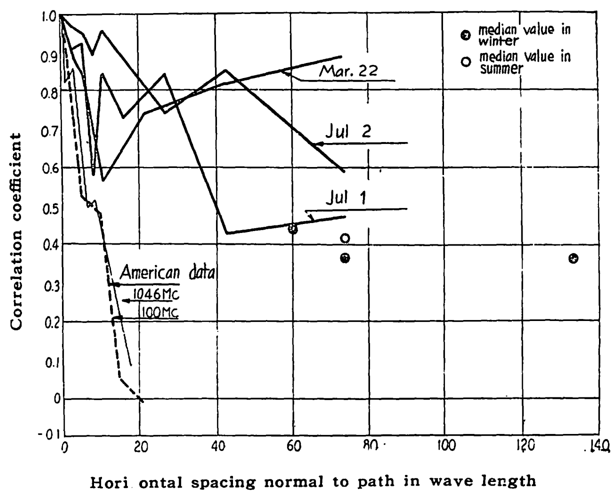


Fig. 11. Spatial correlation of VHF field strength

is inconvenient for diversity reception, but this characteristic is worthy of notice in view of less degradation of antenna gain and greater capability of frequency band for actual communication.

4. Conclusion

The results of the experiment and the consideration are summarized as follows:

(i) The observed annual median of basic transmission loss is about 13 db greater than the estimated value in atmospheric scattering. On the other hand, as for multiple diffraction waves over mountain ridges, the observed value is 3 db greater than the estimated value of VHF and 8 db smaller than the estimated value of UHF.

(ii) The mean difference between the basic transmission losses on VHF and UHF is about 18 db, and it is considered that the basic transmission loss is proportional to the 3rd power of the frequency.

(iii) The transmission loss is large in winter and small in summer. The difference between the maximum and minimum of monthly medians of transmission loss during a year is about 12 db, and this difference is relatively small as compared with the data in America.

(iv) The diurnal variation of transmission loss has no marked tendency.

(v) There is a negative correlation between the transmission loss and *Ns* or atmospheric temperature. For engineering purposes, it is interesting that the correlation between the monthly median of transmission loss and *Ns* is very good.

(vi) The type of distribution of 5-min. medians of transmission loss is log-normal. The range of variation in a month is about 10~14 db (10% to 90% ratio), and the range in a year is about 16 db.

(vii) The fading range of short term variation of transmission loss is slightly smaller than that of Reyleigh distribution.

(viii) In general, when the transmission path is covered by anticyclone, the transmission loss is small and the fading rate is also small.

(ix) Spatial correlation of transmission loss is very good as compared with the data in America.

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