Review of Path Loss Measurements

- High Base Station antenna Measurements for <u>Macrocells</u>
- Low base Station Antenna Measurements for <u>Microcells</u>
  - Line of Sight (LOS) Paths
  - Obstructed Paths

Signal Characteristics and Prediction Goals

- Scales of variability
  - Fast fading (scale ~ λ/2)
  - Shadow fading (average over ~ 20 λ, 5 - 10 m)
  - Range and direction dependence

    : Simplest form is A/R^n

Macrocells vs Microcells

- Early Systems Using Large Cells (Macrocells)
  - Base station antennas well above buildings
  - Isotropic propagation with range variation A/R^n
  - Hexagonal tessellation(mosaic) of plane
  - Frequency reuse independent of antenna height
- Modern Systems Using Small Cells (Microcells)
  - Base station antennas near (or below) rooftops
  - Anisotropic propagation: A, n depend on
    - ✓ Direction of propagation relative to street grid
    - ✓ Base station height, frequency, location relative to buildings
    - ✓ Style of buildings
  - Unresolved system design issues:
    - ✓ Cell shape for tessellating the plane
    - ✓ Frequency reuse factor
    - ✓ Reuse Configuration

Abstract

- Propagation tests for land-mobile radio service
  - VHF (200MHz) and UHF (453, 922, 1310, 1430, 1920MHz)
  - Various situations of irregular terrain/environmental clutter
- The parameters of statistical analysis of measured results
  - Distance
  - Frequency dependences of median field strength
  - Location variability
  - Antenna height gain factors of the base and the vehicular station
  - In urban, suburban, and open areas over quasi-smooth terrain
- A method for predicting the field strength and service area
- Comparison of the predicted field strength with the measured data

Outline of Propagation Tests Performed

- First series of tests
  - In 1962
  - Simple & flat areas, Quasi–smooth terrains containing many built-up cities
  - Distance up to 100 km
  - Two or more mobile courses for each base station
  - 453, 922, 1310, 1920 MHz
- Second series of tests
  - In 1965
  - Using lower base station antennas
  - Hilly, mountainous, irregular terrain
  - 453, 922, 1317, 1430 MHz

Path Condition and Mobile Course

- First Propagation Test

Transmitting Base Station	h_{ts}/h_{tg} (m)	Name of Moblie Course	Direction of Trans. Ant. Beam	h_{ga} (m)	h_{te} (m)	Situation of Path Terrain
Top of Mt. Tsukuba	848/35	Tachikawa Tokyo	SW 50 ° SW 30 °	20 25	828 823	Quari-smooth Terrain, urban, suburban, open area
Halfway of Mt. Tsukuba	239/6	Tachikawa Tokyo	SW 50 ° SW 30 °	20 25	219 214	
Upper Floor of Tokyo Tower	246/228	Mito Kumagaya	NE 42.5 ° NW 24 °	10 25	236 221	
Lower Floor of Tokyo Tower	156/138	Mito	NE 42.5 °	10	146	
Marunouchi Tokyo	63/60	Soka Funabashi Asaka Tamakawa	In the city of Tokyo	3 3 3 3	60 60 30 30	Nikko-Road Keiyo-Road Kawagoe-Road Tamakawa Road

Path Condition and Mobile Course (Cont’d)

- Second Propagation Test

Transmitting Base Station	h_{ts}/h_{tg} (m)	Name of Moblie Course	Direction of Trans. Ant. Beam	h_{ga} (m)	h_{te} (m)	Situation of Path Terrain
Lower Floor of Tokyo Tower	150/132	Mito Choshi Hakone	NE 42.5 ° NE 81.5 ° SW 45 °	10 5 30	140 145 120	Quasi-smooth Terrain Hilly and Mountainous Terrain
Kuramae Relay Station	62/59	Mito Kumagaya	NE 42.5 ° NW 30 °	10 20	52 42	Quasi-smooth Terrain
Enkai Relay Station	163/9	Hachioji Tachikawa	NW 35 ° NW 20 °	55 55	108 108	Hilly and Mountainous terrain

Parameters of Measurement

- Vertically polarized wave was in use for all frequencies

Frequency MHz	Transmitter Power	Transmitting Antenna Gain Type	Receiving Antenna Gain Type
453	150 W	11.3 dB 5-element Yagi	1.5 dB Omni-directional unipole antenna
922	60 W	11.3 dB 90 ° Corner	1.5 dB ″
1317	150 kW Pulse	11.3 dB 1.2 m in diam. Parabola	1.5 dB ″
1430	30 W	11.3 dB 1.5 m parabola	1.5 dB ″
1920	60 W	11.3 dB Horn	1.5 dB ″

Mobile Field Strength Measurements

- Receiving Antennas
  - 3 m high above ground installed at both sides on top of the mobile radio van / 1.5 m high antennas
- Data recording
  - Input signals from the antennas → field strength meters classified by frequencies → outputs recorded simultaneously, parallel and continuously by a 4-pen recorder; if necessary, magnetic tape recorder at the same time
  - Normal mobile recording: the variation of the median level
    - ✓ The averaged traveling speed: 30 km/hr
    - ✓ The averaged recording paper speed: 5 mm/sec
  - Instantaneous level variation: the method of sampling recording for a small sector of 50 m for some prominent terrain irregularities and environmental clutter
    - ✓ The averaged traveling speed: 15 km/hr
    - ✓ The averaged recording paper speed: 5 mm/sec
  - Minimum input level recordable : -125 dBm (-12 dBμ)
  - Recorder scope : almost linearly 50 dB

Mobile Field Strength Measurements(ctd.)

- Obtaining Data
  - Excluded regions – the corrected ratio of ant. directional characteristics became indistinct
  - Within 10 km(the built-up areas) – horizontal omni-directional Tx antenna.
  - Measurements along the path and across the path

Classification and Definition of Terrain Features

- Quasi-smooth terrain: the reference terrain
  - A flat terrain where the undulation height is about 20 m or less with gentle ups and downs
  - The average level of ground does not differ much (less than 20 m)

- Irregular terrain: rolling hilly terrain, isolated mountain, general sloping terrain, mixed landsea path
- Base Station Effective Antenna Height(Fig. 4)
- Terrain Undulation Height(Fig. 5)

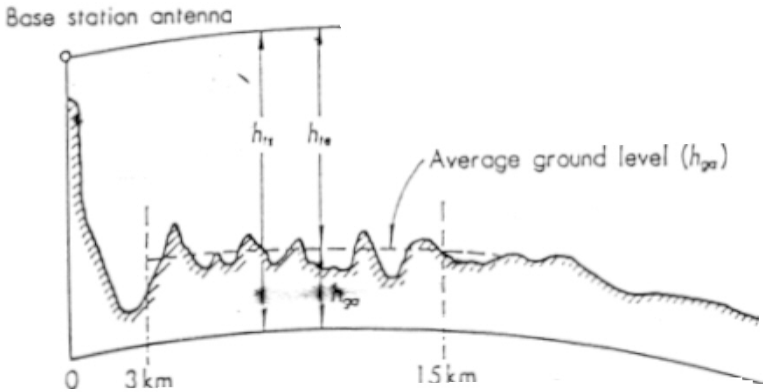


Fig. 4—Definition of effective transmitting antenna height (h_{te}).

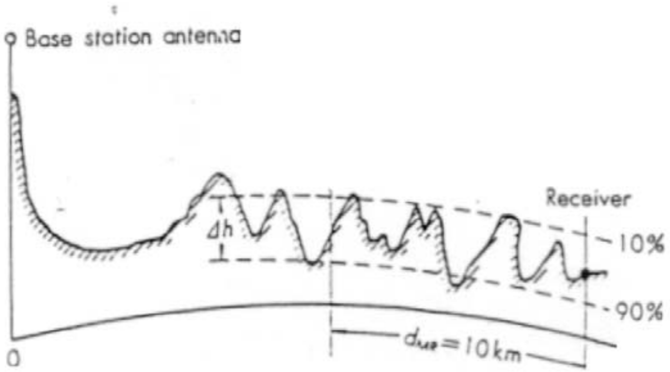


Fig. 5—Definition of the parameter (Δh, "terrain undulation height") for rolling hilly terrain.

Classification and Definition of Terrain Features(Ctd.)

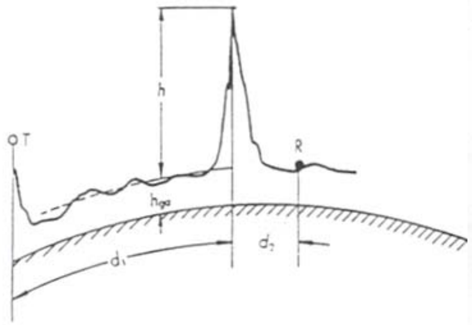
- Isolated Mountain Ridge and Path Parameter: knife edge
- Average General Slope Angle – Slope over a distance 5 ~ 10 km

$$\theta_m = \frac{h_n - h_m}{d_n}$$

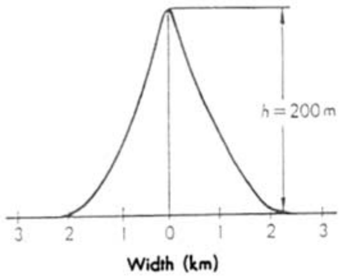
$h_n > h_m$: uphill, slope angle is positive ($+\theta_m$)

$h_n < h_m$: downhill, slope angle is negative ($-\theta_m$)

- Distance Parameter for Mixed land-Sea Path

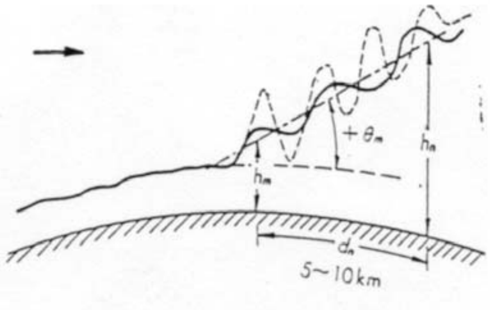


(a) Path parameter

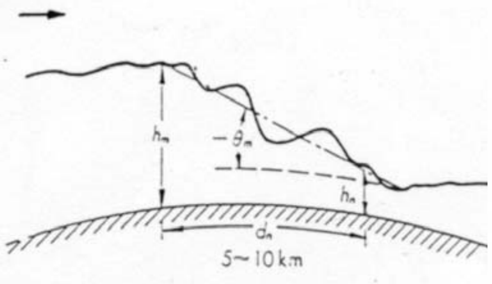


(b) Model

Fig. 6—The model and geometrical parameter of isolated ridge.



(a) Positive slope ($+\theta_m$)



(b) Negative slope ($-\theta_m$)

Fig. 7—Definition of average angle of general terrain slope.

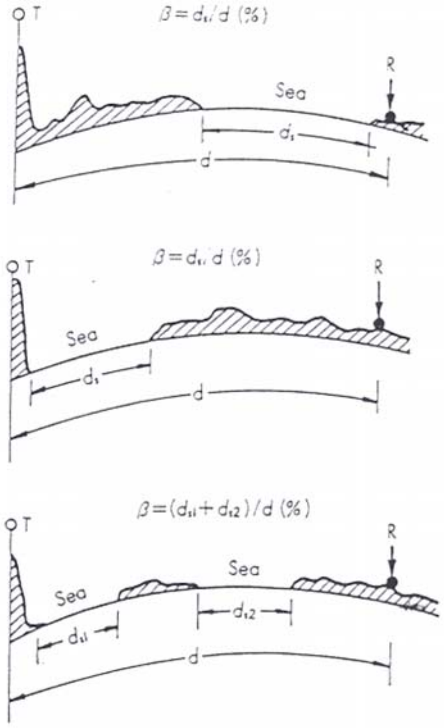


Fig. 8—Definition of distance parameter (β) for mixed land-sea path.

Classification and Definition of Environmental Clutter(Ctd.)

- Open Area – No obstacles in the propagation path
- Suburban Area – Having some obstacles near the mobile
- Urban Area – Built-up city or large town

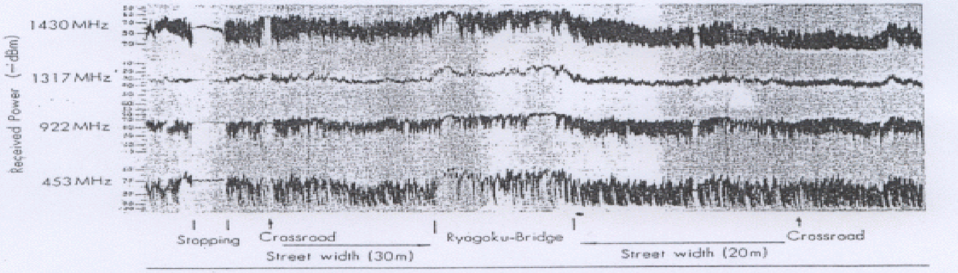
Treatment of Data; Method of Expression

- Field strength data: Treated statistically
- Entire distance: Divided into “sampling interval” of 1~1.5 km
- Readings: Taken “small-sector medians” at intervals of about 20 m
- The standard field strength: Urban field strength median in a quasi-smooth terrain (“ basic median field strength”)
- Correction factor: The difference between the standard and the measured for each of the terrain features

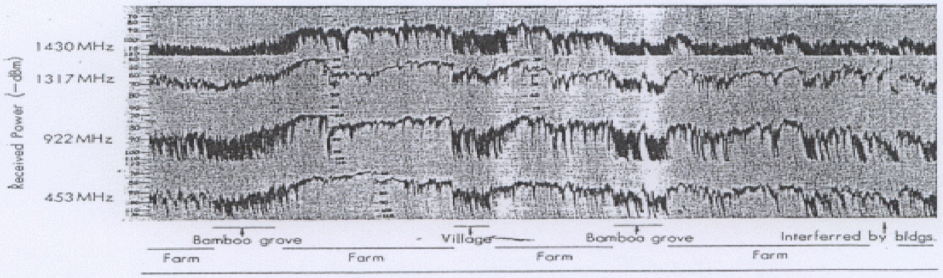
Propagation Characteristics on Quasi-Smooth Terrain

- How the field strength varies
  - A deep instantaneous variation of quick periodic motion
  - Median attenuation relative to free space

    Urban area > suburban area > open area
  - Behind the obstacles: Rayleigh distribution(multipath inteference)



(a) Field strength on 42.5° NE radial from Tokyo Tower. (Urban across path, $d \doteqdot 6.5$ km)



(b) Field strength on the Atsugi-road from Enkai station. (Rural, oblique path, $d \doteqdot 25$ km)

Fig. 9—Examples of amplitude recording of the received field strength.

Median Field Strength vs. Distance Curves at Various Frequencies

- Quasi-smooth terrain
- Measured values: averages of the medians of sampling intervals
    - Sampling intervals: 1 - 1.5 km
    - Small sector medians: intervals of about 20 m
    - Comparatively smooth change with distance: averaged values for various directions

Distance Dependence of Field Strength in Urban Area

- Median attenuation relative to free space with d
  - h_{te}: 140 m
  - Freq.: 453, 922, 1430, 1920 MHz

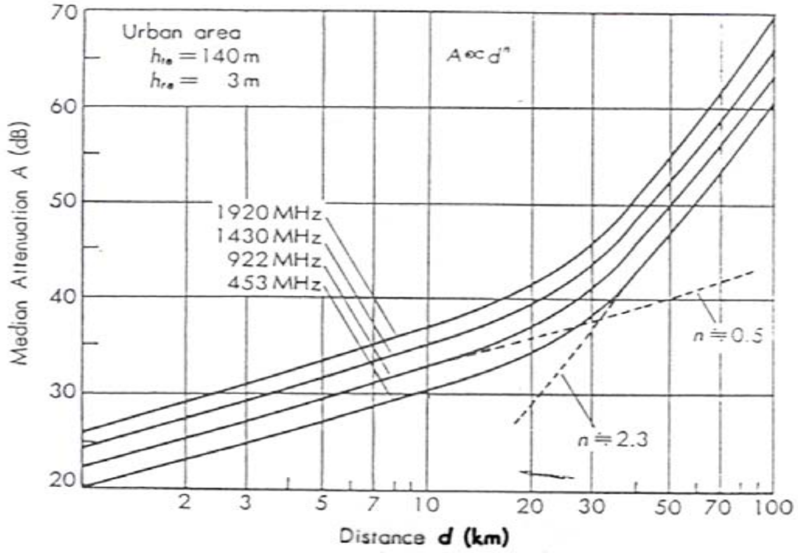


Fig. 11—Example in distance dependence of median field strength attenuation in urban area.

- ✓ d < 15 km : $A \propto d^{1/2}$
- ✓ 15<d<40 km: sudden increase
- ✓ 40<d<100km : $A \propto d^{2.3}$

A: median attenuation

d: distance

Distance Dependence of Field Strength in Urban Area

- The relation of the median field strength (E_m) to the base station antenna effective height (h_{te})

$$E_m \propto d^{-n}$$

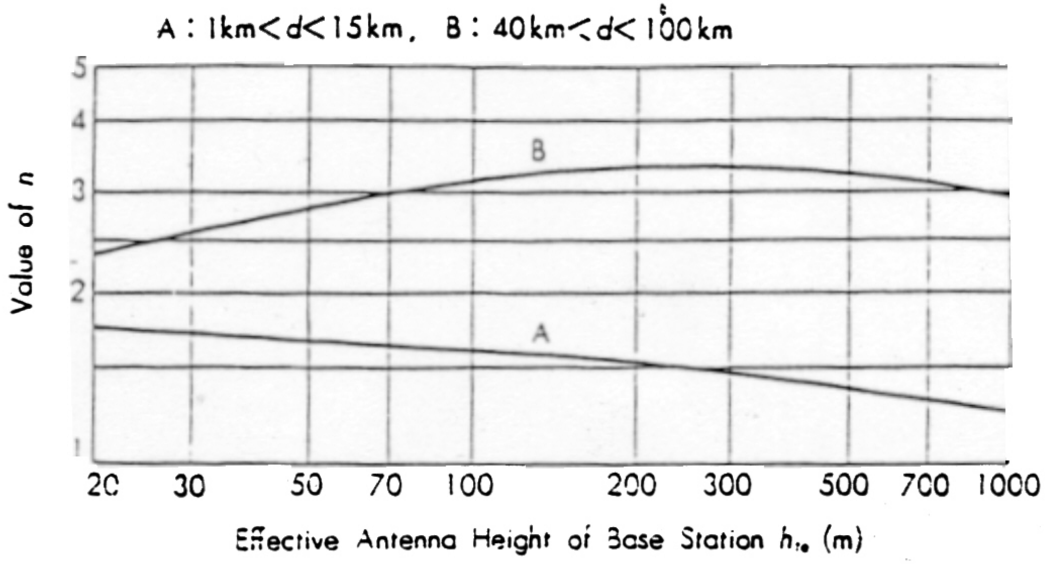


Fig. 12—Distance dependence of median field strength in urban area ($E_m \propto d^{-n}$).

Frequency Dependence of Median Field Strength

- The Attenuation $\propto$ Freq.
- Median attenuation relative to free space in an urban area
  - h_{te} = 140 m, the standard freq. f = 453 MHz
- Fig. 14: Field strength lapse rate relative to frequency : $E_m \propto f^{-n}$

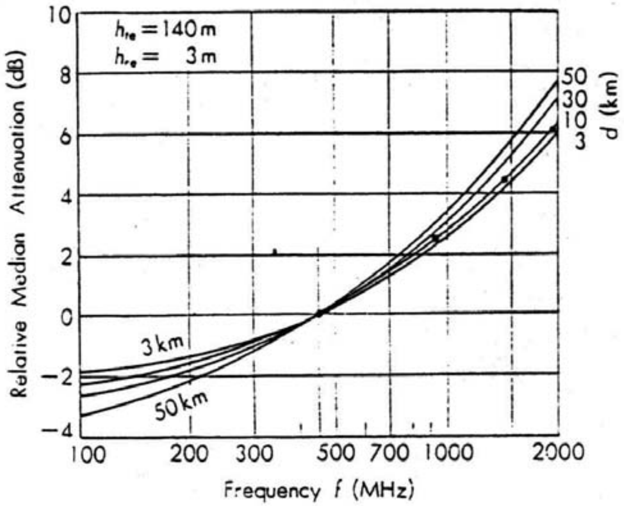


Fig. 13—Example of frequency dependence of median attenuation relative to free space in urban area.

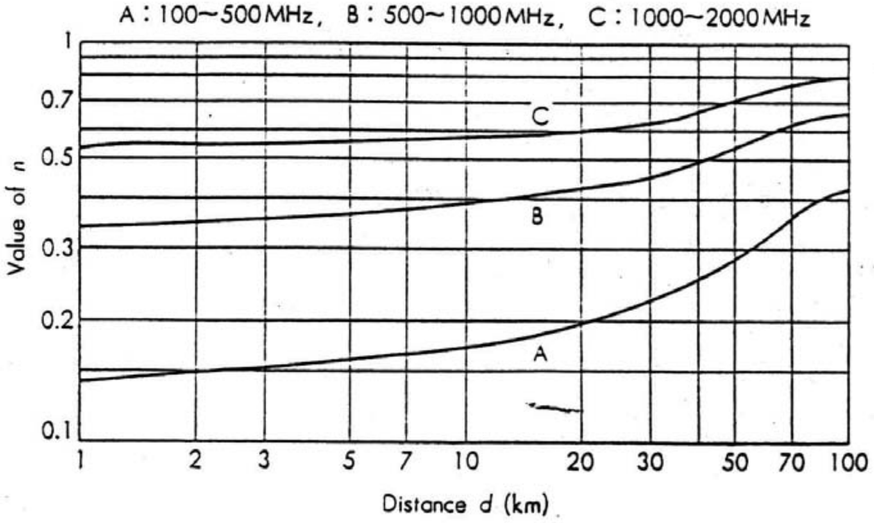


Fig. 14—Frequency dependence of median field strength in urban area ($E_m \propto f^{-n}$).

Freq/Distance Dependence of Median Field Strength

- The prediction curves depending on distance and frequency, which represent the median attenuation relative to free space

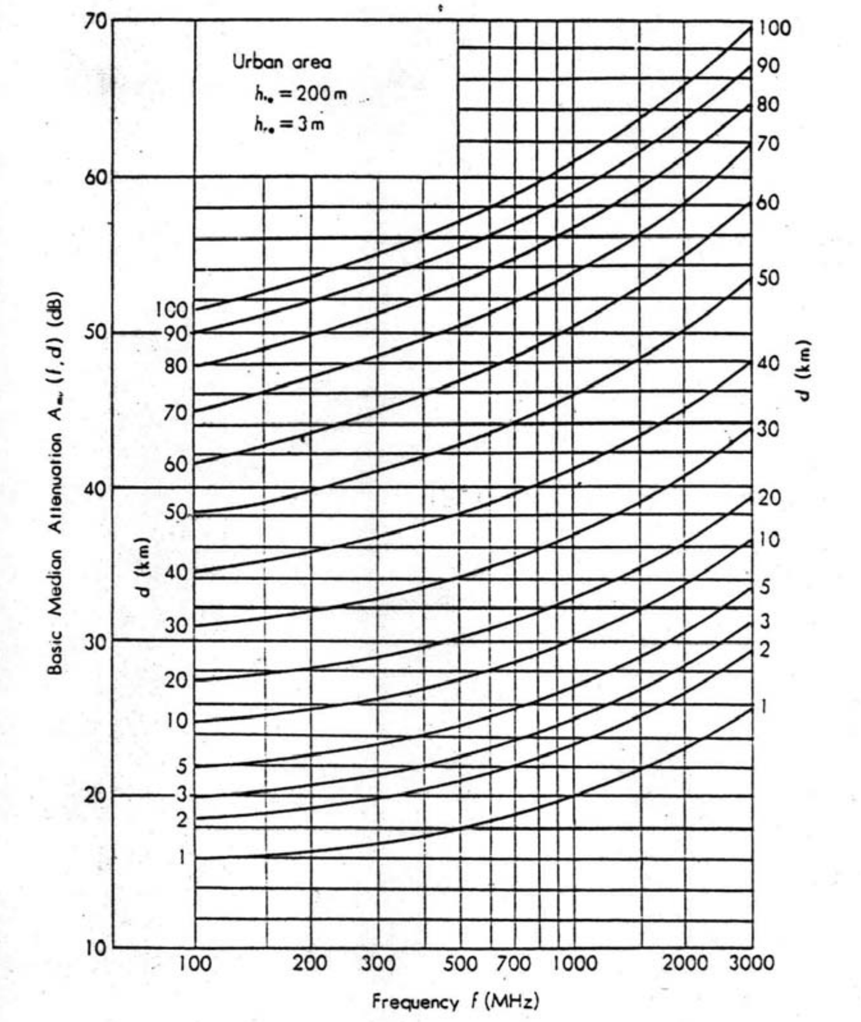


Fig. 15—Prediction curve for basic median attenuation relative to free space in urban area over quasi-smooth terrain, referred to $h_{te}=200$ m, $h_{re}=3$ m.

Attenuation in Relation to Vertical Angle of Arrival

- The relation to the vertical angle of arrival: the elevation angle the bnase station antenna forms with the mobile radio

- The results of an experiment in Italy
- Attenuation relative to free space, traveling interval being 500 ~ 1000 m
- Distance range
  - Within 2 to 3 km

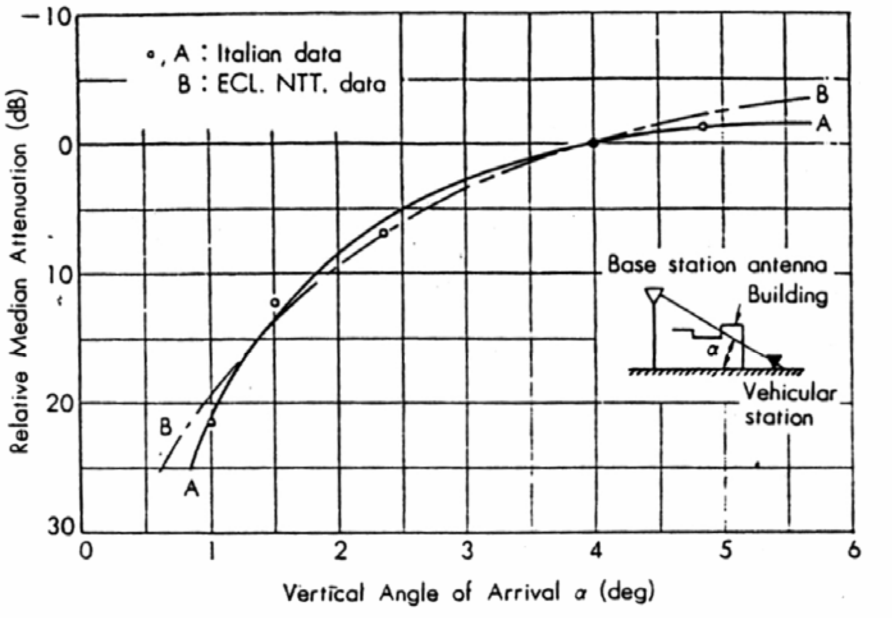


Fig. 16—Dependence of the additional attenuation on the vertical angle of arrival (attenuations are referred to 4°).

Attenuation due to Orientation of Urban Street

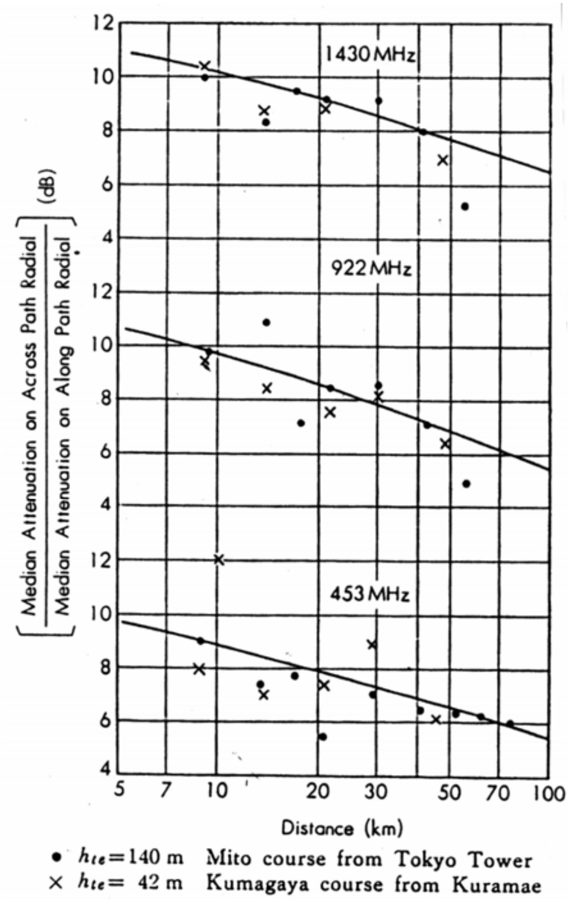


Fig. 17—Difference of attenuation in urban area due to the orientation of the street with respect to the radius starting from the base station.

- Received field Strength changes according to the orientation of the road with regard to the direction of the signal

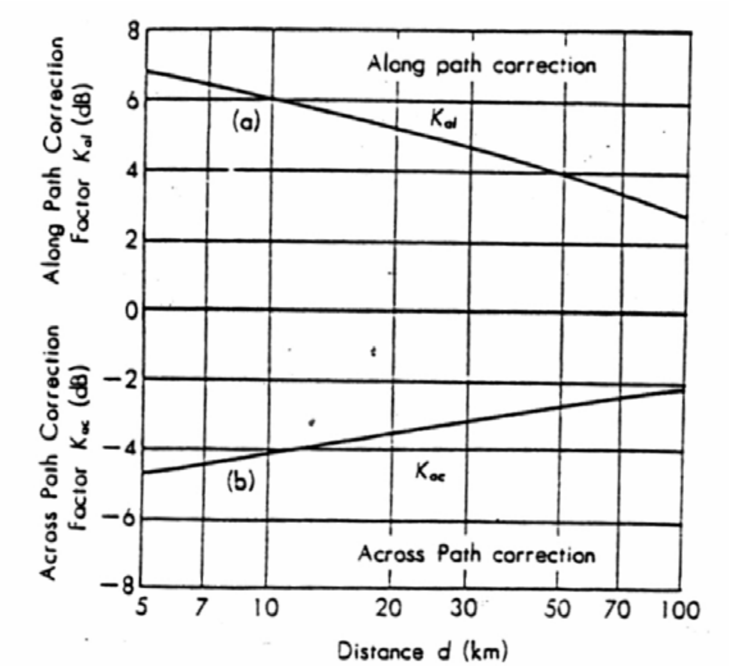


Fig. 18—Prediction curves for along and across path correction factor in urban areas.

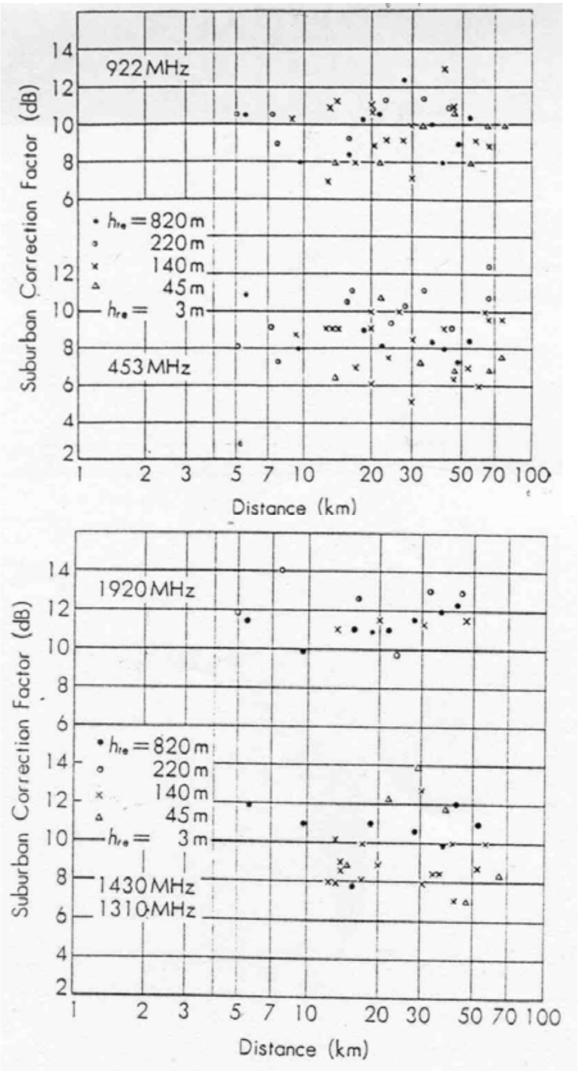
Median Attenuation in Suburban Area

- The degree of congestion and shielding due to obstacles: suburban < urban

  -> the median field strength is usually high in surbaban

- Suburban correction factor: constant for the whole distance
  - ☞ 8.5 dB at 453 MHz, 10 dB at 922 MHz, 12 dB at 1920 MHz

Median Attenuation in Suburban Area - Graph



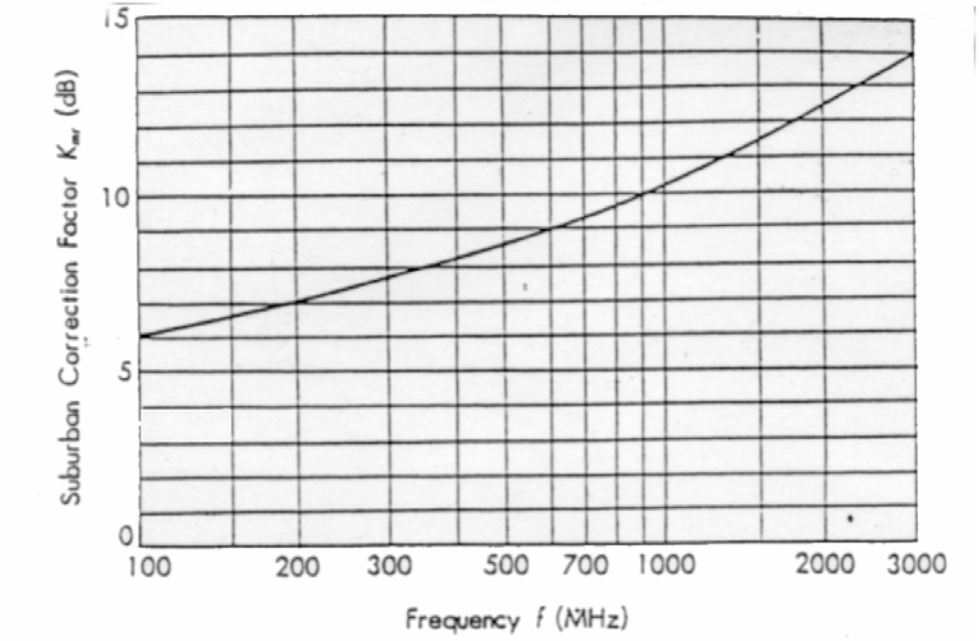


Fig. 20—Prediction curve for "suburban correction factor" as a function of the frequency.

Attenuation in Open Area

- Propagation experiments obtained the quasi-maximum of field strength for analysis
- Attenuation begins to appear at about 5 km from the base station
  - ☞ h_{te} = 140 m, h_{re} = 3 m, f = 922 MHz
- The difference between quasi-maximum attenuation relative to free space and Urban area median attenuation
  - ☞ 26 dB at 453 MHz, 29 dB at 922 MHz, 32 dB at 1920 MHz
  - ☞ Constant on the whole regardless of the distance
- The open area field strength remains nearly constant for all frequencies, as in a suburban area

Attenuation in Open Area - Graph

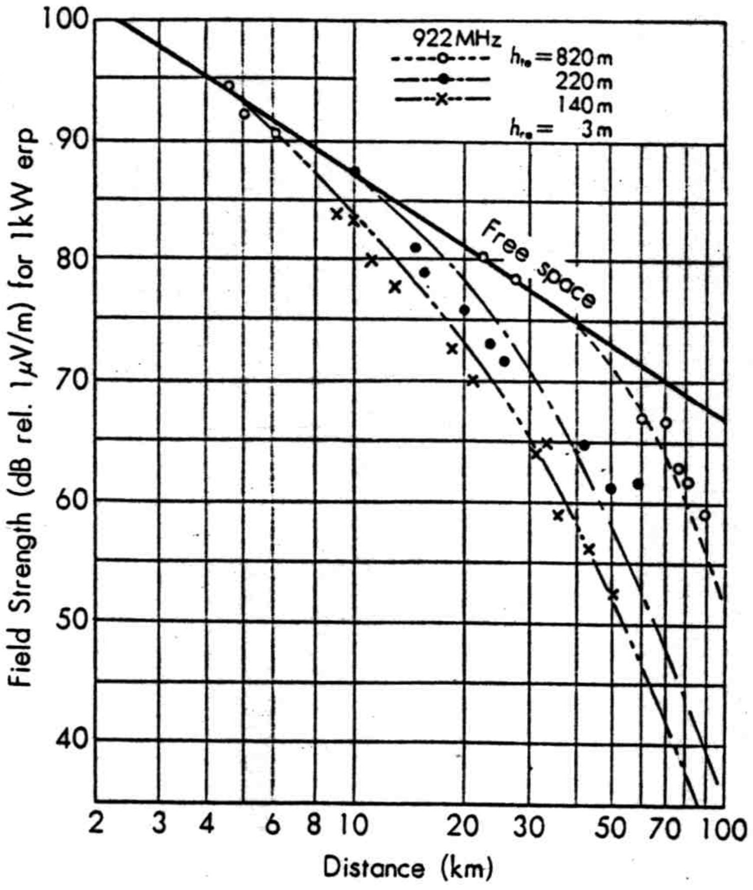


Fig. 21 (b) 922 MHz

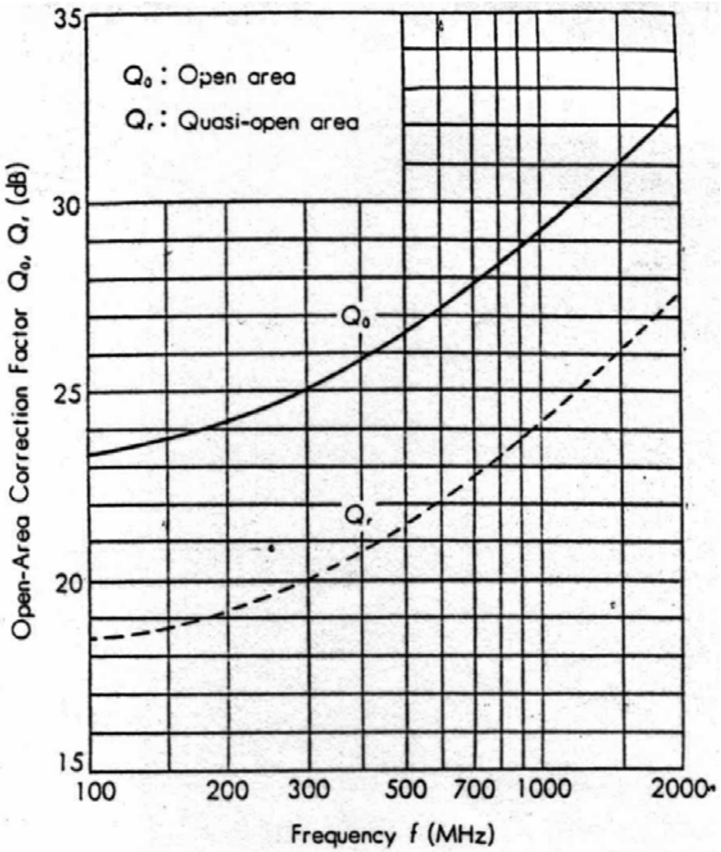


Fig. 22—Prediction curves of "open-area correction factor" as a function of the frequency.

Base Station Antenna Height Gain Factor

- The distance: 5 ~ 80 km
- The effective Ant Height:
  30 ~ 1000 m
- The field strength: 6dB/oct ($n=1$, $E \propto h_{te}^{n}$) for the distanc of about 10 km
- 9dB/oct ($n=1.5$) with a high antenna at a long distance

cf) oct.: double distance

- The tendency is the same wit other freq.

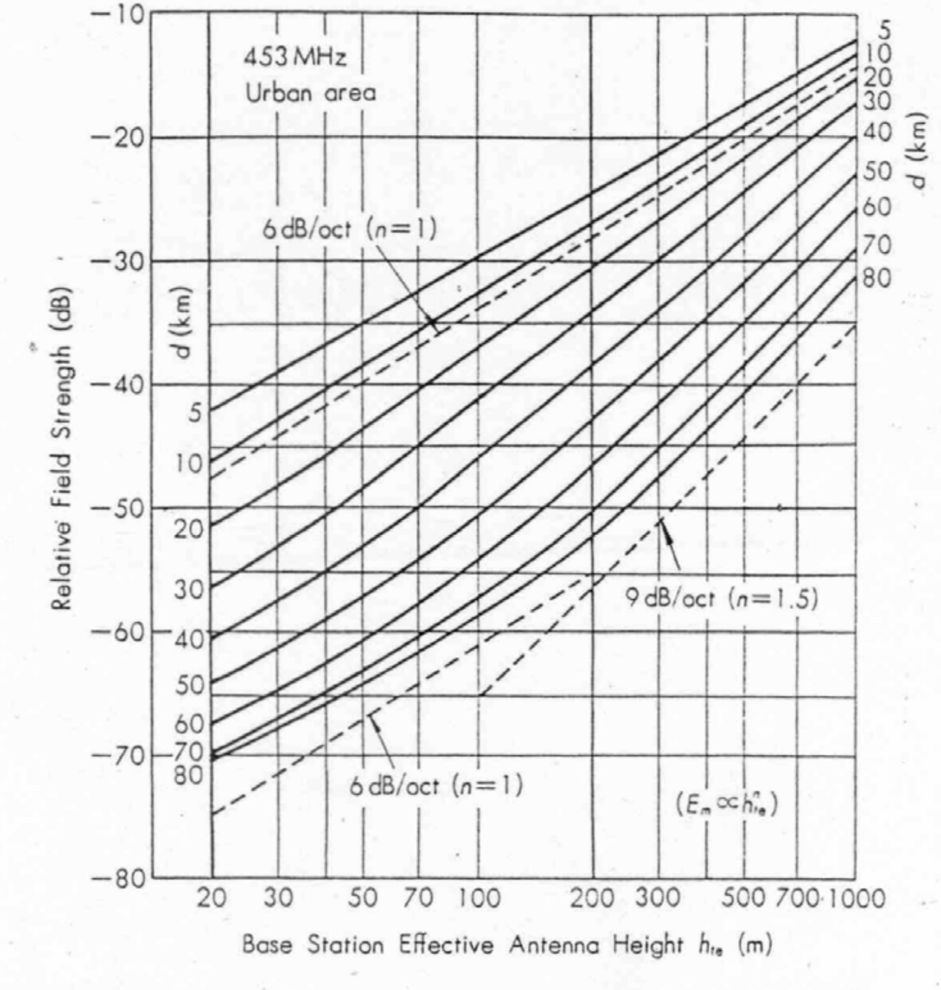


Fig. 23—Dependence of base station effective antenna height on median field strength in urban area.

Base Station Antenna Height Gain Factor (Cont'd)

- The prediction curves
  - ☞ h_{te} fixed at 200 m

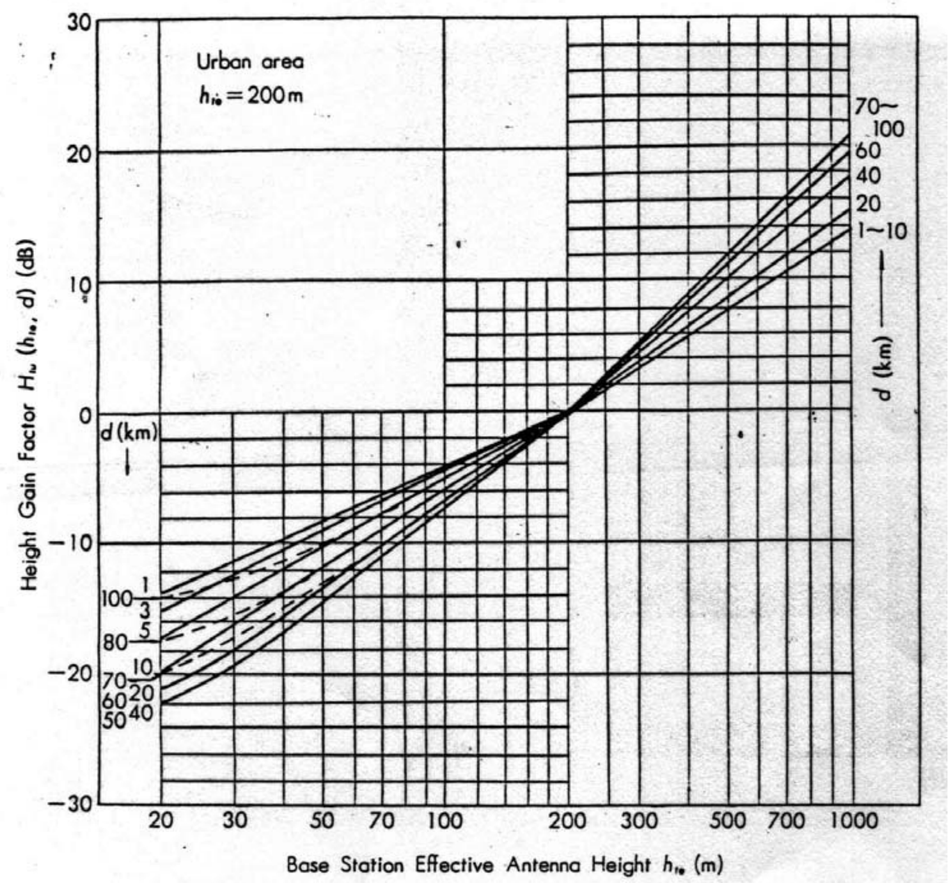


Fig. 24—Prediction curves for base station antenna height gain factor referred to h_{te}=200 m, as a function of distance.

Vehicular Station Antenna Height Gain Factor

- Relative Gain Factor for 1.5m and 3m
  - There are slight fluctuations in the measured value
  - No remarkable changes w.r.t the distance and h_{te}
  - The vehicular station antenna height gain factor for a height of 3m or less

    $\rightarrow$ 3 dB/oct ($n=1/2$, $E \propto h_{re}^{n}$)

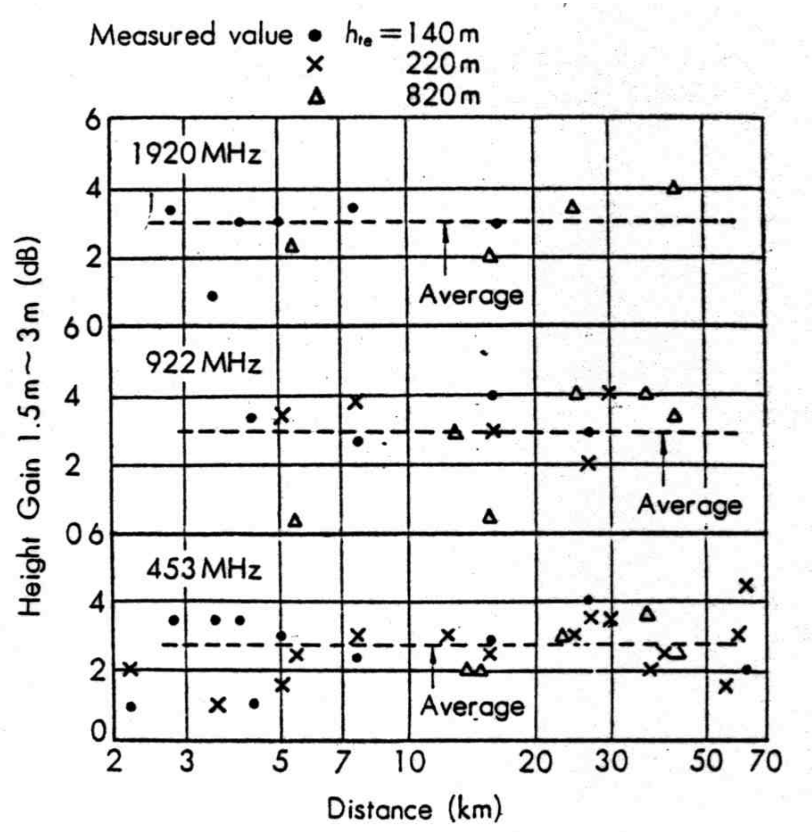


Fig. 25—Measured values of 1.5 m to 3 m height-gain of vehicle in urban area.

Vehicular Station Antenna Height Gain Factor

- Gain Factor for Height above 3m
  - The higher the frequency the larger the height gain
  - 6 to 8 dB/oct ($n=1\sim3$, $E \propto h_{re}^{n}$)
  - The antenna height 4 ~ 10 m
    - ✓ Inflection appear in the neighborhood of 4 to 6m
    - ✓ Sharp linear inclination for more heights up to 10 meters

      → the average height of the houses in Japanese cities being 5m
    - ✓ Shielding effect

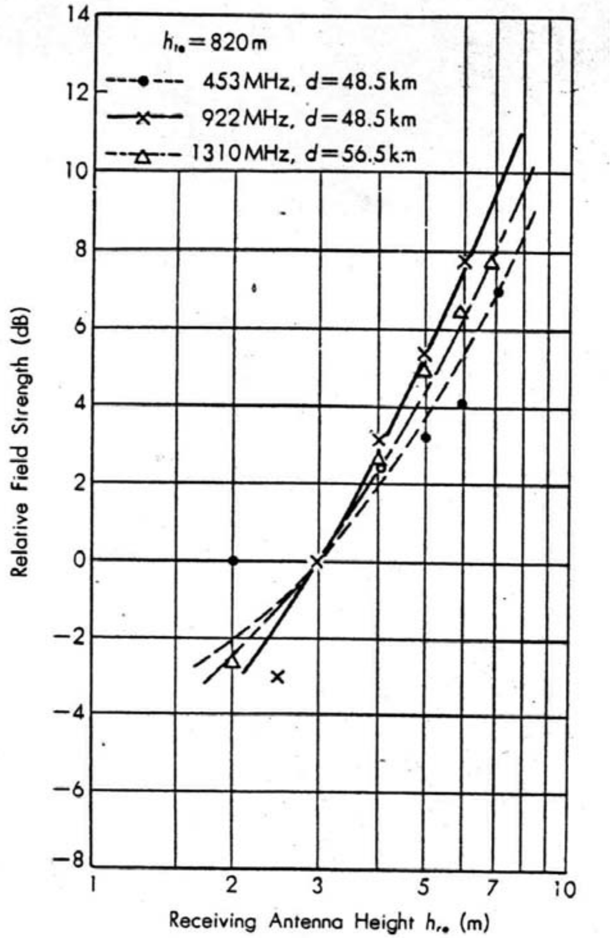


Fig. 26—Examples of height gain measurement of receiving antenna in urban area.

Vehicular Station Antenna Height Gain Factor (Graph)

- The building height averages more than 15m
  - Points of inflection would move up to more than 10m in the pattern curve showing n<1 $(E \propto h_{re}^{n})$ between 3 ~ 10m
- Relative gain factor for heights of 10m and 3m

Frequency Band	Suburban area	Large city
450~1000 MHz (Band IV, V)	6 ~ 7 dB $(n \cong 0.7)$	4 ~ 5 dB $(n \cong 0.7)$
30 ~ 250 MHz (Band III)	7 dB $(n \cong 0.78)$	4 ~ 6 dB $(n \cong 0.5)$

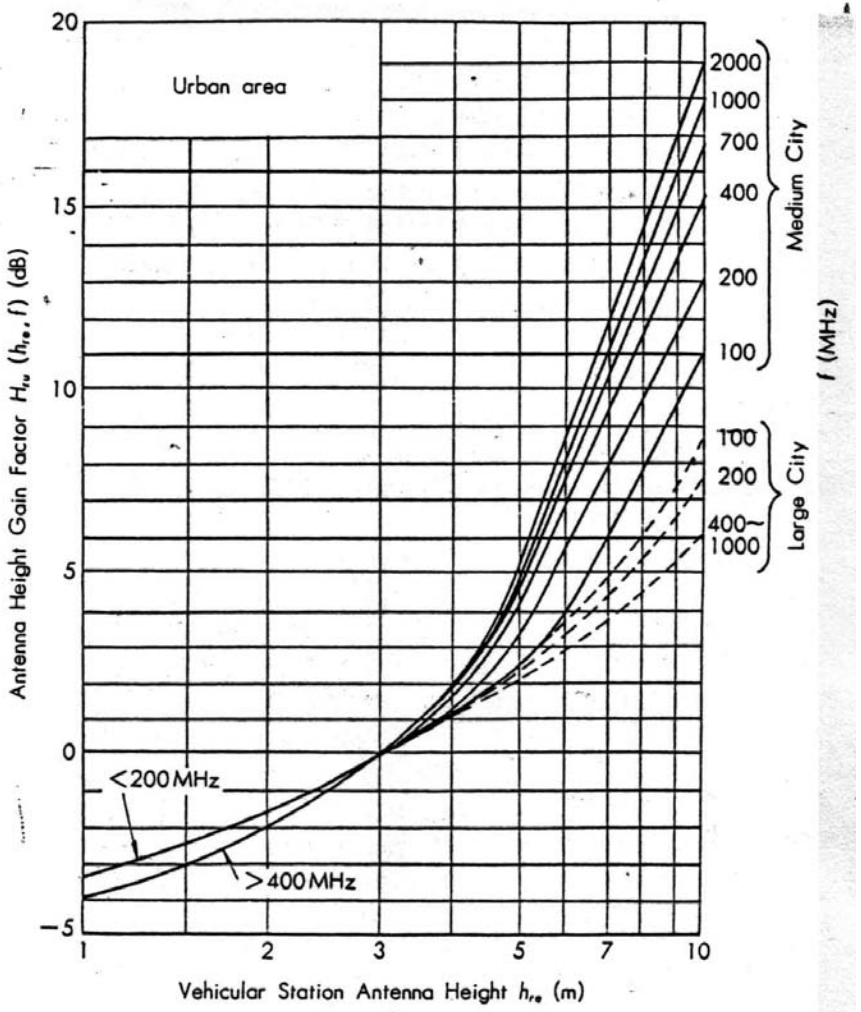
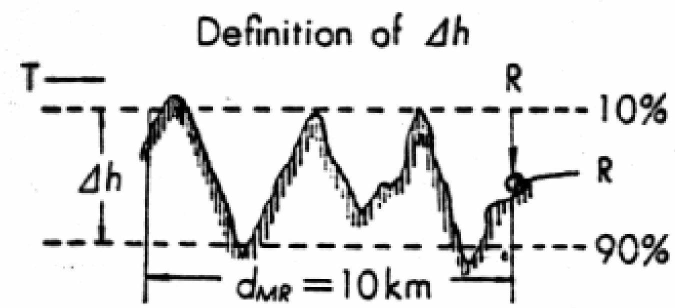


Fig. 27—Prediction curves for vehicular antenna height gain factor in urban area.

Correction Factor of Field Strength on Rolling Hilly Terrain

- Decision of Terrain Parameters
  - Correction factor for field strength in a sampling interval
  - To obtain the terrain undulation height Δh
  - To apply this Δh to undulations of more than a few in number
    - Average angle of general slope θ_m
  - To resort to a measure of fine correction
    - The correction for the rolling hilly terrain ; the sampling interval median and the fine correction adapted to the terrain undulation



Sampling Interval Correction Median on Rolling Hilly Terrain

- The addition median attenuation
  - Analyzed with the difference between the two values ;
    - ✓ The sampling interval median of field strength in the rolling hilly terrain
    - ✓ The median field strength in the quasi-smooth terrain urban area

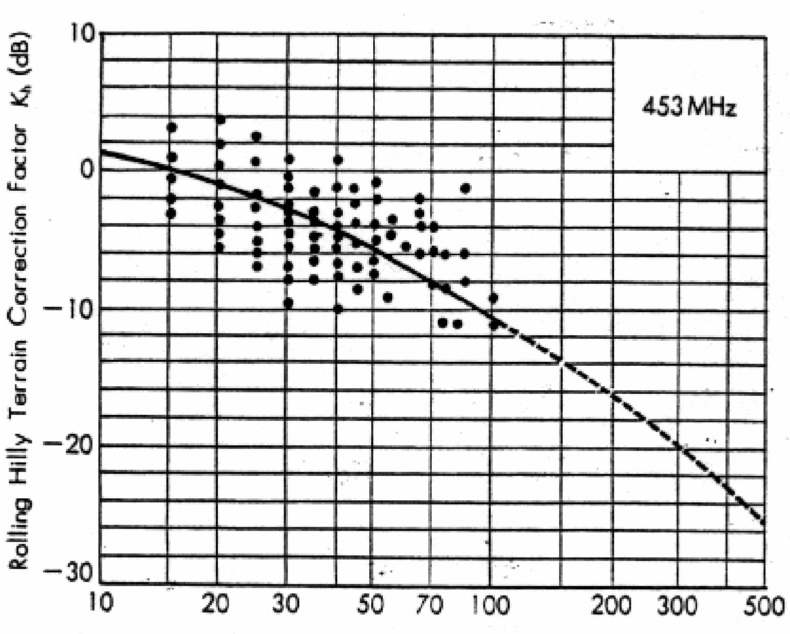


Fig. 28(a) 453 MHz

- The correction factor relative to Δh
  - Fluctuating for all frequency and becoming larger as Δh increases
- Correction factor dependence on Δh at 922MHz is 3dB smaller than that for 453MHz, and a midway between the factors for 1430MHz

Sampling Interval Correction Median on Rolling Hilly Terrain (Graphs)

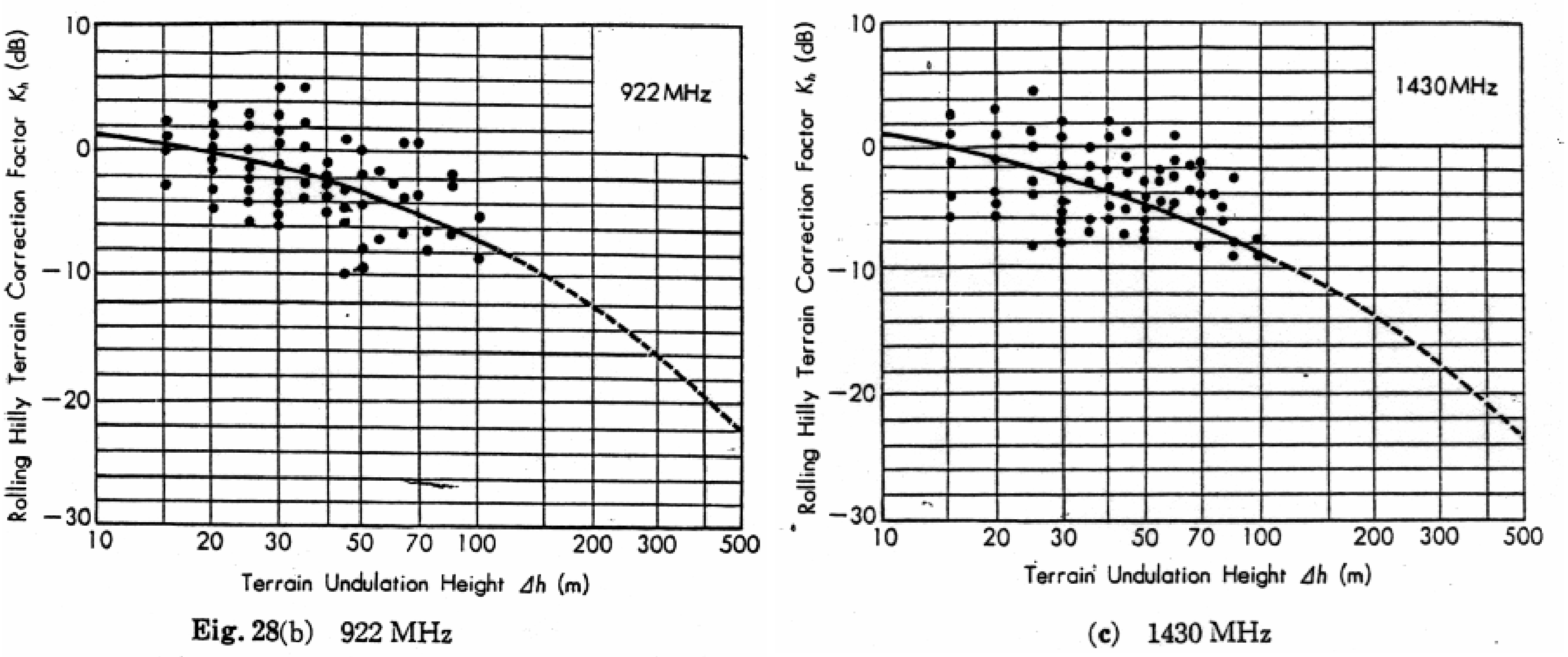


Fig. 28 – Measured values and prediction curve for "rolling hilly terrain correction factor."

Fine Correction Factor on Rolling Hilly Terrain

- Near an undulation
  - ☞ The attenuation rises far above the correction factor
- Close to the top of the undulation
  - ☞ The field strength ascending in the meantime
- The fine correction factor
  - ☞ The mobile van is traveling on a road lying at bottom or on top of an undulation
- In the position at the bottom
  - ☞ Correction factor : $-K_{hf} - K_h$
- On the top of the undulation
  - ☞ Correction factor : $K_{hf} - K_h$

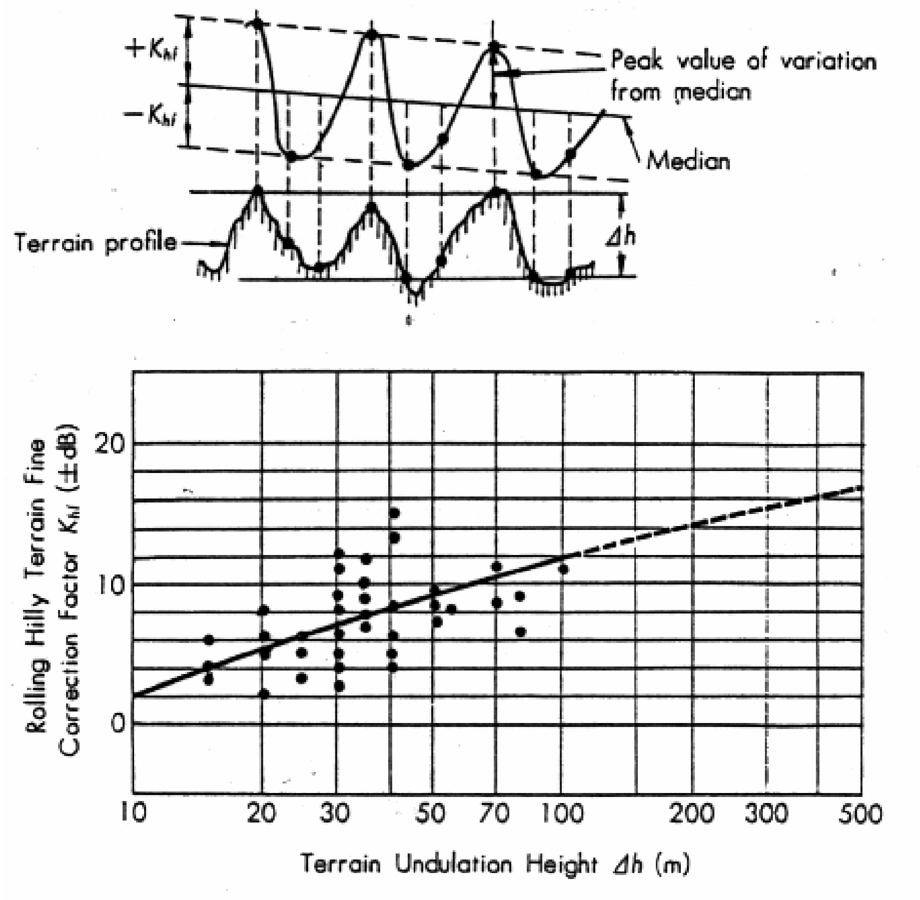


Fig. 29—Measured values and prediction curve for "rolling hilly terrain fine correction factor."

Vehicular Station Antenna Height Gain Factor on Rolling Hilly Terrain

- The differences of the medians in one and the same sampling interval measured, with the antenna height 3m and 1.5m
- There seems to be no distinct variation with respect to the distance
- The gain factor
  - 2.8 dB at 453 MHz
  - 3.3 dB at 922 MHz
  - 3.3 dB at 1430 MHz
- The estimation of antenna height gain factor for heights below 3m on a rolling hilly terrain – 3 dB/oct

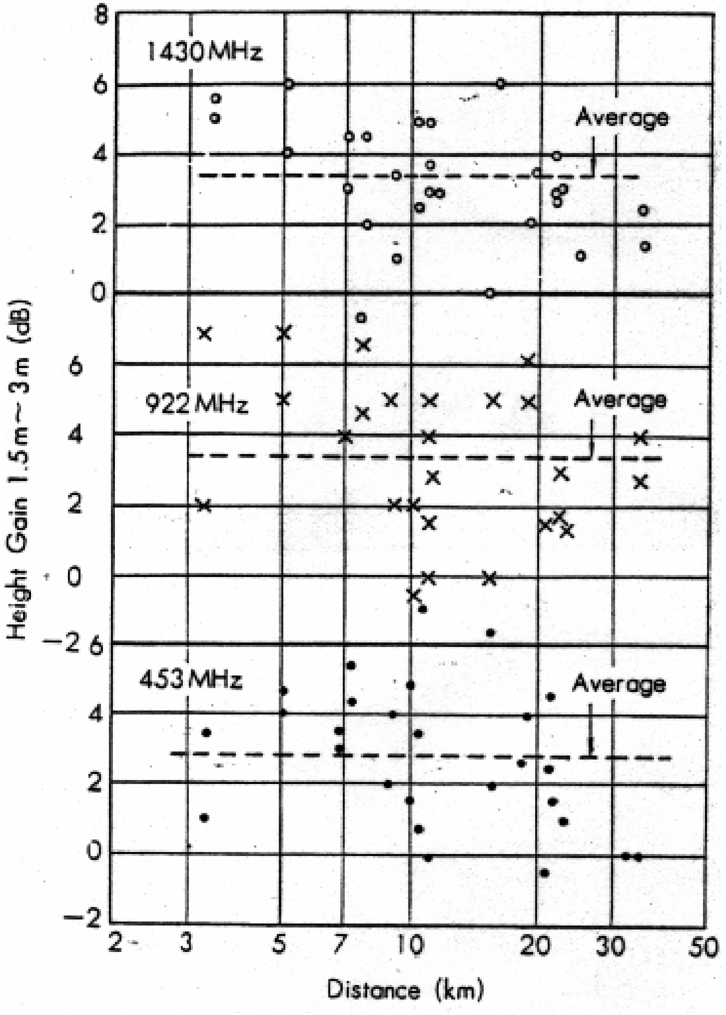
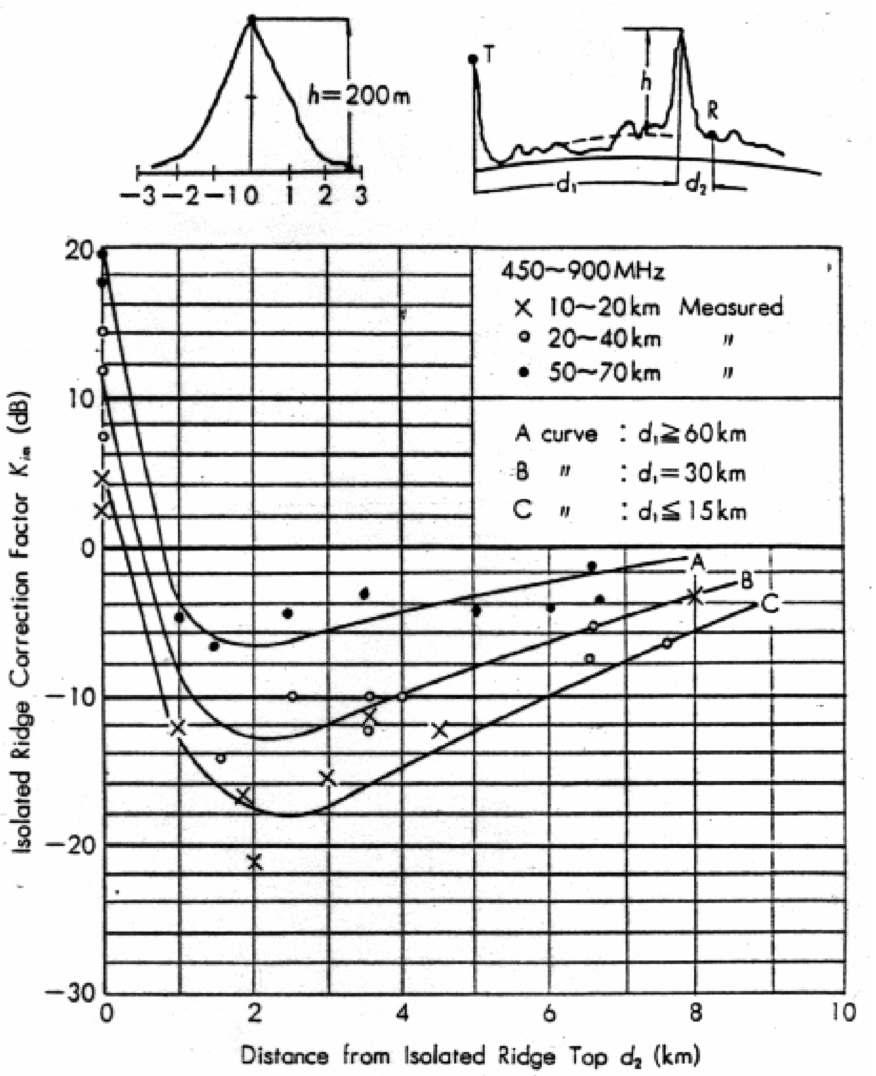


Fig. 30—Measuured values of 1.5 m to 3 m height-gain of vehicular station in rolling hilly terrain.

Correction Factor for Isolated Mountain

- There is an isolated mountain ridge like a knife edge, it must be dealt with differently
- The receiving antenna is low
  - the received field strength behind the ridge usually suffers more loss than the free space value minus the knife-edge diffraction loss
- Ridge height correction factor normalized at h = 200m, for each of the three distance ranges



Correction Factor for Isolated Mountain (Cont'd)

- In normalizing the ridge heights
  - measured correction factors (in dB) were multiplied by α
- The field strength
  - Higher than the basic median on the ridge top
  - Approximately equal to the basic median in a position a little way down the top (back distance $d_2 < 1$ km)

$$\alpha = 0.07\sqrt{h}$$

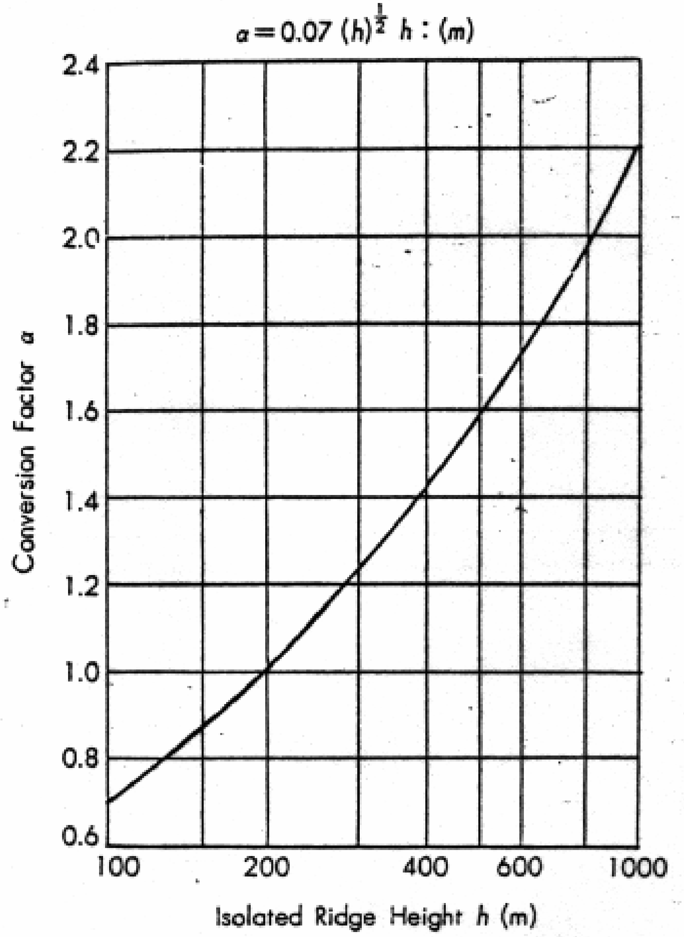


Fig. 32—Conversion factor to be multiplied to the value of Fig. 31, when ridge height $h \neq 200$ m.

Correction Factor for Isolated Mountain (Cont'd)

- Curve B
  - Measured correction factor at $d_1 = 30$ km
- Curve K
  - Calculated value of knife-edge diffraction loss for d_2
- The loss on Curve K in increases if $d_2 < 2$ km
  - The isolated ridge model has a thickness while the knife-edge model has none
- The relation between the two curves in their absolute value
  - differs according to the terrain factors relative to distances

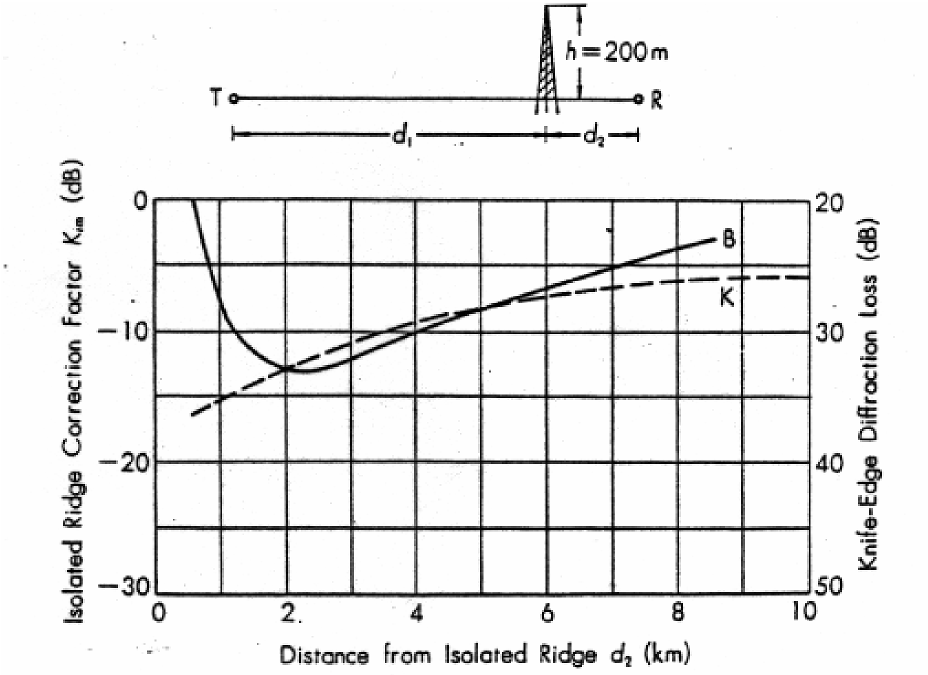


Fig. 33—Relation between the curves of Fig. 31 and of knife-edge diffraction loss. (450 MHz)

Correction Factor for General Slope of Terrain

- The relation of the average angle θ_m of general slope on terrain to the correction factors
- The correction factor varies with the distance
- For the sloped rolling hilly terrain
  - ☞ The correction factor

    ; rolling hilly correction factor

    \+ general slope correction factor

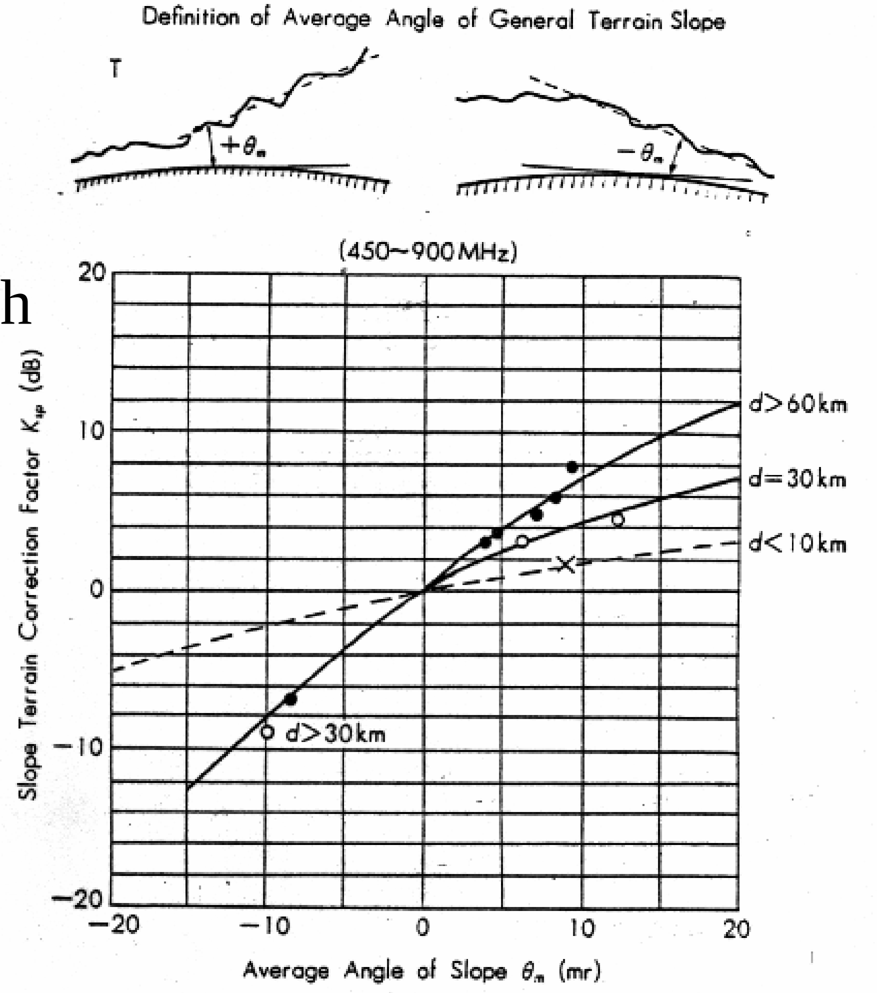
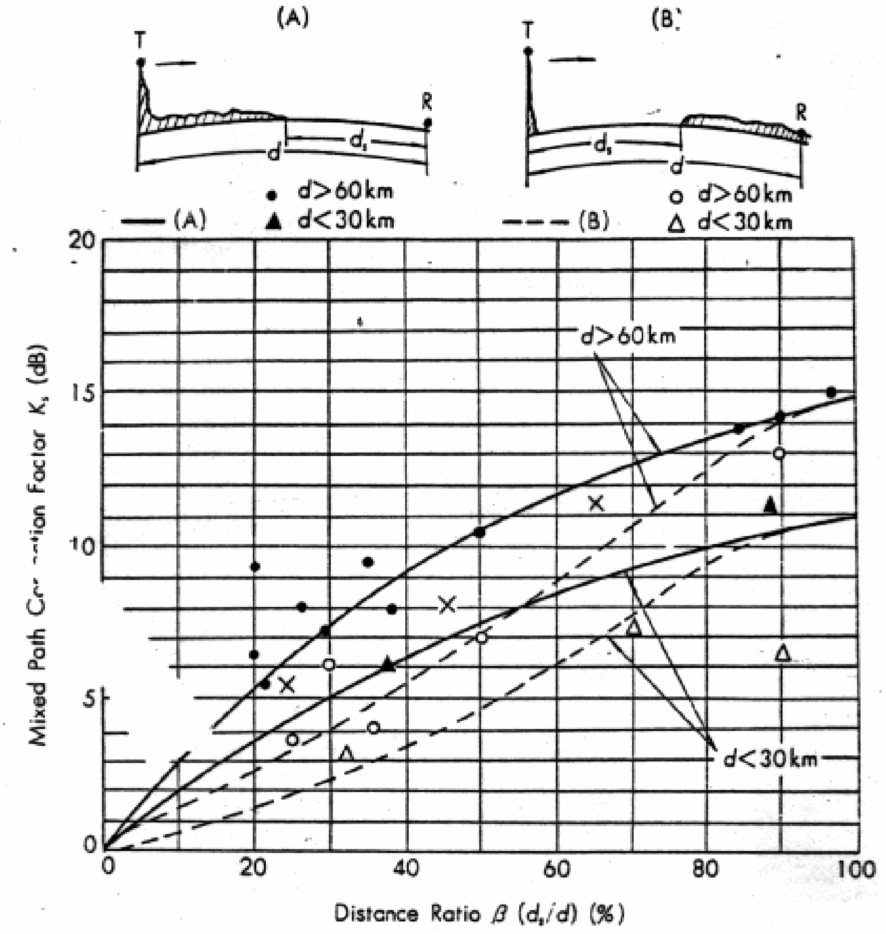


Fig. 34—Measured value and prediction curves for "slope terrain correction factor."

Correction Factor for Mixed Land-Sea Path

- Where there is an expanse of sea or lake in the propagation path, the field strength is generally higher than on land only
- Correction factor for mixed land-sea path
- The degree of field strength rise is larger if the water adjoins the vehicular station than if it adjoins the base station
- If the water is in the middle of the path, the intermediate values are chosen



× When the sea lies in the middle of the path.

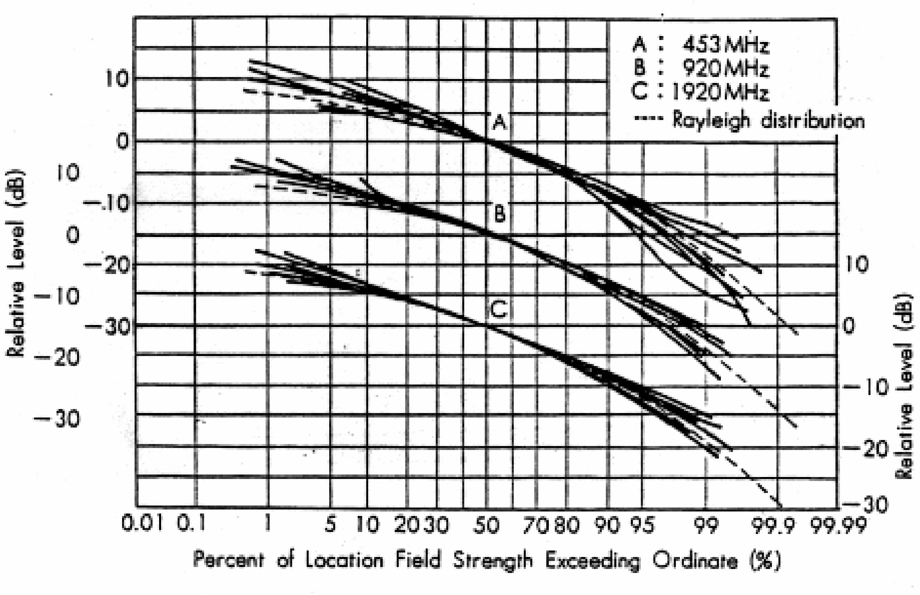
Fig. 35—Measured values and prediction curves for "mixed path correction factor."

Location Variability

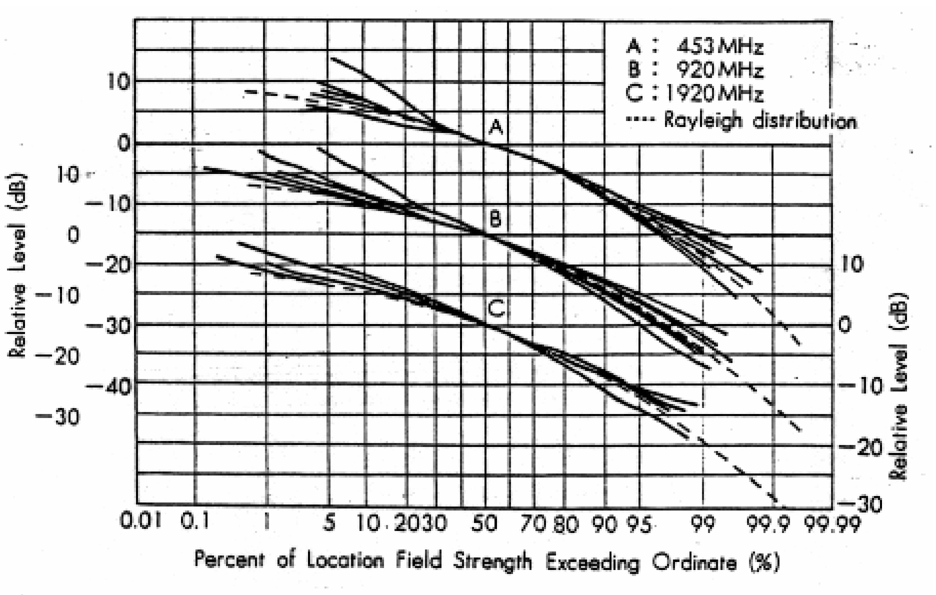
- Location variability
  - Comes next in importance to attenuation
- Location variability be considered from the viewpoint of variations
  - In the median level for a sampling interval
  - In the instantaneous level for a small sector in the same interval

Distribution of Instantaneous Field Strength in Small Sector of about 50 m

- The variation in the instantaneous field strength level
  - Standing waves which result from the multi-path reflection & diffraction
- The form of distribution – Rayleigh distribution
- In a suburban area
  - log-normal distribution with σ = 6 ~ 7 dB



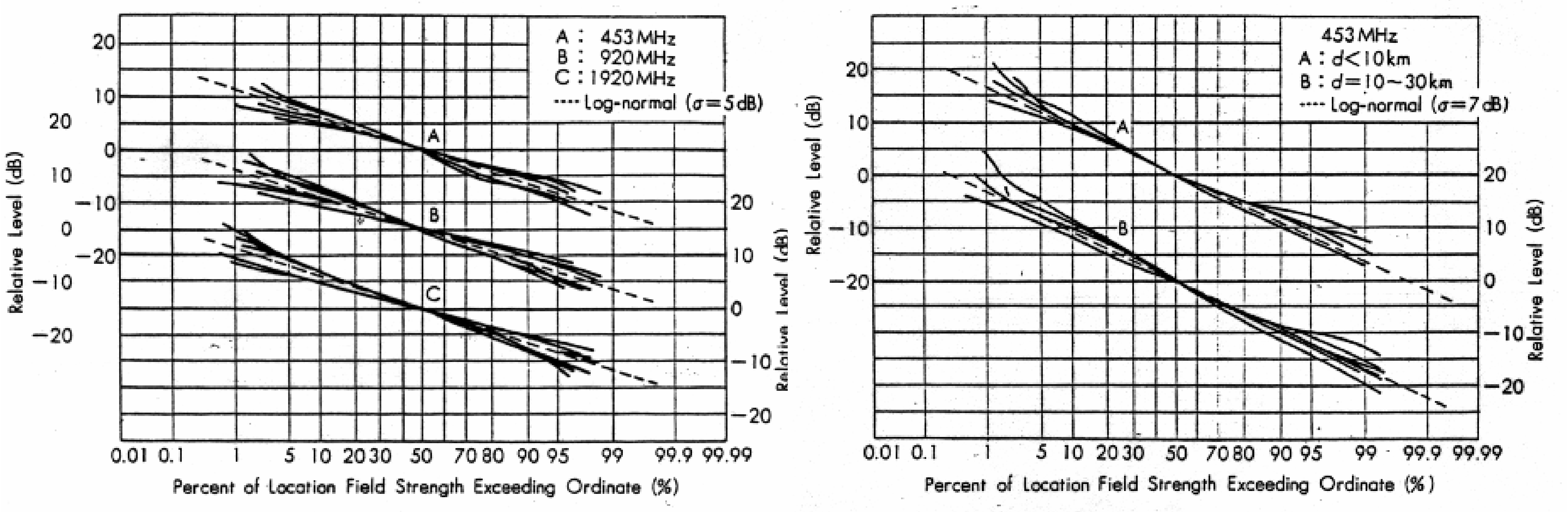
(a) In urban area (h_{te}=220 m, h_{re}=3 m)



(b) In forest or behind forest (h_{te}=820 m, h_{re}=3 m)

Distribution of Small Sector Median in Sampling Interval (1 ~ 1.5 km)

- In an urban area - the area or interval becomes wide
  - the small sector median of instantaneous field strength will change considerable degree
- The cumulative distribution of median field strength for a small sector (about 20m) in an urban/suburban sampling interval (1 ~ 1.5 km)
  - log-normal distribution



(a) In urban area (h_{te}=220 m, h_{re}=3 m)

(b) In suburban area (h_{te}=60 m, h_{re}=3 m)

Prediction of Median Field Strength Location Variability

- The mean values of σ
    - not connected with h_{te}, d
    - slightly larger at high frequency
- The values of σ in a suburban and a rolling hilly terrain area
    - larger than those for an urban area
    - grow large as the frequency increase
- The small sector median distribution

  - the obstacles are uniformly mixed
    - Log-normal distribution

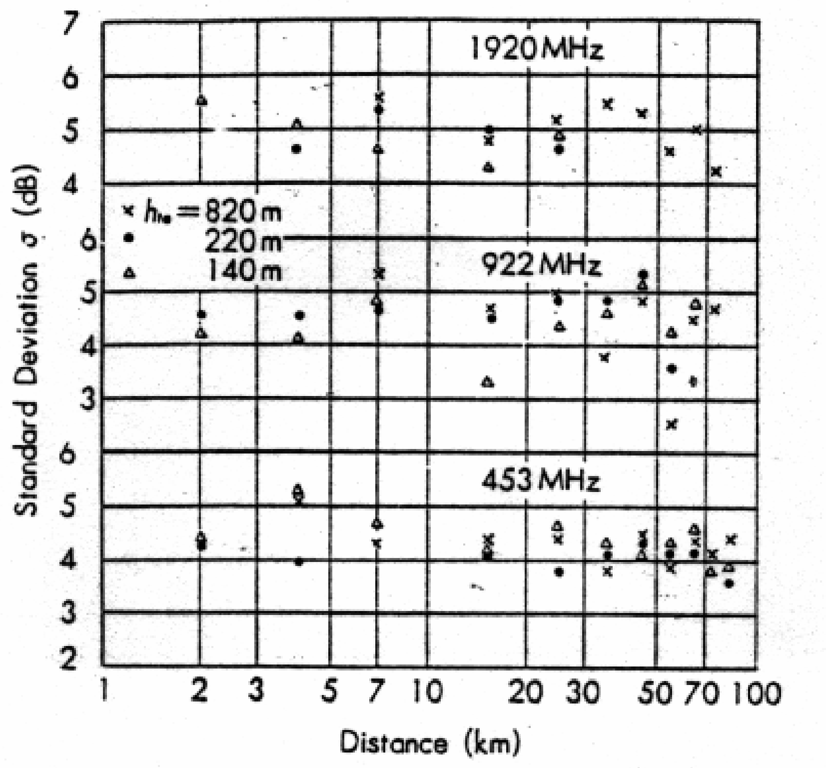


Fig. 38—Measured mean values of standard deviation of small-sector median field strength variation in urban area sampling interval (1~1.5 km).

Prediction of Median Field Strength Location Variability (Cont'd)

- In determining the extent of land for which location variability
  - the design of the land mobile service
  - the size of interval or area traveled by the mobile for one telephone call
- The interval
  - 3 ~ 4 km, the area 2km in radius
- σ of the median variability in an urban area in this respect
  - larger than that in urban area sampling interval (1~1.5 km)

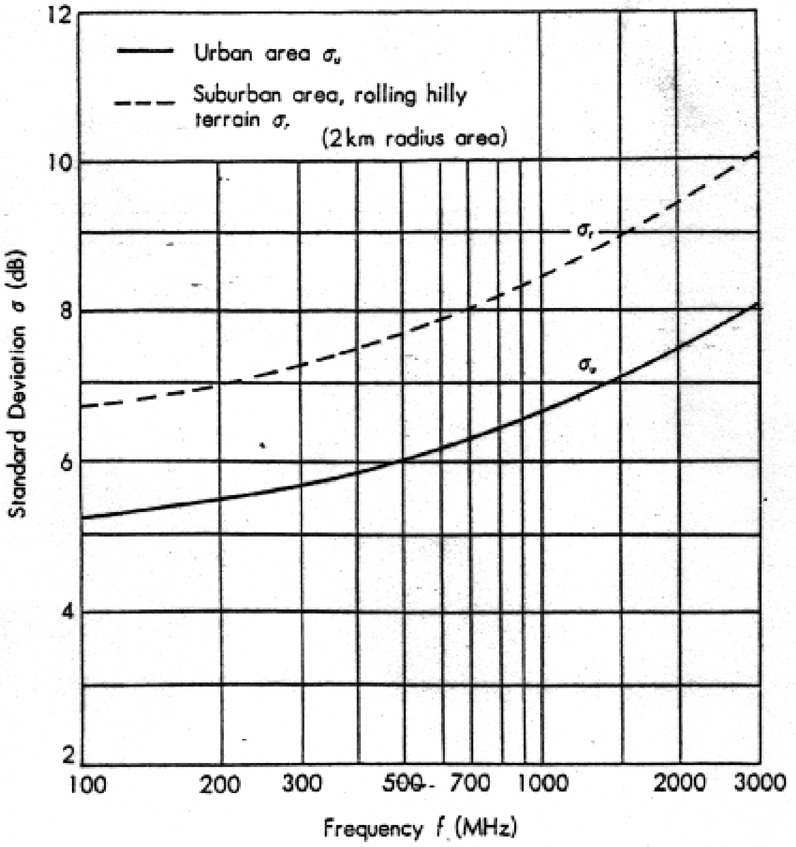


Fig. 39—Prediction curves for standard deviation of median field strength variation in urban, suburban and rolling hilly terrain.

Prediction of Instantaneous Field Strength Location Variability

- In an urban small sector
  - The instantaneous variation of field strength
    - ✓ Rayleigh distribution
  - Small sector medians
    - ✓ Log-normal distribution
- In suburban area and rolling hilly terrain area
  - The instantaneous variation of field strength
    - ✓ Log-normal distribution
  - Small sector medians
    - ✓ Log-normal distribution

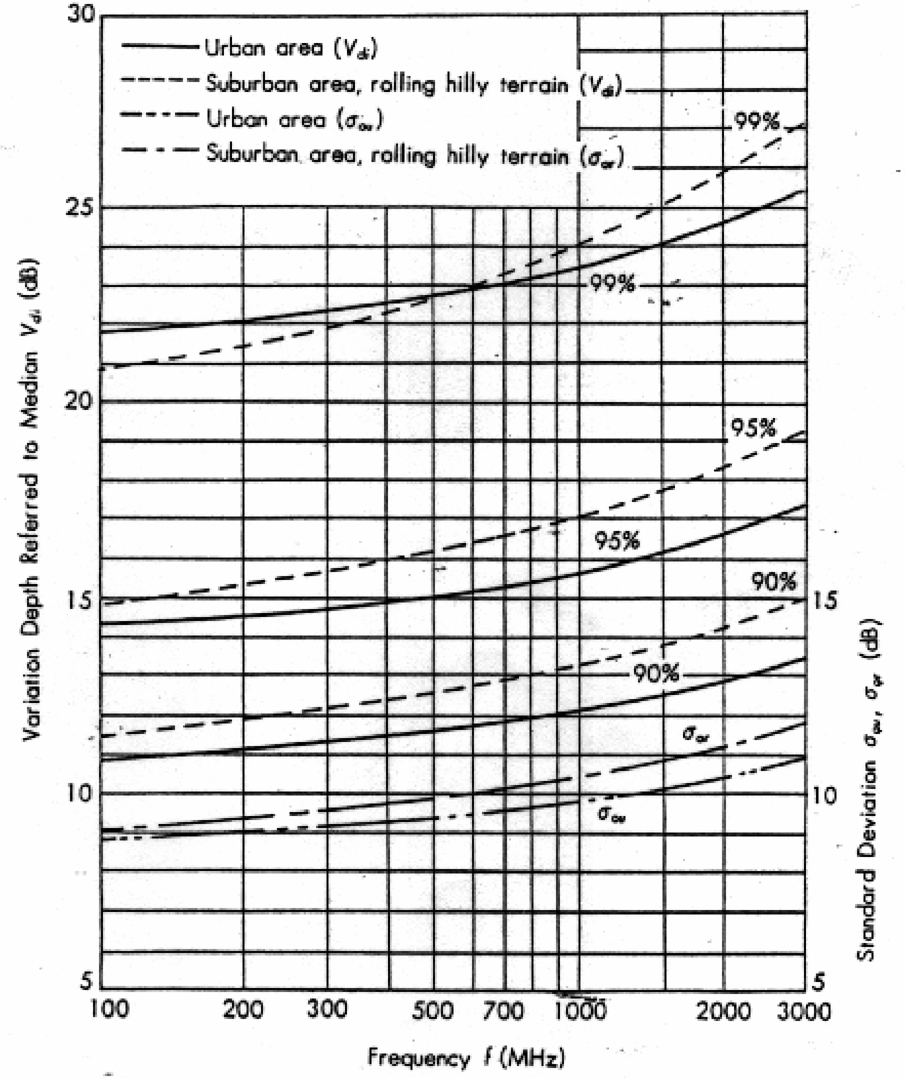


Fig. 40—Prediction curves for instantaneous variation depth from median field strength and standard deviation.

Prediction of Field Strength : Comparison between Predicted and Measured Values

- To obtain the field strength and its variability
- Prediction Procedures
  - ☞ The starting : to obtain the basic median field strength in a quasi-smooth terrain urban area
  - ☞ The prediction curves
    - ✓ obtained by adjusting the correction factors for the respective terrain parameters

Prediction of Basic Median Field Strength

- The basic field strength median
  - the standard of prediction procedures

E_{mu} : The median field strength (dB rel. 1μV/m) for a quasi-smooth terrain urban area under a given condition of transmission

E_{fs} : The free-space field strength (dB rel. 1μV/m) for a given condition of transmission

$A_{mu}(f,d)$: The median attenuation relative to free space in an urban area, where $h_{te} = 200m$, $h_{re} = 3m$

$H_{tu}(h_{te},d)$: The base station antenna height gain factor (dB) relating to $h_{te} = 200m$

$H_{ru}(h_{re},d)$: The vehicular station antenna height gain factor (dB) relating to $h_{re} = 3m$

Prediction Curves of “basic median field strength”

P_{erp} = 1kW, h_{re} = 1.5m

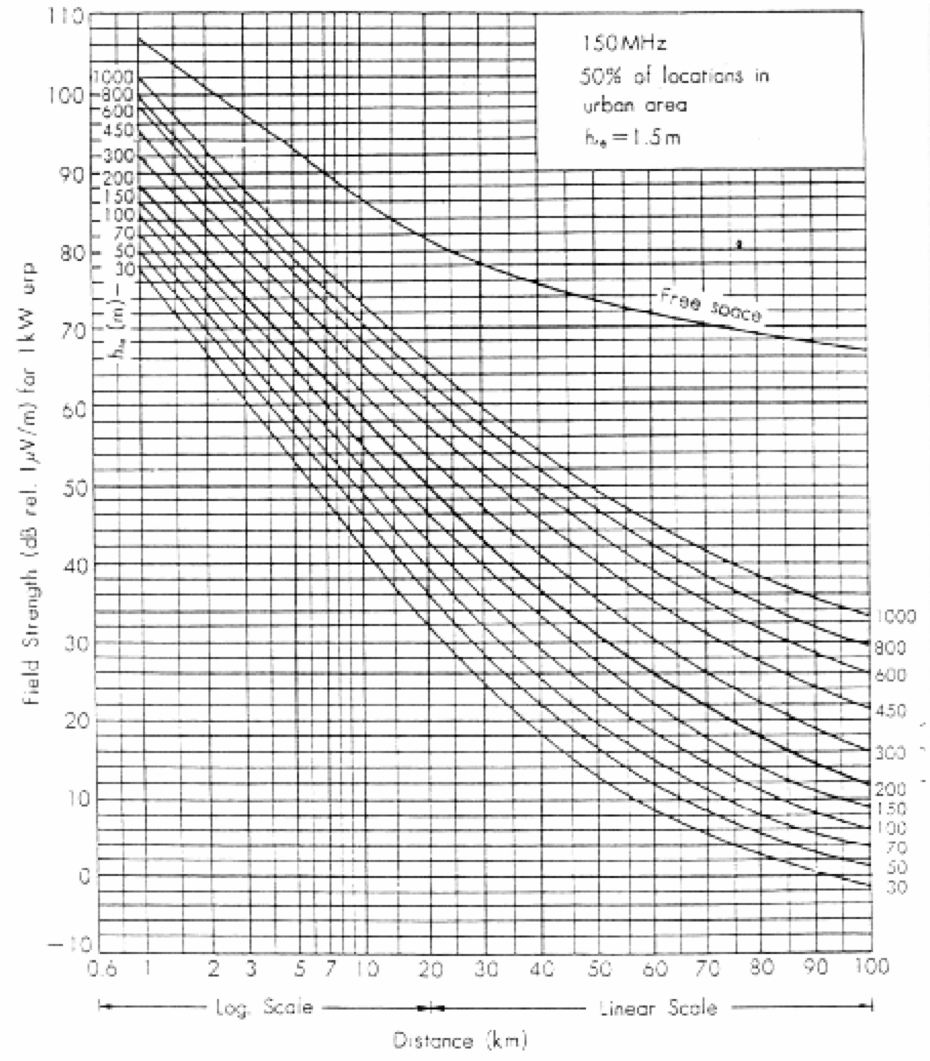


Fig. 41(a) 150 MHz Band

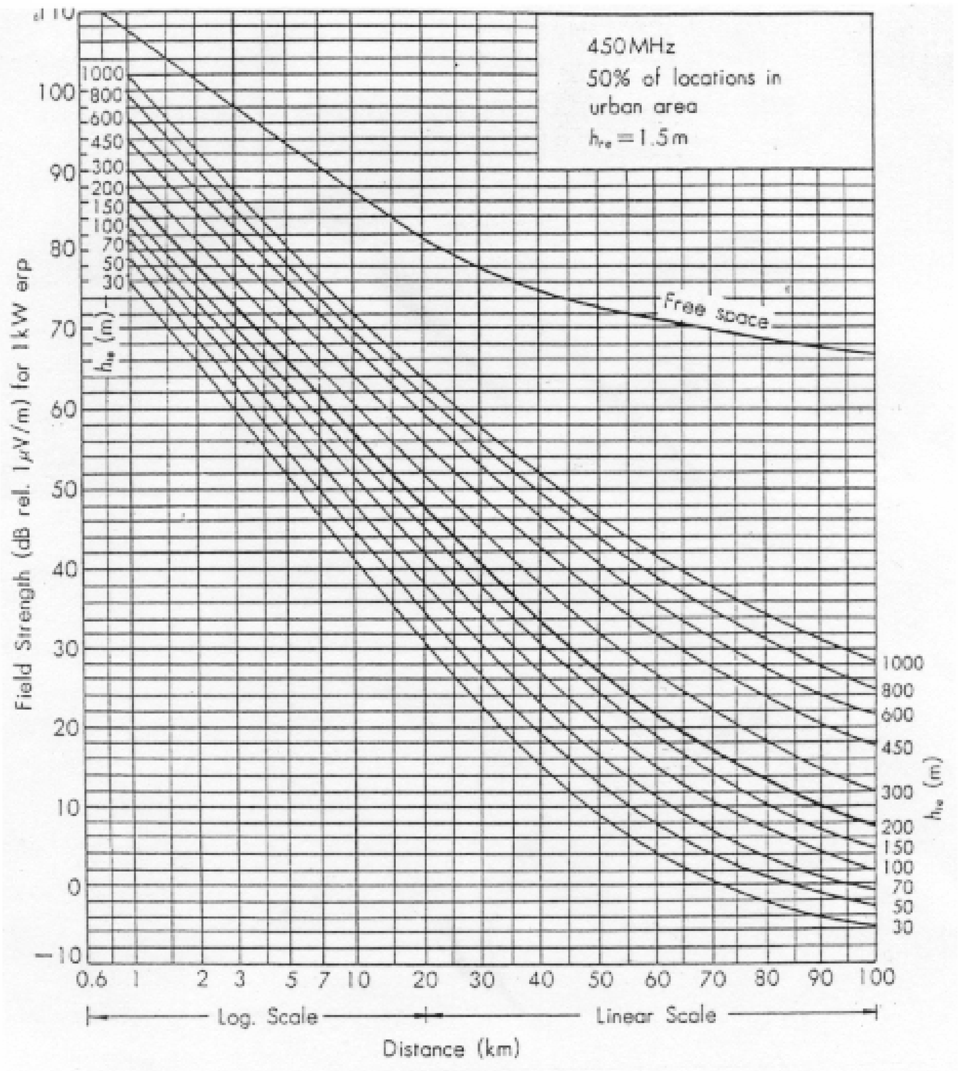


Fig. 41(b) 450 MHz Band

Prediction Curves of “basic median field strength” $P_{erp} = 1kW, h_{re} = 1.5m$

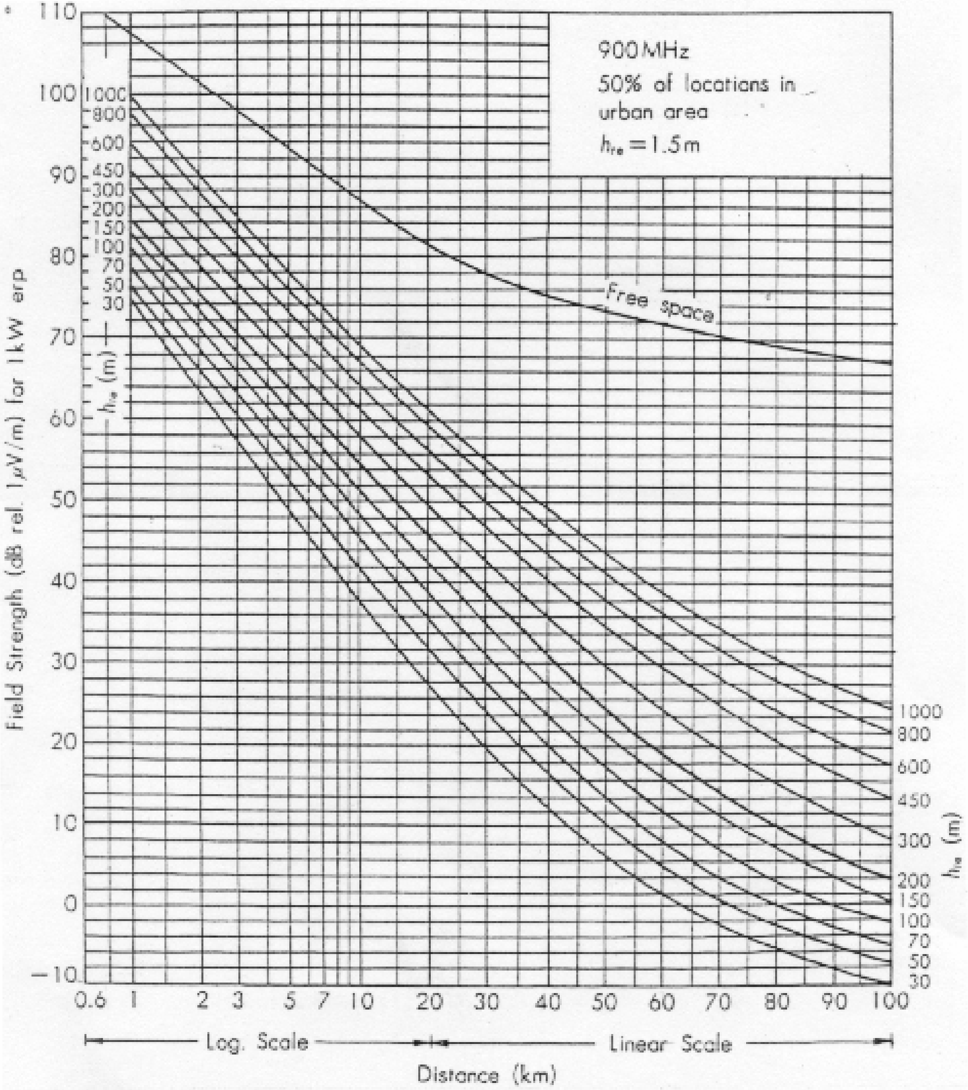
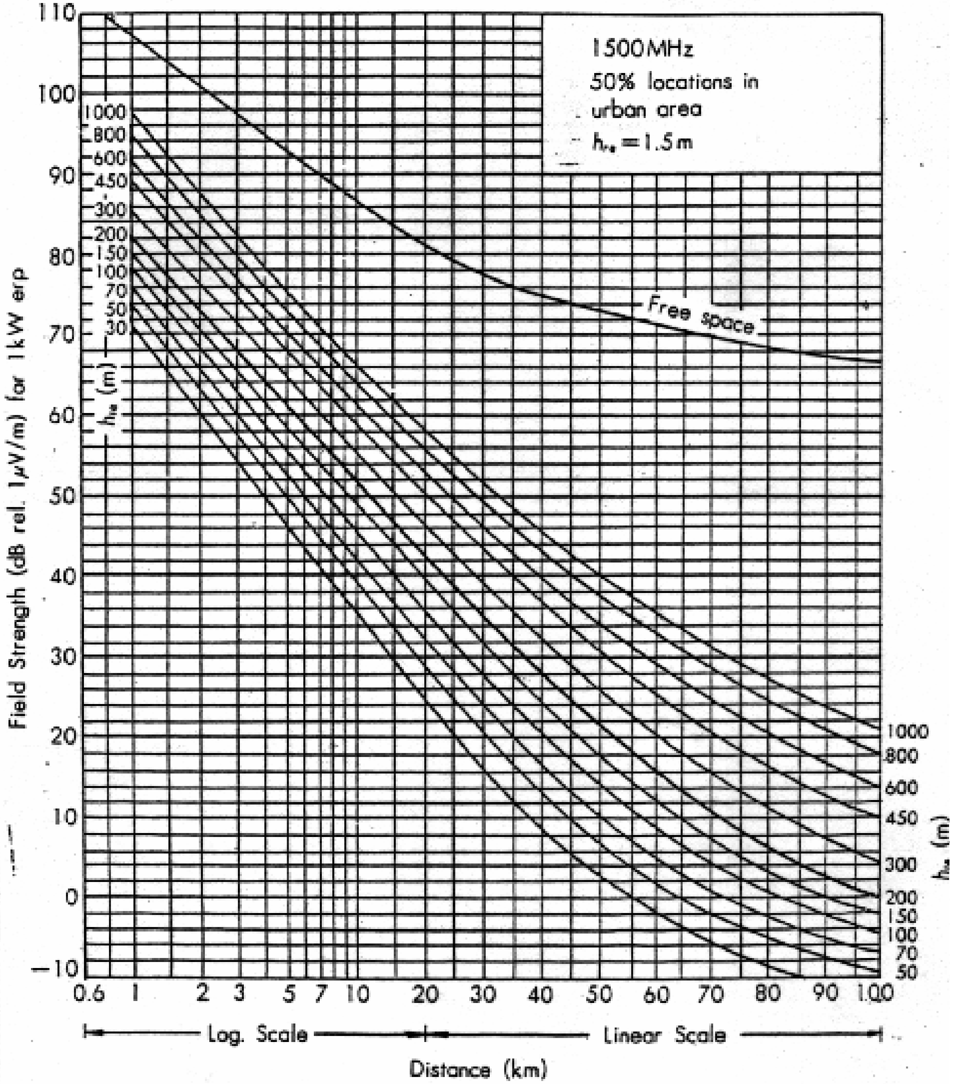


Fig. 41(c) 900 MHz Band



Fis. 41(d) 1500 MHz Band

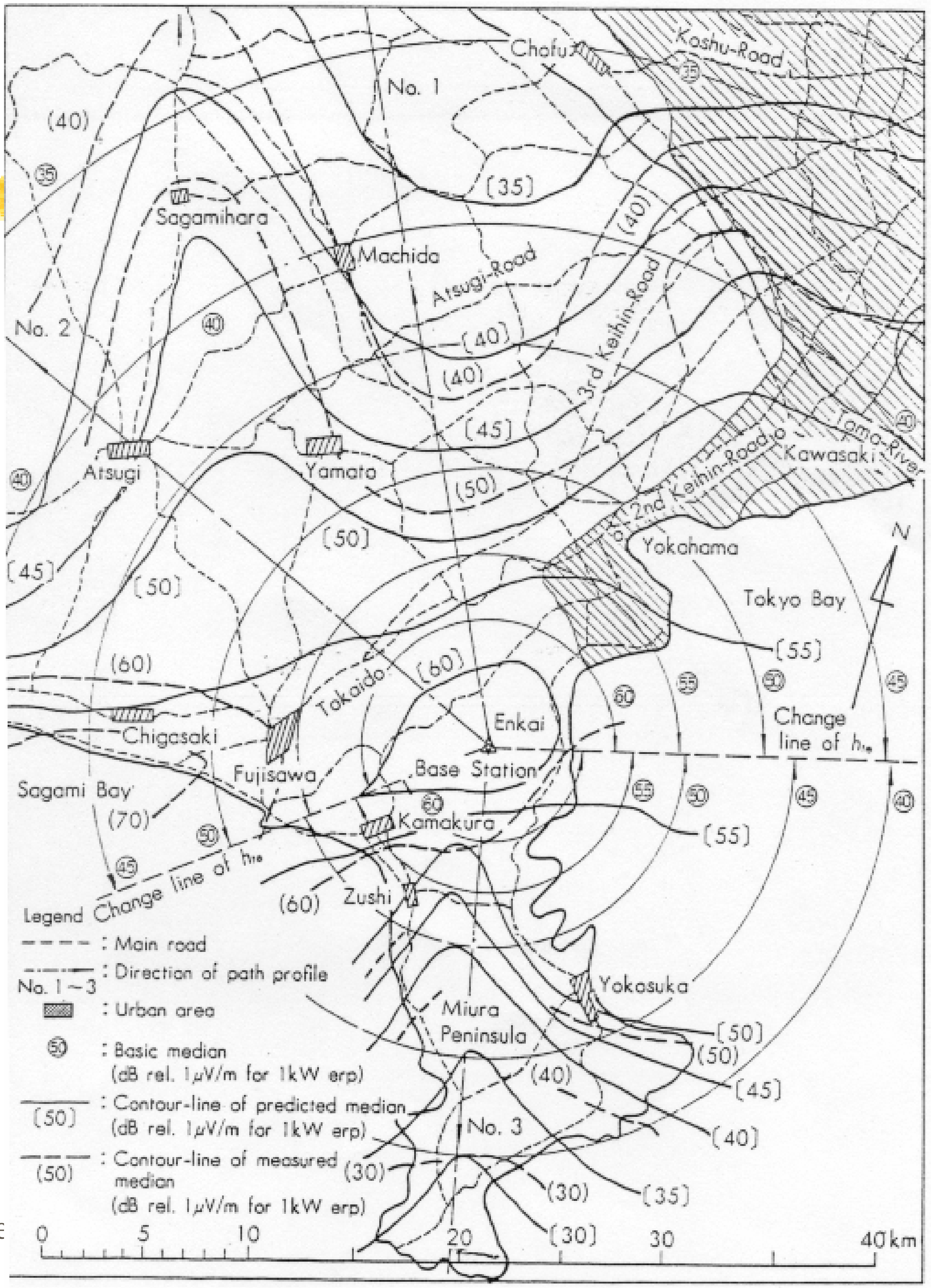
Drawing Field Strength Contour Curves over a Service Area

- Draw a terrain profile for each proper azimuth angle
- Draw on a map, with the site of the base station as their center
- Amend the basic median concentric circles according
  - Correction to the orientation of an urban area street
  - Correction for a suburban area
  - Correction for an open area
  - Correction for a slope terrain
  - Correction for a mixed land-sea path
  - Correction for a rolling hilly terrain
  - Fine correction for a rolling hilly terrain
  - Correction for an isolated ridge

- Comparison between Prediction Values and Measured of Field Strength

freq. = 450 MHz

h_{ts} = 183 m



Example of A Given Broad Area

- The representative path profile in this area along three different directions from the base station
  - ☞ No.1 ~ No.3 as indicated in the previous figure

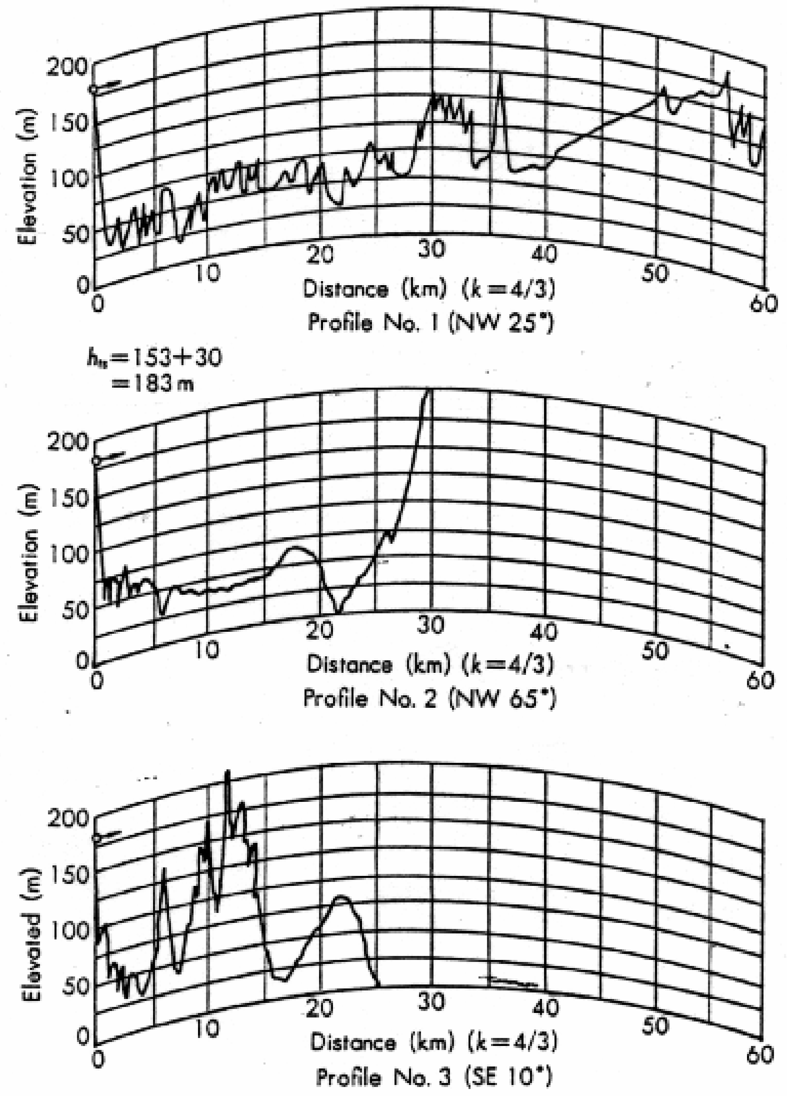
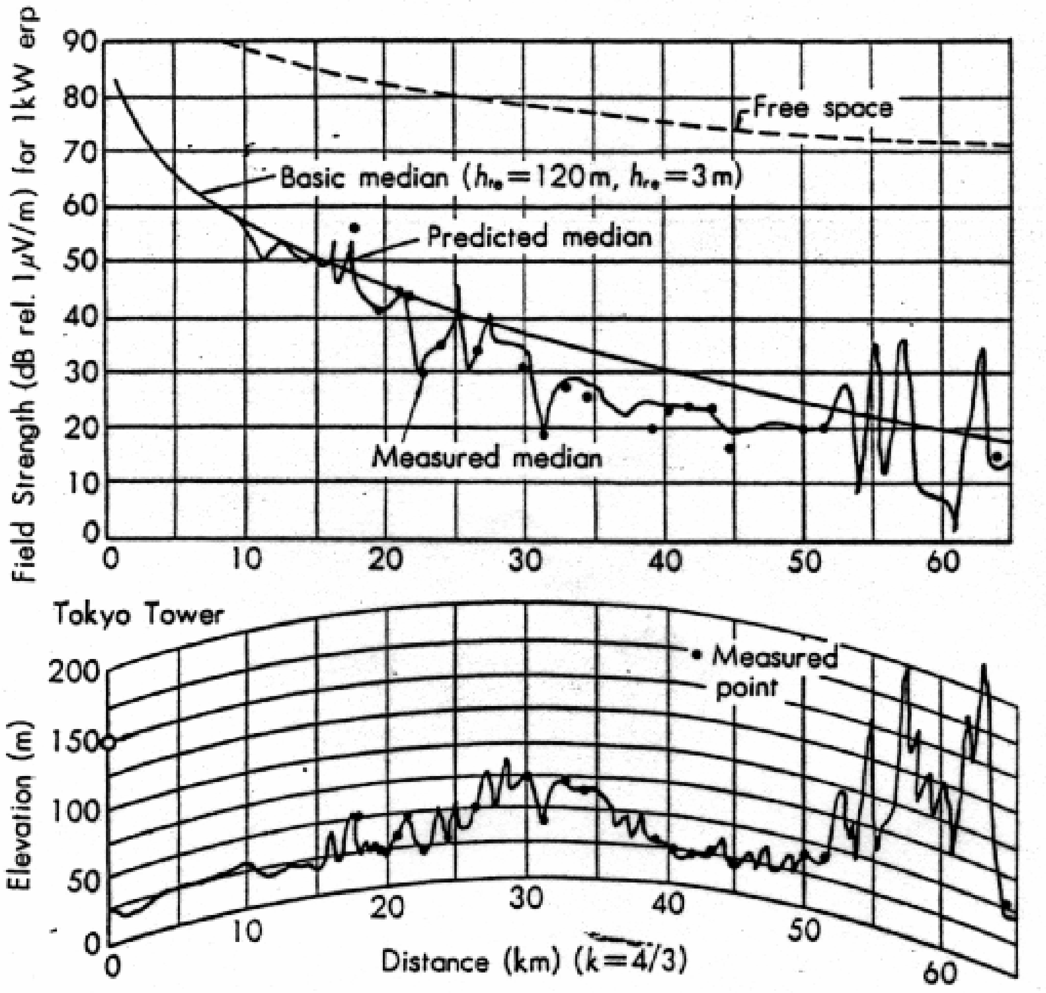


Fig. 43—Path profile on representative direction from Enkai base station.

Example of A Given Terrain Profile

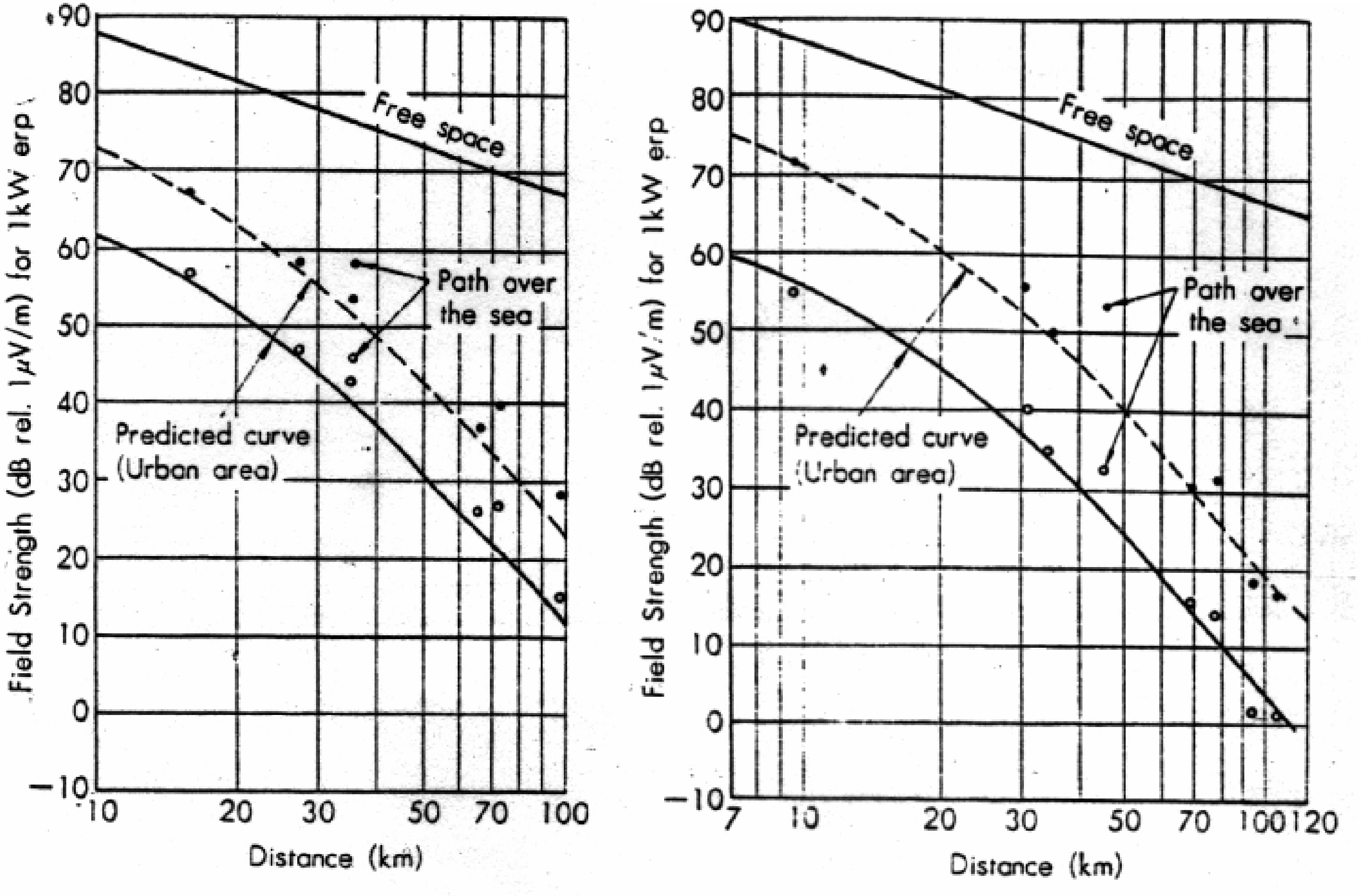
- Comparison between the measured field strength for the sampling interval on the propagation path



Ffg. 44—Comparison of measured and predicted median field strength on 55° SW radial from Tokyo Tower. ($h_{te}=120$ m, $h_{re}=3$ m, 453 MHz)

Comparison of NHK's data with predicted median field strength curves (urban area)

- Medium and small cities
- twenty fixed points per city

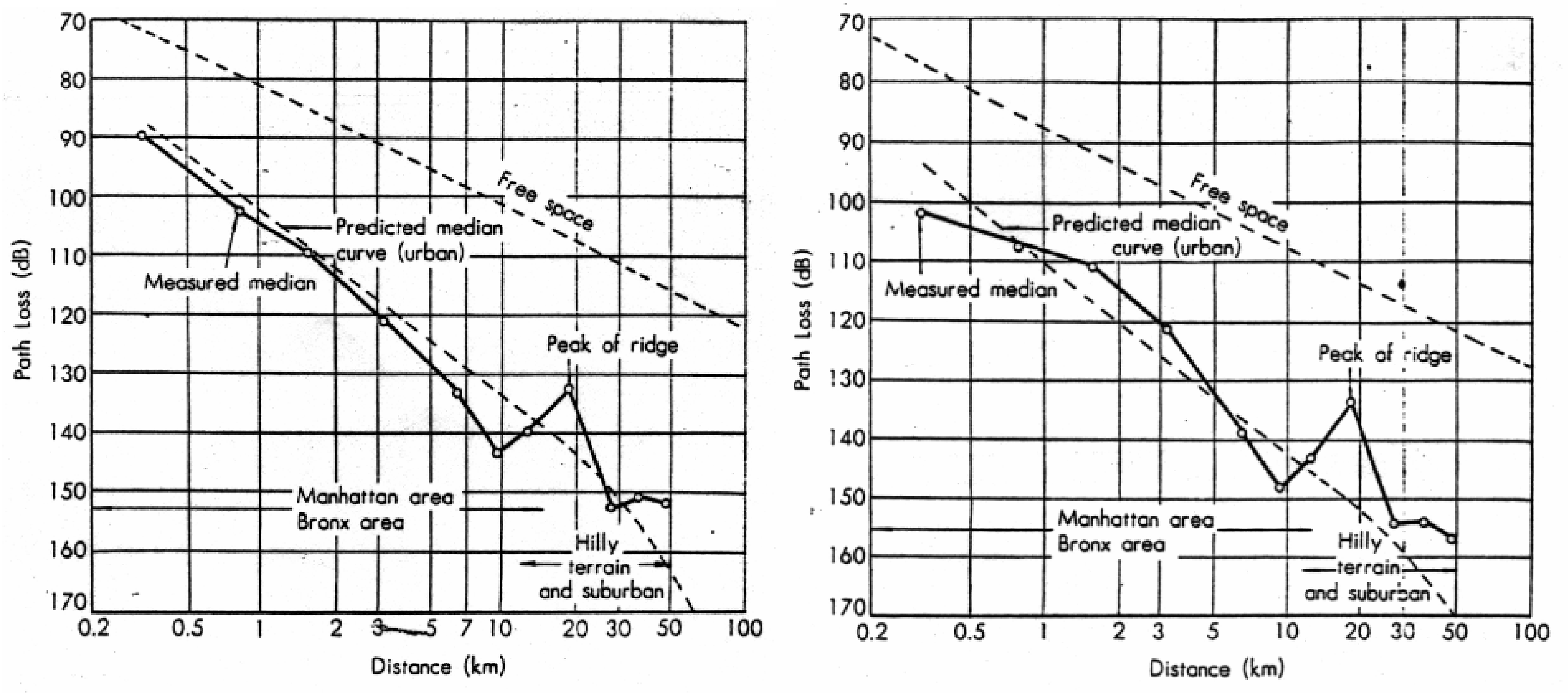


(a) ● ; $f = 176$ MHz $h_{te} = 140$ m, $h_{re} = 10$ m
○ ; 〃 〃 , $h_{re} = 4$ m

(b) ● ; $f = 670$ MHz $h_{te} = 100$ m, $h_{re} = 10$ m
○ : 〃 〃 , $h_{re} = 4$ m

Comparisons of Bell Laboratories' data with predicted median field strength curves

- Two medians
  - short-distance values measured at the lofty-building area of Manhattan
  - Those measured along several directions for a distance of 10km or more, at suburban and hilly terrain areas



(a) ○; $f=450$MHz median, $h_{te}=137$ m, $h_{re}\doteqdot 3$ m

(b) ○; $f=900$ MHz Median, $h_{te}=137$ m, $h_{re}\doteqdot 3$ m

Comparison of RCA's data with predicted median field strength curve

- The results for a comparatively smooth terrain area

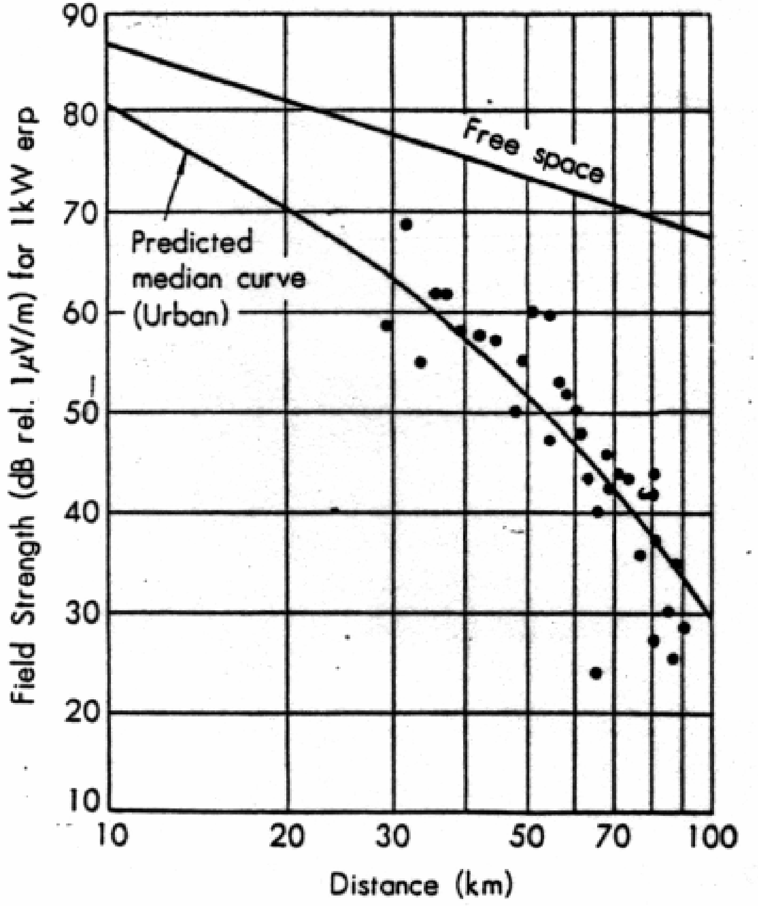


Fig. 47—Comparison of RCA's data with predicted median field strength curve.

Comparison between Representative Propagation Curves and Prediction Curves

- Dashed lines
  - The propagation curves in the urban area for a 3m high vehicular station antenna
- Solid lines
  - The prediction curves at 650MHz

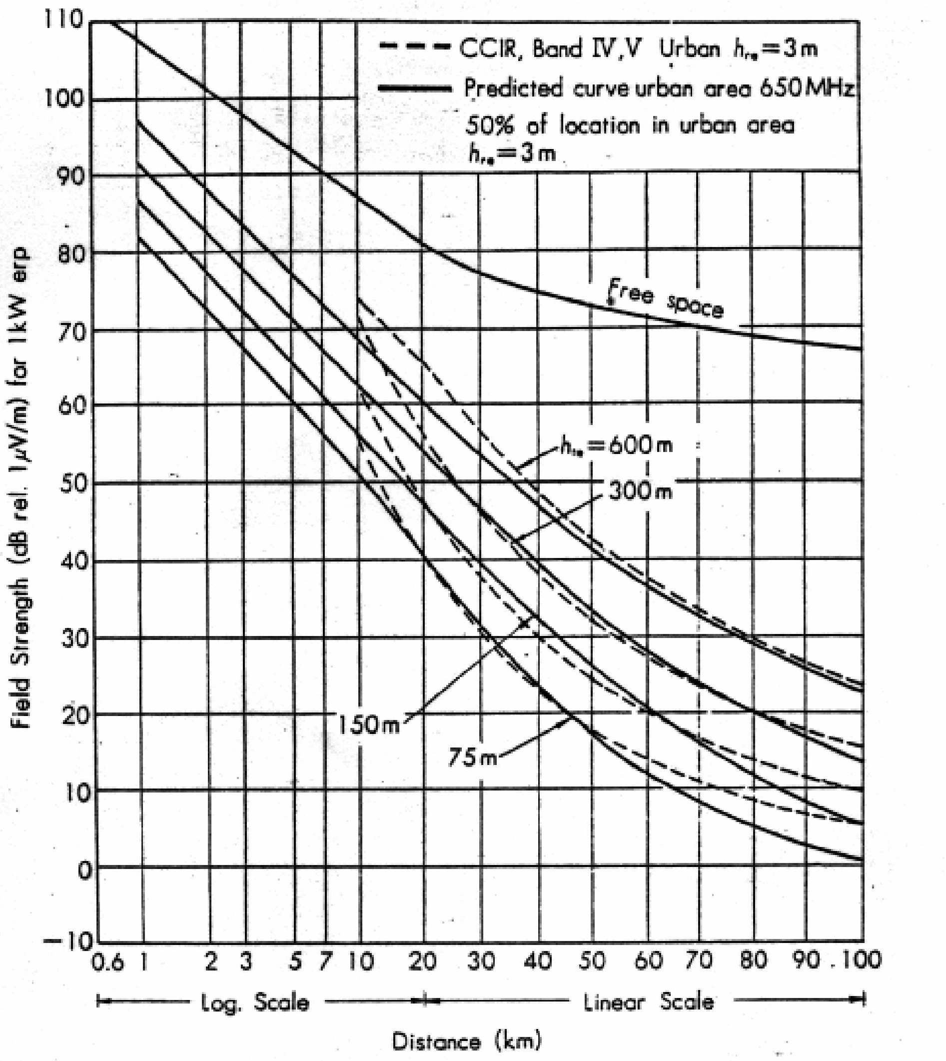


Fig. 48—Comparison of CCIR propagation curves with predicted curves.