# Radio Wave Propagation

## Federal Radio Frequency Spectrum Management Seminar

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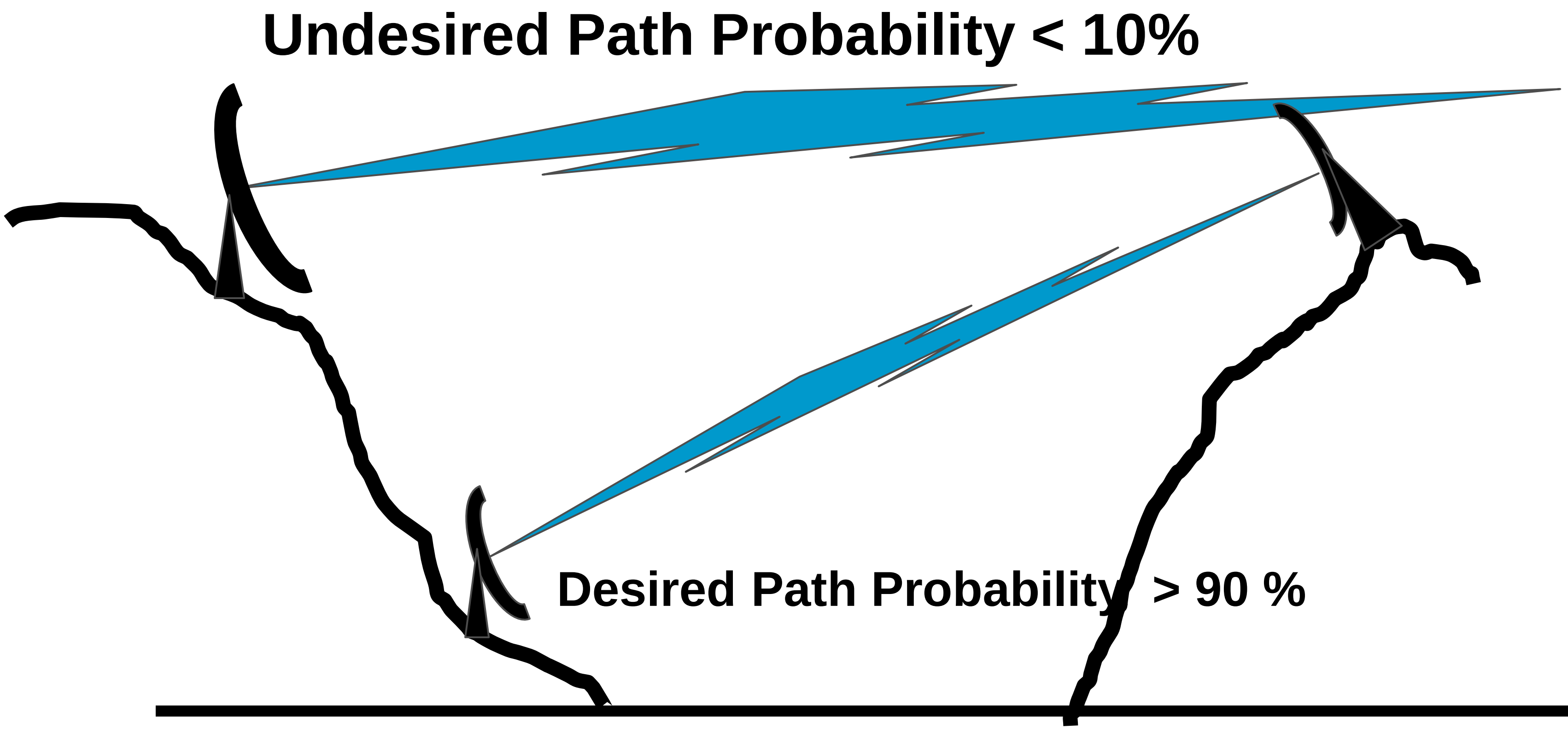
# OVERVIEW

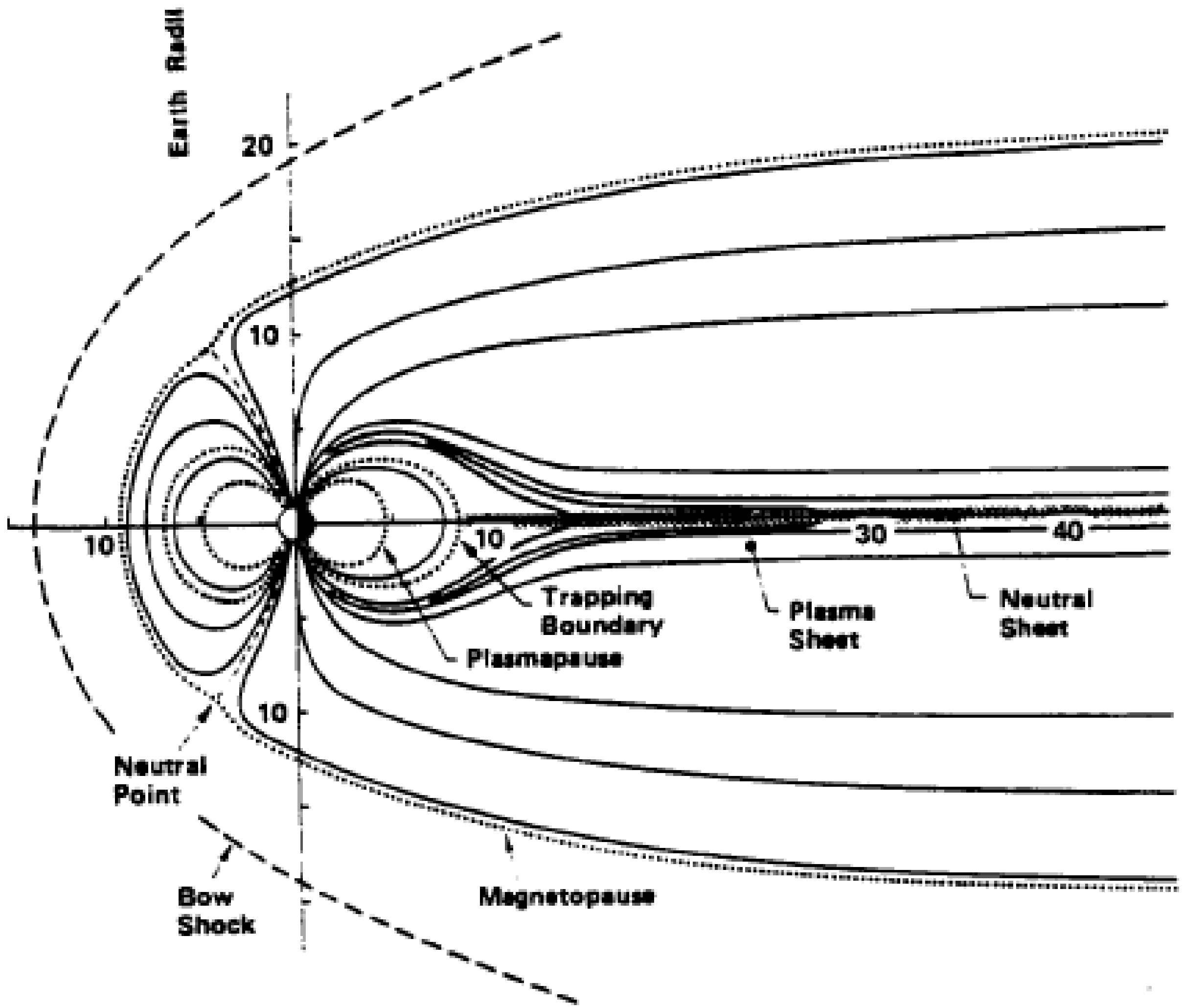
- Fundamentals
- Propagation Over Irregular Terrain
- MSAM Propagation Models
  - ITM: Irregular Terrain Model
  - LMS: Land Mobile Services Model
- ITS Models
- Relevant ITU-R Recommendations

# Generalized Interference Prediction Process




## Terms - Probability/Reliability/Percentages

# Sun's Effect on Earth's Magnetic Field




Shuttle/Spacelab Contamination Environment and Effects Handbook

**NASA Photos**

## Dry Air gases at sea level

78% nitrogen

21% oxygen

<< 1% argon

0.04% carbon dioxide

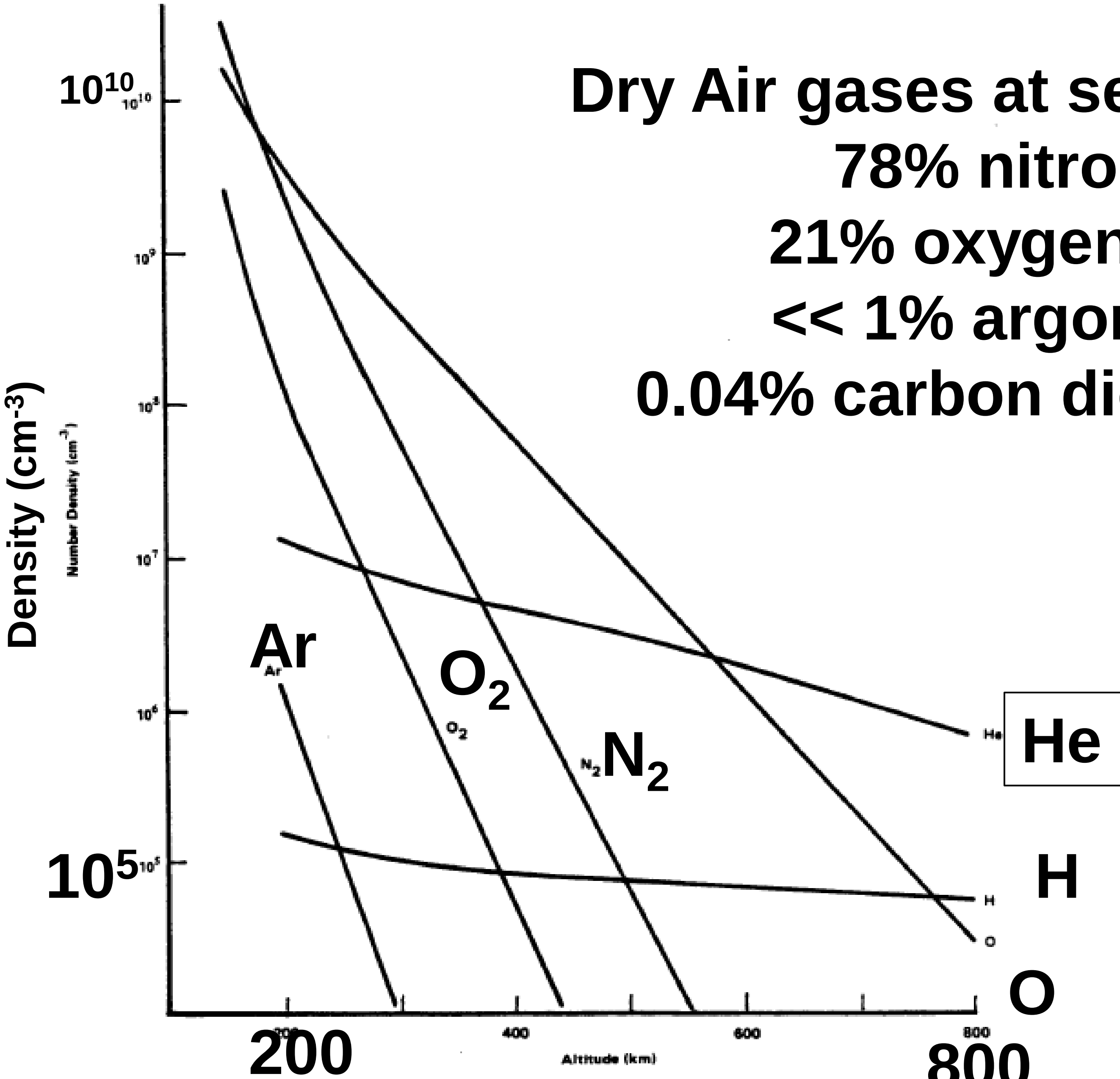


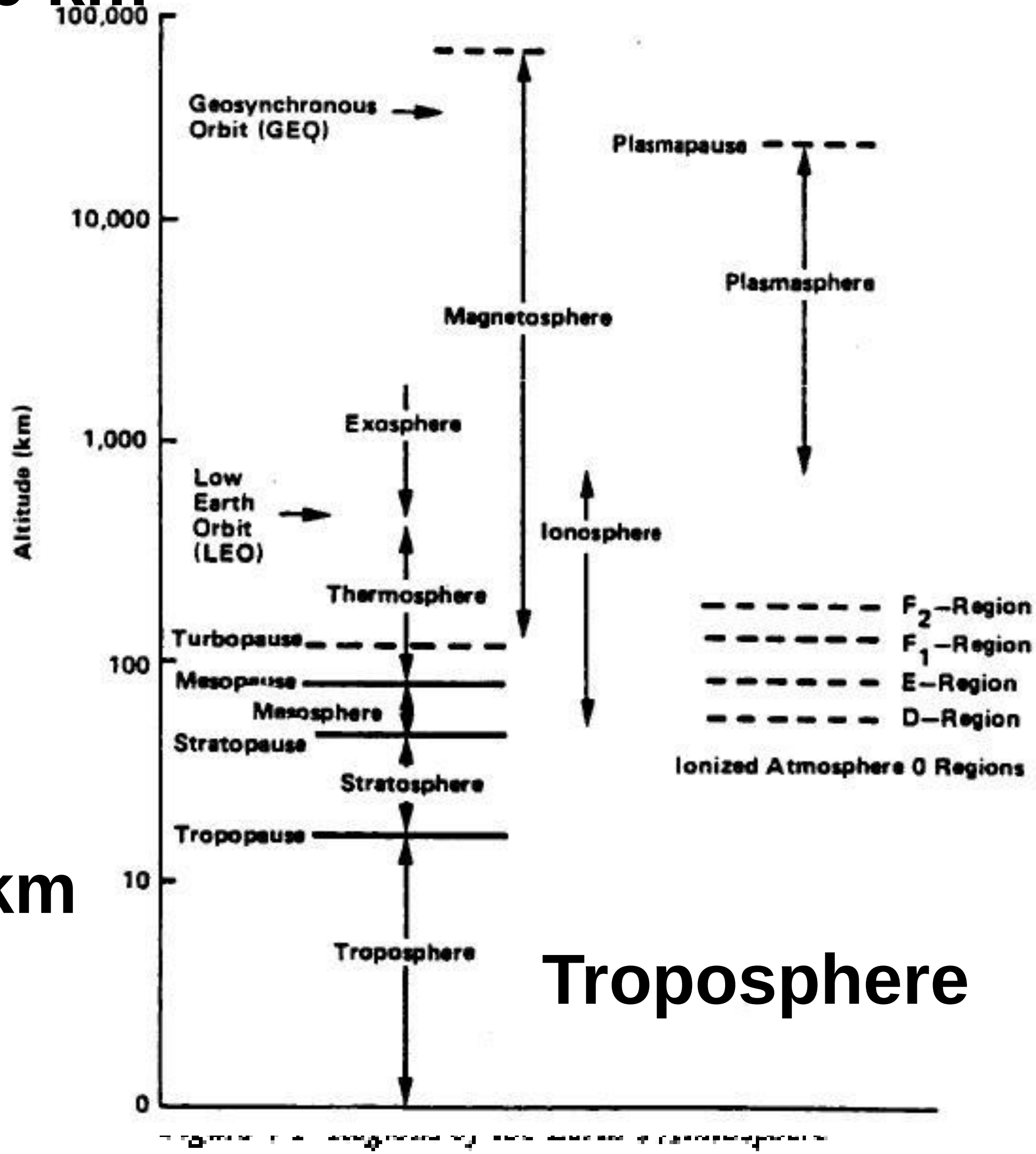

*Figure 4.1-1 COESA Model Atmosphere (Ref I-2)*

**100,000 km**

**1000**

**LEO**

**10 km**




**Ionosphere**

**Troposphere**

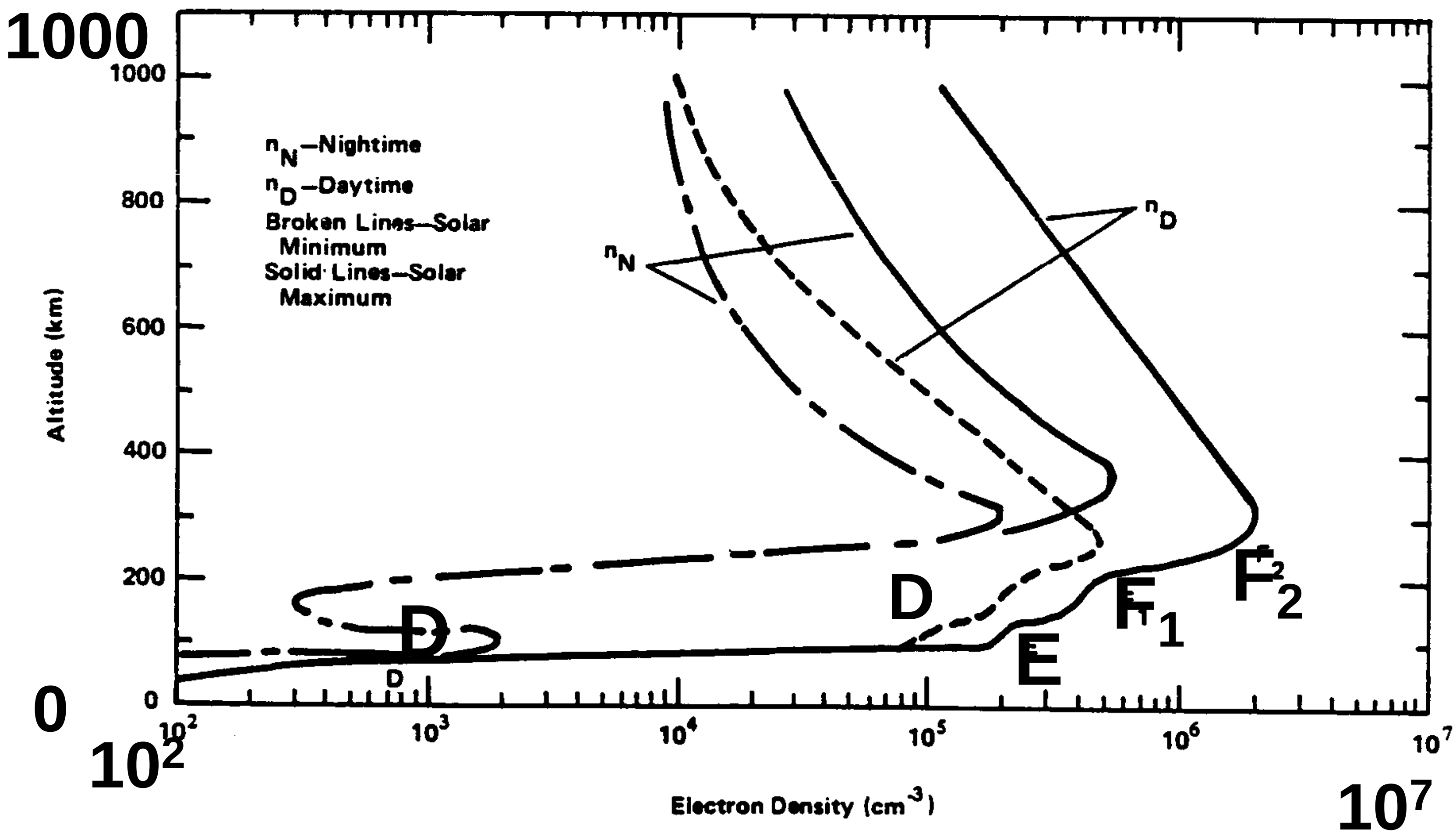
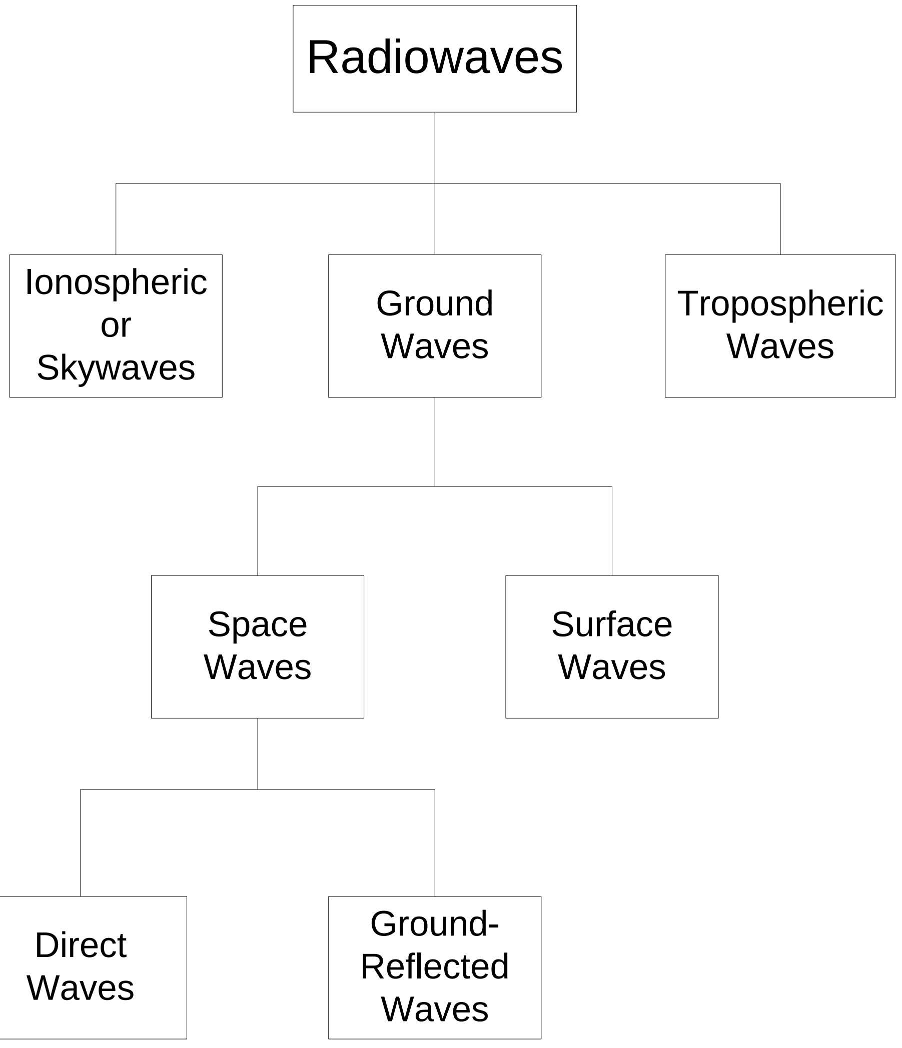



*Figure 4.2-2 Ionospheric Electron Concentration*

# LARGE SCALE PROPAGATION EFFECTS

- **Free Space Loss**
- **Diffraction**
- **Refraction**
- **Reflection**
  - **Scattering**
  - **Ducting**

# Modes of Radiowave Propagation

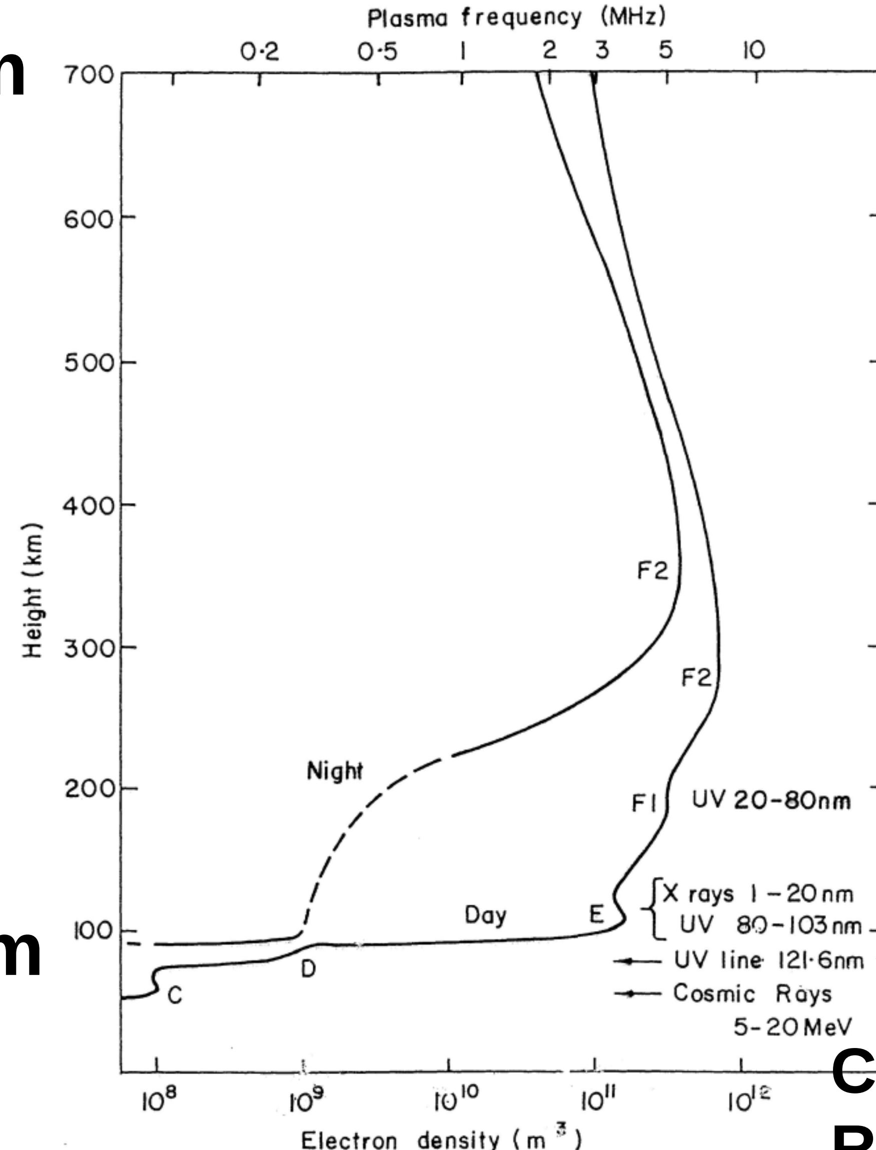


# ION0SPHERIC SUMMARY

- Ionized Medium – Reflects Signals in HF Spectrum
- Created By Solar Radiation (Daily, Seasonal and Solar Cycle Variations)
- Five Principle Regions (D, E, $E_S$, F1, F2)

**Electron-density profiles showing the radiations that produce the ionospheric layers.**

700 km




UV

X-ray

Cosmic Ray

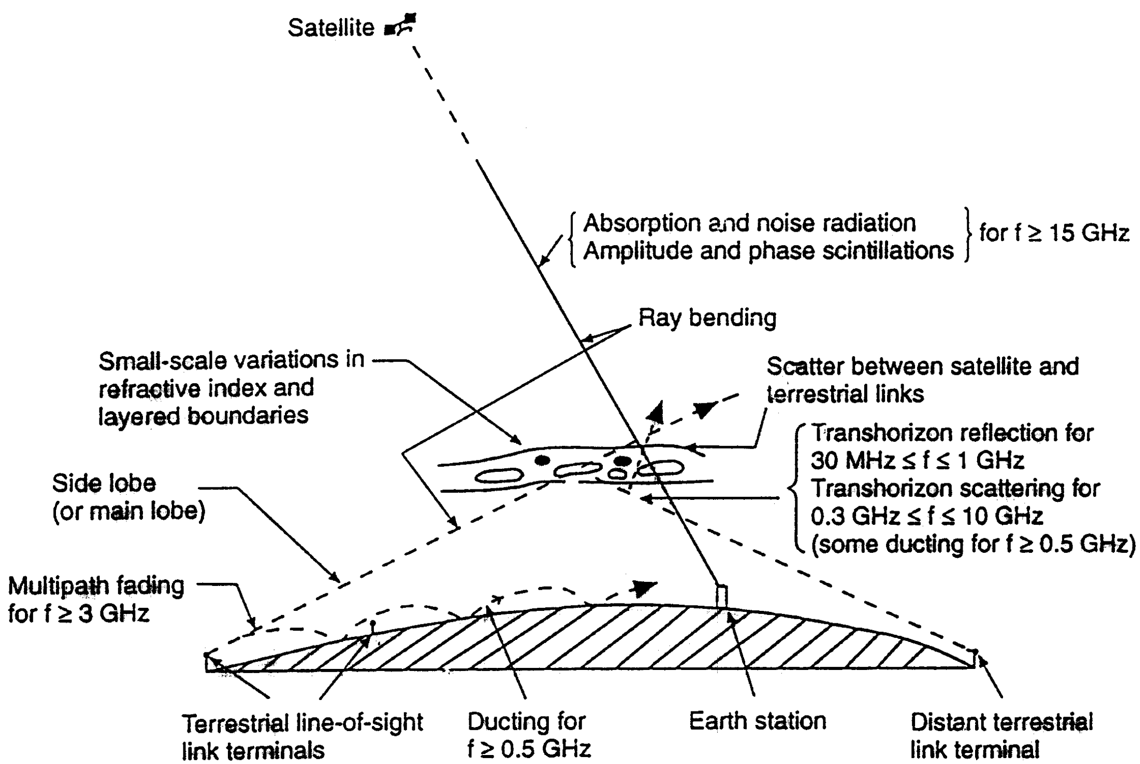
100 km

[Contemp. Phys. 1973, 14.230 (Taylor & Francis, London)]

$10^8$

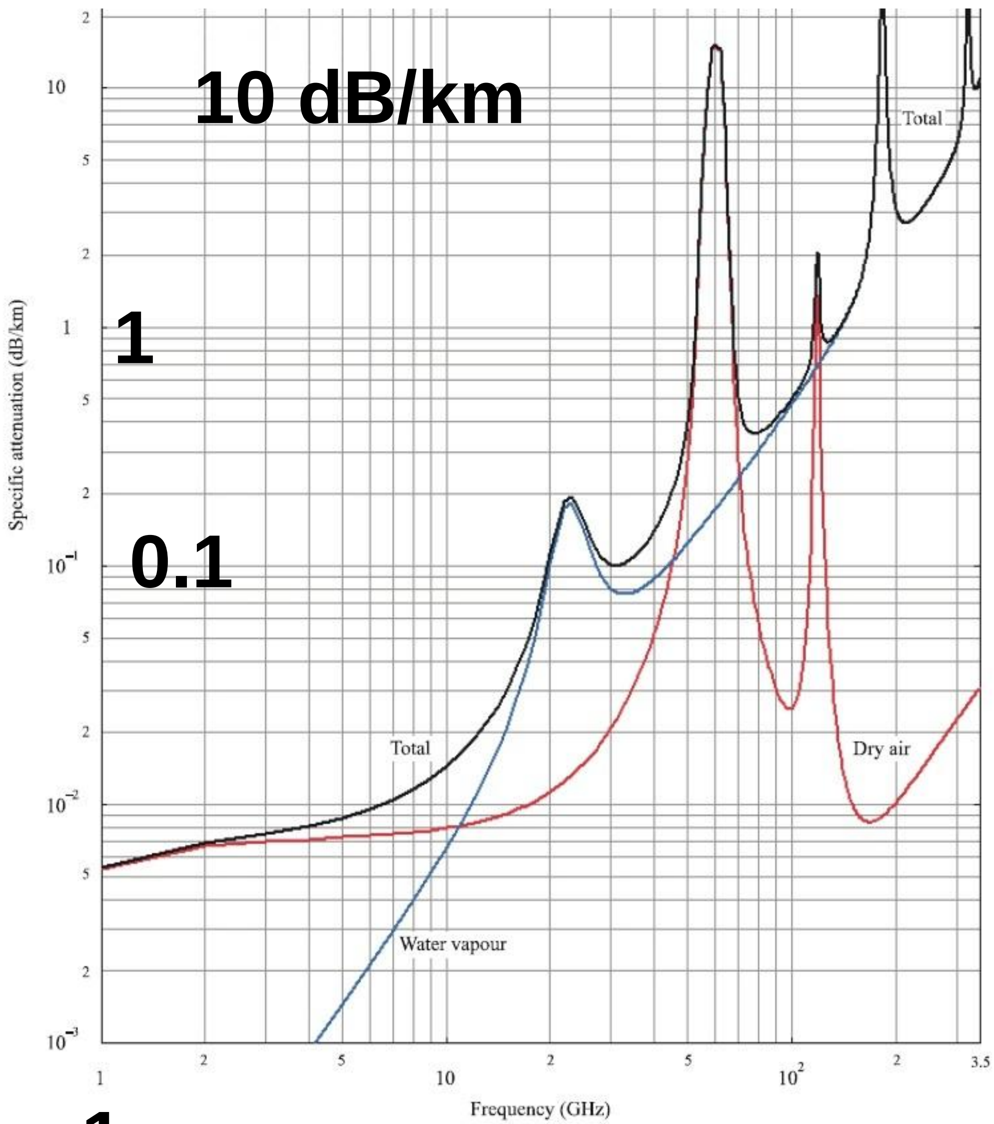
$10^{12}$

# Effects of Atmospheric Gasses Refractive-Index Changes




**Ref. Propagation of Radiowaves, Edited by Les Barclay**

# Atmospheric Gas and Water Vapor Attenuation




1 10 GHZ 200

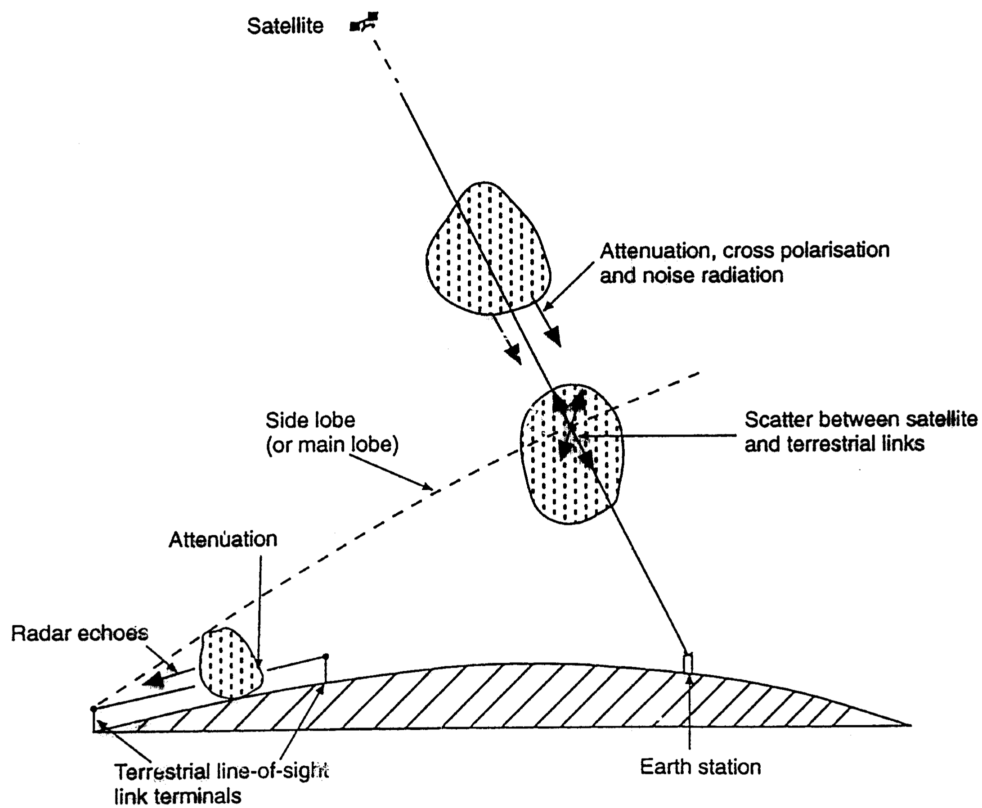
**Temperature:**
20° C

**Pressure:**
1 atm

**Water Vapor:**
7.5 g/m$^3$

**From ITU-R P 676**

# Effects of Cloud and Precipitation (Above several GHz)




**Ref. Propagation of Radiowaves, Edited by Les Barclay.**

# PROPAGATION ASPECTS AND SERVICES IN DIFFERENT FREQUENCY BANDS

| Frequency Band | Atmospheric Influence | Terrestrial Influence | Applications | Comments |
|---|---|---|---|---|
| **ELF** < 3 kHz | Waveguide and cavity propagation with ionosphere as upper boundary | Earth forms lower boundary of waveguide, waves propagate deep into earth or sea | Long-range comm with submarines | Very Large Antennas, very low data rate |
| **VLF** 3 – 30 kHz | Waveguide propagation with D-region as upper boundary | Earth forms lower boundary | Worldwide telegraphic services with ships | Very Large Antennas, low data rate |
| **LF** 30 – 300 kHz | Waves below D region up to 100 kHz, sky waves distinct from ground waves above 100 kHz | Ground waves follow earth | Long-range communication with ships | Large antennas, difficult to make it directional |
| **MF** 300 – 3000 kHz | Sky waves for longer distances and higher frequencies | Surface waves for shorter distances and lower frequencies, ground reflections | Broadcasting, navigational aids | Large antennas, service area about 100 km during day, longer distances at night |

| Frequency Band | Atmospheric Influence | Terrestrial Influence | Applications | Comments |
|---|---|---|---|---|
| **HF** 3 - 30 MHz | Ionospheric beyond skip distance (6-30 MHz) | Surface waves only at short distance (3-6 MHz), reflection, scatter | long distance broad-casting | Curtain arrays, vertical whips, log periodic arrays |
| **VHF** 30 - 300 MHz | Tropospheric waves sporadic E cause interference | Terrestrial LOS and BLOS with diffraction, multipath effects due to reflection | Broadcasting, land, aero and maritime mobile, cordless phones, radionavigation | Yagi, slots and helixes used, broadband, surface waves attenuated |
| **UHF** 300 - 3000 MHz | Refraction, reflection at lower and ducting at higher frequencies, troposcatter above about 500 MHz | Terrestrial and earth-space LOS and slightly BLOS, screening by hills and buildings | TV broad-cast, radars, | Both wideband and high gain antennas used, more severe screening effects |
| **SHF** 3-30 GHz | Refraction and ducting, attenuation due to rain etc., scintillation | Terrestrial and earth-space LOS, diffraction and screening due to buildings, scatter and reflection from buildings, terrain, trees and sea | Fixed terrestrial and satellite services, mobile | High gain parabolic dishes and horns, ducting may cause interference, multipath cause fading, absorption by rain, snow, fog, cloud and gasses |

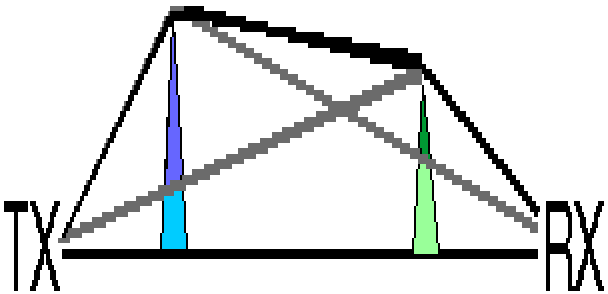
# PROPAGATION ASPECTS IN DIFFERENT BANDS

| Frequency Band | Atmospheric Influence | Terrestrial Influence | Applications | Comments |
|---|---|---|---|---|
| **MILLIMETRIC**<br>**EHF 30 – 300 GHz** | **Refractive index gradient, rain etc. cause attenuation and scatter, absorption by water vapor and oxygen, scintillation** | **Terrestrial short distance LOS, screening by buildings and foliage** | **Short-range fixed and mobile communication systems** | **Small parabolic dishes, technology under development for LMDS, LMCS, WLAN and indoor communications** |
| **SUB-MILLIMETRIC 300 – 3000 GHz** | **Localized refractive index gradient, rain etc. cause severe attenuation, absorption by gases, scintillation** | **Very short range LOS, screening by trees** | **Short-range communications, remote sensing** | **Mirror or lens antennas, equipment lacking** |
| **INFRARED AND OPTICAL**<br>**3 – 430 THz and**<br>**430 – 860 THz** | **Localized refractive index gradient, rain etc. cause very severe attenuation, absorption by gasses, scintillation** | **LOS, screening by small objects** | **Short-range and indoor for far-infrared, alarms, smoke detectors, remote control and spectrometry for near-infrared, optical LOS links** | **Mirrors and lenses for antennas, little communication use at far-infrared, no potential seen at near-infrared, optical short LOS** |

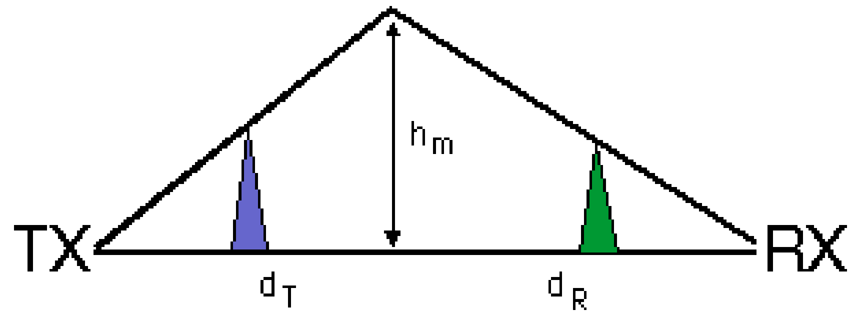
# PROPAGATION OVER IRREGULAR TERRAIN

- **Single Knife Edge Diffraction**
- **Diffraction Over Rounded Obstacles**
- **Multiple Knife Edge Diffraction** (also smooth Earth)
  - Vogler's Method
  - Bullington's Method
  - Epstein-Peterson's Method
  - Deygout Method

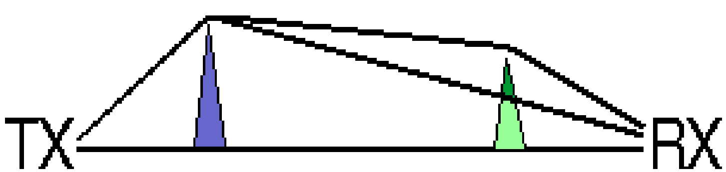
# Various Knife Edge Constructions



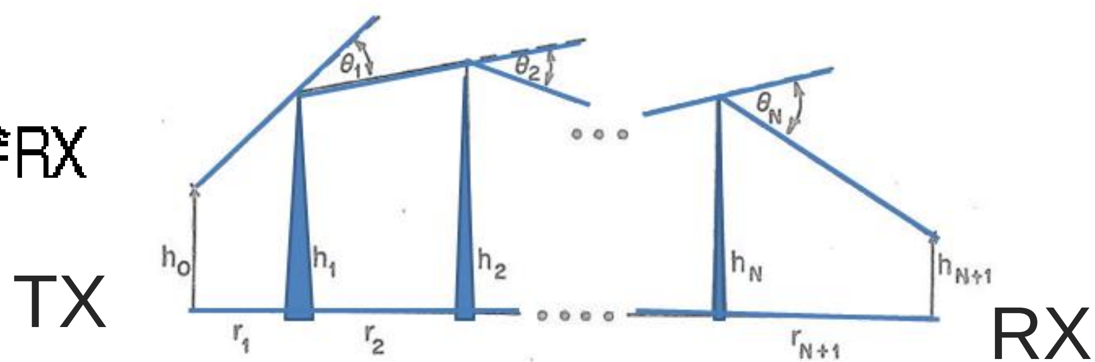

Epstein Peterson




Bullington




Degouot

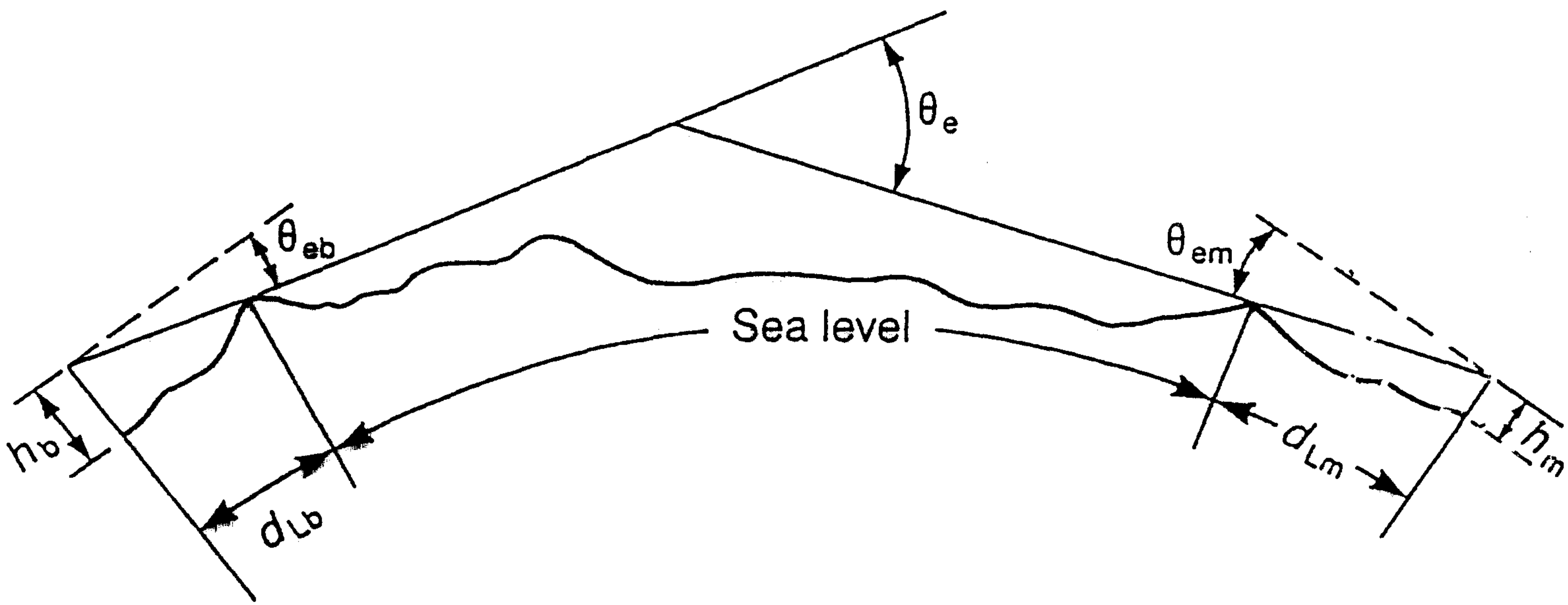



Vogler

# Primary Path Loss Prediction Models

- Longley-Rice Model (MSAM)
- TIREM
- CRC-Predict
- Walfish-Bertoni Model
- Walfish-Ikegami Model
- Models Based on Okumura's Data
- IF-77

# THE MOBILE RADIO PROPAGATION CHANNEL




## Geometry of a Trans-horizon Radio Path

# INPUT PARAMETERS FOR THE ITS MODEL WITH THE DESIGN LIMITS

**System Parameters**

| | |
|---|---|
| Frequency | 20 MHz to 20 GHz |
| Distance | 1 km to 2000 km |
| Antenna Heights | 0.5 m to 3000 m |

**Environmental Parameters**

| | |
|---|---|
| Terrain Irregularity Parameter, Delta h | |
| Electrical Ground Constants | |
| Surface Refractivity | 250 to 400 N-units |
| Climate | one of seven |

**Deployment Parameters**

| | |
|---|---|
| Siting Criteria | random, careful, or very careful |

**Statistical Parameters**

| | |
|---|---|
| Reliability and Confidence Level | *0.1 % to 99.9 % |

(*see slide 3)

# Suggested Values for the Terrain Irregularity Parameter

| | Dh (meters) |
|---|---|
| Flat (or smooth water) | 0 |
| Plains | 30 |
| Hills | 90 |
| Mountains | 200 |
| Rugged Mountains | 500 |
| For an average terrain, use $\Delta h$ = 90 m | |

# Suggested Values for Electrical Ground Constants

| | Relative Permittivity | Conductivity (Siemens per Meter) |
|---|---|---|
| Average Ground | 15 | 0.005 |
| Poor Ground | 4 | 0.001 |
| Good Ground | 25 | 0.020 |
| Fresh Water | 81 | 0.010 |
| Sea Water | 81 | 5.0 |
| For most purposes, use the constants for an average ground | | |

# Radio Climate and Suggested Values for $N_s$

| | $N_s$ (N-Units) |
|---|---|
| Equatorial (Congo) | 360 |
| Continental Subtropical (Sudan) | 320 |
| Maritime Subtropical (West Coast of Africa) | 370 |
| Desert (Sahara) | 280 |
| Continental Temperate | 301 |
| Maritime Temperate, Over Land (United Kingdom and Continental West Coasts) | 320 |
| Maritime Temperate, Over Sea | 350 |
| For average atmospheric conditions, use a Continental Temperate climate and $N_s$ = 301 N-Units | |

# Popular Land Mobile Services Models

- Original Okumura-Hata Model
- COST 231 Extension
- ITU Extension
- Okumura-Hata-Davidson
- MSAM LMS package

# Okumura Curves

## Mean Loss

Frequency 150 – 1.9 GHz

(Extrapolated to 3 GHz)

$h_1$: Base Height meters 30 m to 1k m

$h_2$: Mobile Height meters, 1 to 10 m

d: Distance 1 to 100 km

$A_{mu}(f,d)$: Median Attenuation Rel to FSL

$L_{50}(dB)$: $L_f + A_{mu}(f,d) - G(h_1) - G(h_2) - G_{area}$

## Antenna Height Gain Factors

$G(h_1) = 20 \log (h_1/200)$, $1k\ m > h_1 > 10\ m$

$G(h_2) = 10 \log (h_2/3)$, $h_2 < 3\ m$;

$= 20 \log(h_2/3)$, $10 > h_2 > 3\ m$

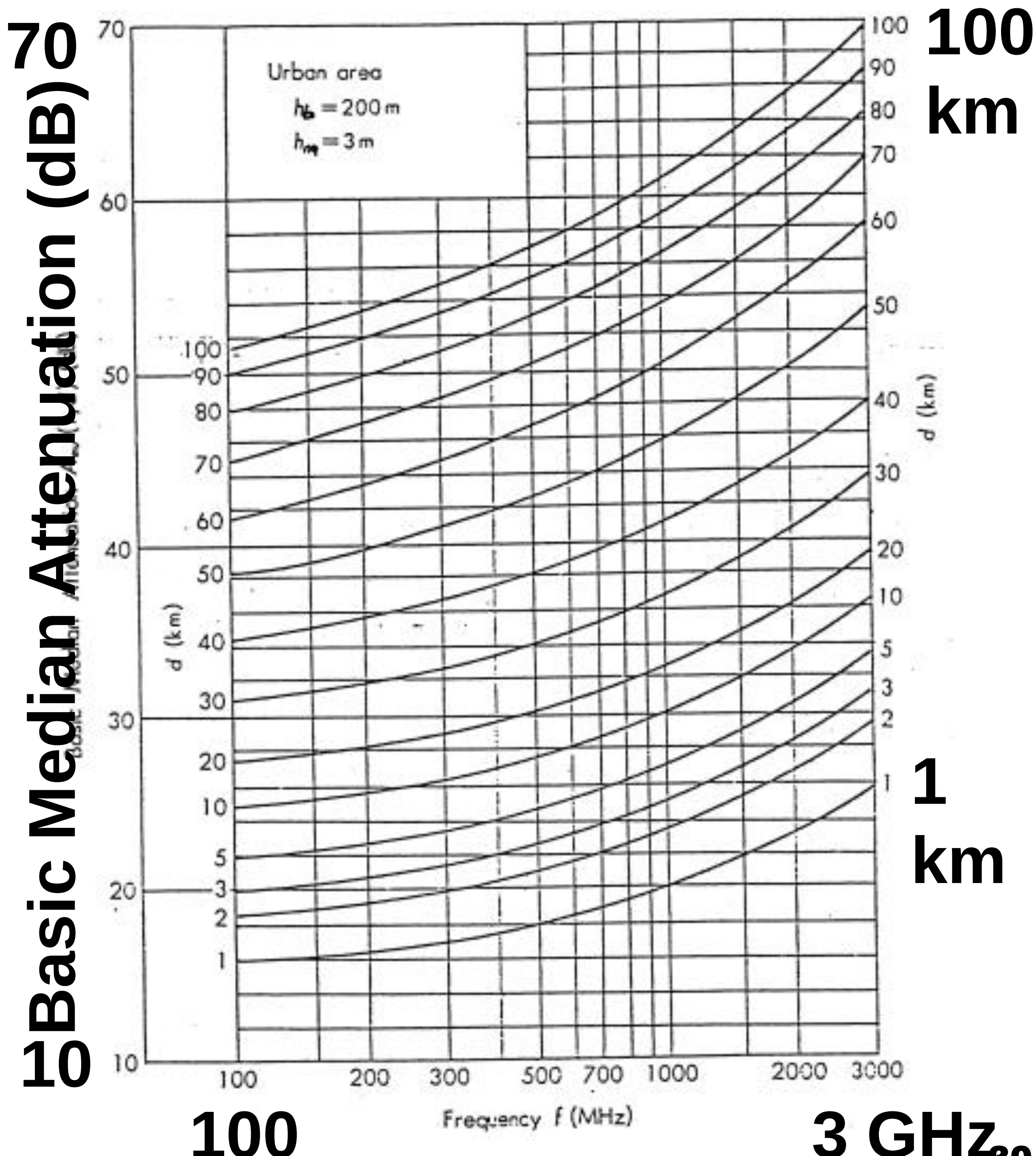
$G_{Area}$: Gain due to type of environment

$A_{mu}$ and $G_{Area}$ Curves are given.

# Urban Area Prediction for Median Attenuation

**relative to FSL over quasi-smooth terrain**

**Base = 200 m, mobile = 3 m**

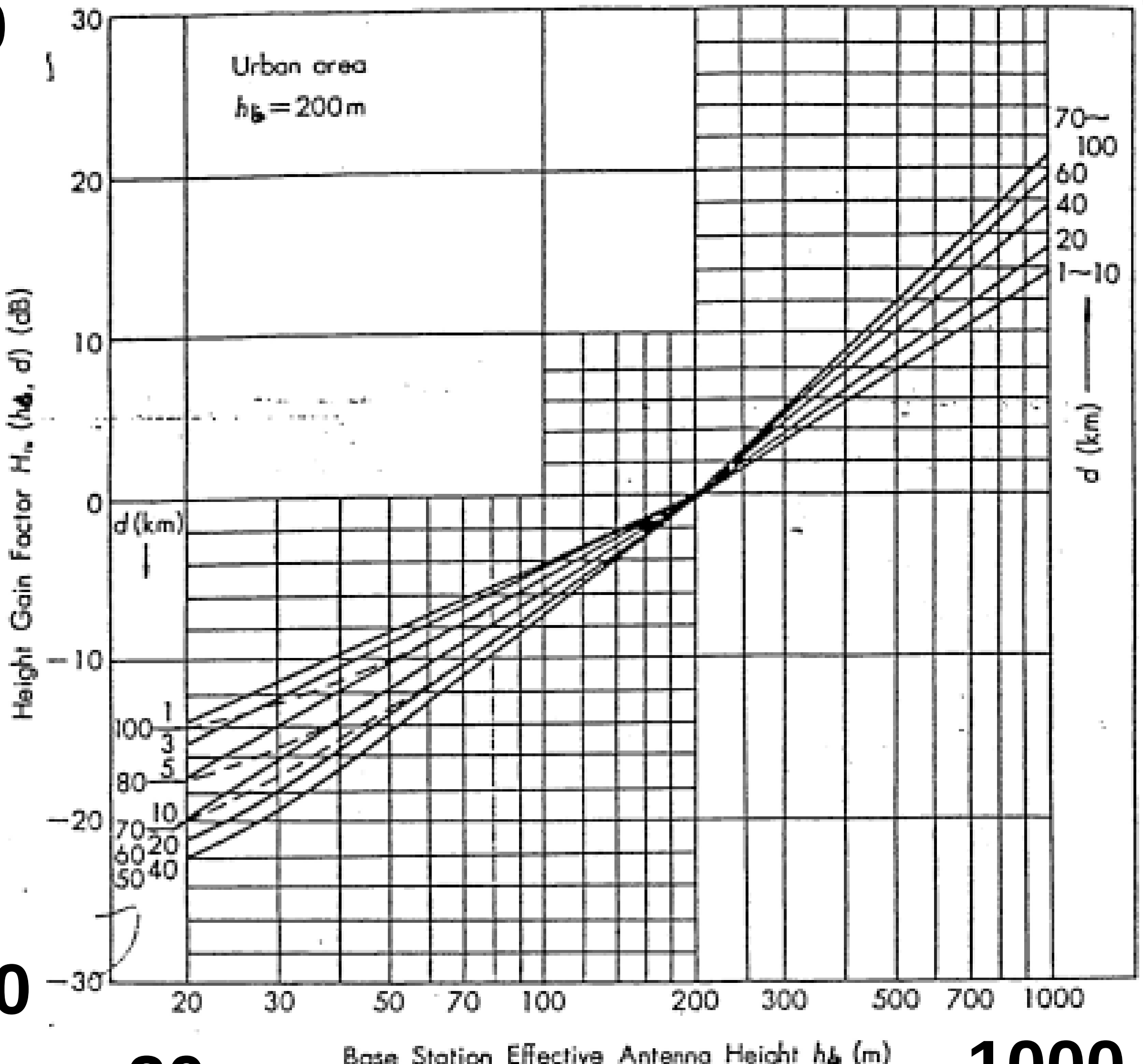


**Urban Area Prediction Curve for Base Station Antenna Height gain factor relative to 200m**

30

0

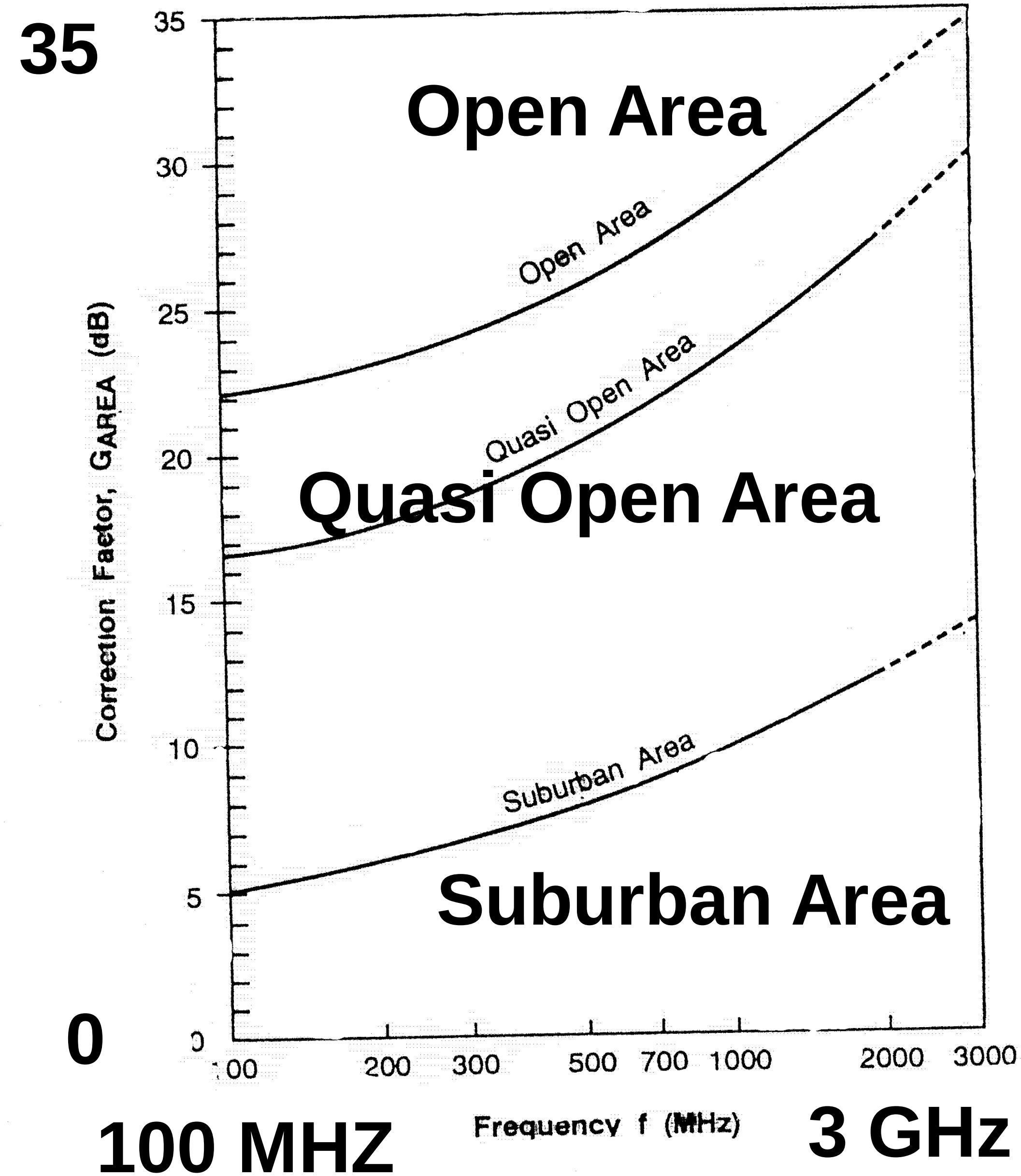
-30



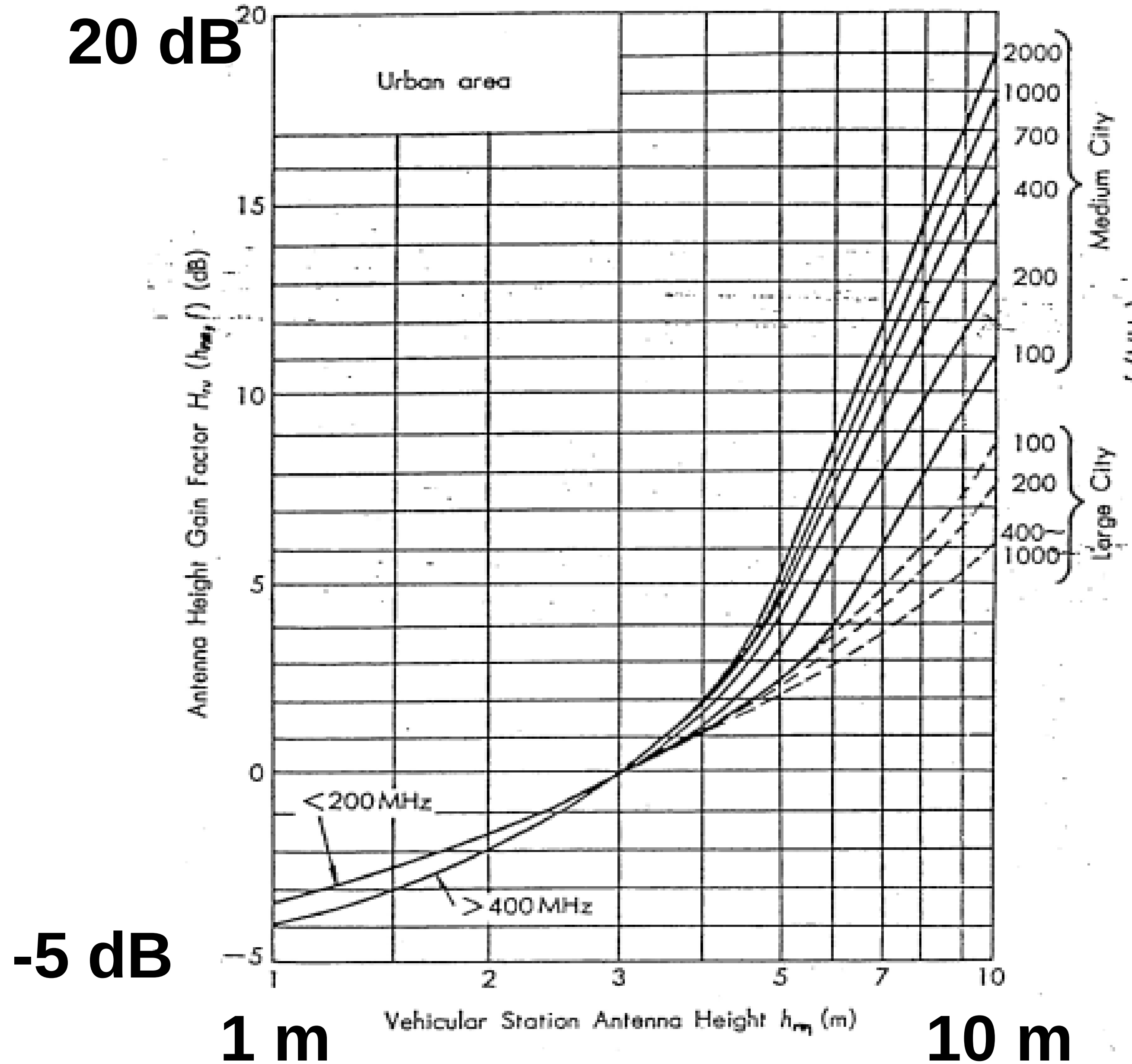

20

1000

# Area Correction Factor $G_{AREA}$ (dB)



# Urban Area Prediction Curve for Vehicular Antenna Height



# The Hata Model

**Standard formula for median path loss in urban areas is given by**

$$L_{50}\text{ (urban)} = 69.55 + 26.16 \log_{10} f - 13.82 \log_{10} h_1 - a(h_2) + (44.9 - 6.55 \log_{10} h_1) \log_{10} d$$

**For a small to medium sized city, the correction factor is given by**

$$a(h_2) = (1.1 \log_{10} f - 0.7)\, h_2 - (1.56 \log_{10} f - 0.8)\ \text{dB}$$

**and for a large city, is give by**

$$a(h_2) = 8.29(\log_{10} 1.54 h_2)^2 - 1.1\ \text{db} \qquad \text{for } f <= 200\ \text{MHz}$$

$$= 3.2(\log_{10} 11.75 h_2)^2 - 4.97\ \text{dB} \qquad \text{for } f >= 400\ \text{MHz}$$

**To obtain the path loss in decibels in a suburban are the formula is modified as**

$$L_{50} = L_{50}(\text{urban}) - 2\,[\log_{10}(f/28)]^2 - 5.4$$

**And for the path loss in decibels in open areas the formula is modified as**

$$L_{50} = L_{50}(\text{urban}) - 4.78\,(\log_{10} f)^2 + 18.33\,(\log_{10} f) - 40.98$$

# Modified Cost 231

## (European Cooperative for Scientific and Technical Research)

***Mean Loss***

**$P_t$: transmitter power in watts**

**f: 1.5 – 2.0 GHz**

**$h_1$: 30 to 200 m**

**$h_2$: 1 to 10 m**

**d: 1 to 100 Km**

$$L_{50}(dB) = 46.33 + 33.9 \log_{10} f - 13.82 \log_{10} h_1 - a(h_2) + (44.9 - 6.55 \log_{10} h_1)(\log_{10} d)^b + C_m$$

**Where $C_m$ = 0 dB, for small/medium cities**

**= 3 dB, for large cities**

***Field Strength***

$$E \text{ in dB(dB mV/m)} = 63.1 + 10 \log_{10} P_t - 13.9 \log_{10} f + 13.82 \log_{10} h_1 + a(h_2) - (44.9 - 6.55 \log_{10} h_1)(\log_{10} d)^b - C_m$$

**b as defined earlier**

# Okumura-Hata Model (ITU 1546)

***Field Strength***

**E in dB(dB μV/m ) = $39.82 + 10 \log_{10} P_t - 6.16 \log_{10} f + 13.82 \log_{10} h_1 + a(h_2)$**
**$- (44.9 - 6.55 \log_{10} h_1)(\log_{10} d)$**

**$P_t$: transmitter power in watts**

**f: 150 – 1500 MHz**

**$h_1$: 30 to 200 m**

**$h_2$: 1 to 10 m**

**d: 1 to 100 km**

**$a(h_2) = (1.1 \log f - 0.7)\, h_2 - (1.56 \log f - 0.8)$**

**For d<= 20 Km**

**b=1**

**For d> 20 km**

**$b = 1 + (0.14) + 1.87 \times 10^{-4} \times f + 1.07 \times 10^{-3} h_1)\, (\log(d/20))^{0.8}$**

***Mean Loss***

**$L_{50}(dB) = 69.55 + 26.16 \log_{10} f - 13.82 \log_{10} h_1 - a(h_2) + (44.9 - 6.55 \log_{10} h_1)\, (\log_{10} d)^b$**

# Okumura-Hata/Davidson Model

**f : 30 - 1500 MHz**
**$h_1$ : 20 - 2500 m**
**$h_2$ : 1 - 10 m**
**d : 1 - 300 km**

***Add and/or subtract the following terms:***

**$A(h_1,d) = 0.62137\ (d - 20)\ [0.5 + 0.15 \log_{10} ( h_1 / 121.92 )]$, d > 20 km**

**$S_1(d) = 0.174\ (d - 64.38)$, d > 64.38 km**

**$S_2(h_1,d) = 0.00784\ |\log_{10} ( 9.98/d )|\ ( h_1 - 300 )$, $h_1$ > 300 m**

**$S_3(f) = f/250 \log_{10} (1500/f)$**

**$S_4(f,d) = 0.112 \log_{10} (1500/f)\ (d - 40.238)$, d > 40.238**

***Okumura-Hata/Davidson median path loss***

**$L_{50}(O\text{-}H/D) = L_{50}(O\text{-}H) + A(h_1, d) - S_1(d) - S_2(h_1, d) - S_3(f) - S_4(f,d)$**

***Field Strength***

**$E = 109.36 + 10 \log_{10} P_t + 20 \log_{10} f - L_{50}(O\text{-}H/D)$**

# ITS MODELS

- **ITM (Irregular Terrain Model) Based on Longley-Rice**
  - **Point-To-Point Mode**
  - **Point-To-Area Mode**

- **IF-77 (Johnson-Gierhart) For Aeronautical Mobile Applications used in ITU-R P.528**
- **FAA updated this program in 2010**

- **ITS HF Propagation Analysis Package**
  - **VOACAP, VOAAREA and S/I VOACAP Gives Point-To-Point, Area Coverage Signal-To-Interference Ratio for VOA**
  - **REC533 Point-To-Point Prediction of HF Broadcast, ITU-R P.533-5**
  - **RECAREA: Area Coverage of HF Broadcast**
  - **ICEPAC, ICEAREA and S/I ICEPAC: Ionospheric Communications enhanced Profile Analysis and Circuit Prediction Program**

# Irregular Terrain Model Dimensions of Variability

- **On fixed paths hourly median signal levels have been measured and record for periods of years and median signal levels and standard deviations determined. Results in <u>time variability</u>. Looking at the data one might be able to say for 95% of the time the attenuation did not exceed 36 dB.**
- **Looking at a second similar path with all parameters constant, we would find the statistics are different and the long term statistics have changed. We find that there is a path-to-path variability. We call this <u>location variability</u>. Now we would perhaps say there will be 70% of locations the attenuation does not exceed 36 dB for at least 95% of the time.**
- **If we rerun the experiments in different but like appearing situations we again observe changes in the statistics. These are referred to as <u>situational variability</u>.  Now we would say in 90% of like situations, there will be at least 70% of locations the attenuation does not exceed 36 dB for at least 95% of the time.**
- **Prediction of Tropospheric Radio Transmission Loss over Irregular Terrain – Longley & Rice - Ref ESSA TR ERL 79-ITS 67**
- **Use of the ITS ITM in the Area Prediction Mode NTIA 82-100**

# ITU-R RECOMMENDATIONS

- **ITU-R P. 1144 Guide to the Application of the Propagation Methods of Radiocommunication Study Group 3**
- **ITU-R P. 452 Prediction Procedure for the Evaluation of Microwave Interference Between Stations on the Surface of the Earth at Frequencies Above About 0.7 GHZ**
- **ITU-R P. 530 Propagation Data and Prediction Methods Required for the Design of Terrestrial Line-of-Sight Systems**
- **ITU-R P. 533 HF Propagation Prediction Method**
- **ITU-R P. 1411-3: Propagation Data and Prediction Methods for the Planning of Short-Range Outdoor Radiocommunication System s and Radio Local Area Networks in the Frequency Range 300 MHz to 100 GHz**
- **ITU-R P. 1546-2: Method for Point-to-Area Predictions for Terrestrial Services in the Frequency Range 30 to 3000 MHz.**
- **ITU-R P.1812 A path-specific propagation prediction method for point-to-area terrestrial services in the VHF and UHF bands**
- **ITU-R P. 526 Propagation by Diffraction**
- **ITU-R P. 676 Attenuation by atmospheric gases**
- **ITU-R P.840  Attenuation due to clouds and fog**

NTIA http://www.ntia.doc.gov/osmhome/osmhome.html
NTIA Publications http://www.ntia.doc.gov/osmhome/reports.html
Institute for Telecommunication Sciences (ITS) http://www.its.bldrdoc.gov/
ITS Publications http://www.its.bldrdoc.gov/pub/pubs.php
http://www.voacap.com/index.html - by Jari Perkiomaki (Finland).
www.voacap.com - a website for VOACAP maintained by Jari.
http://www.swpc.noaa.gov/ for real-time monitoring/forecasting of solar & geophysical events.
http://www.ngdc.noaa.gov/ from the National Geophysical Data Center.
http://www.ngdc.noaa.gov/stp/iono/if2ig.html information.
The FCC *www.hfcc.org/* In formally coordinates short wave broadcasting.
*www.bbg.gov/*
*www.**arrl**.org/*
Nat Institute of Standards and Tech (NIST) Propagation
http://w3.antd.nist.gov/wctg/manet/wirelesspropagation_bibliog.html
High Frequency (HF) (2-30 MHz) http://www.its.bldrdoc.gov/elbert/hf.html
Irregular Terrain Model (ITM) (Longley-Rice) (20 MHz - 20 GHz)
http://flattop.its.bldrdoc.gov/itm.html IF-77 Wave Propagation Model
http://flattop.its.bldrdoc.gov/if77.html
“Globe” Terrain Routines http://www.its.bldrdoc.gov/elbert/globe.html