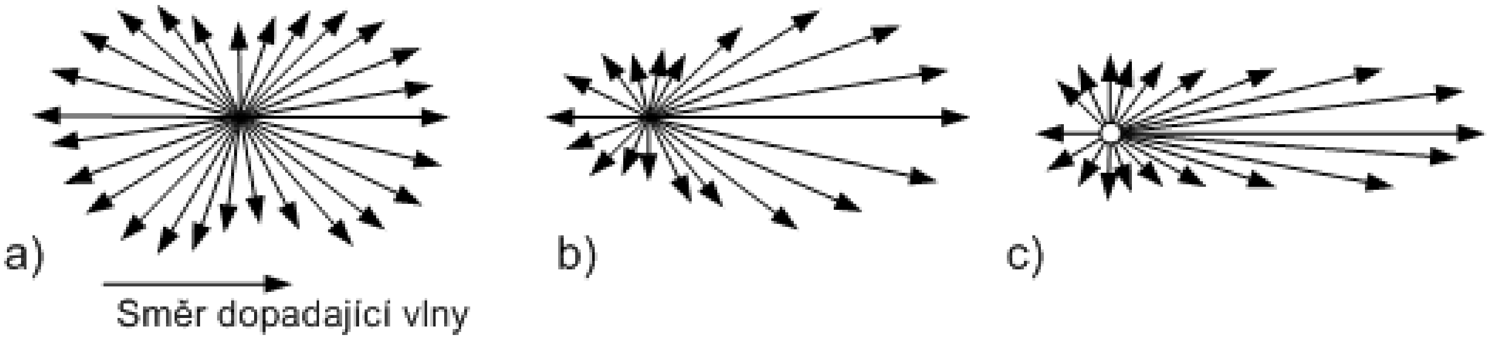
Návrh spojení troposférickou vlnou

Číslo pásma	Mezinárodní zkratka	Frekvence	Vlnová délka	Český ekvivalent	Metrické označení
3	ULF	300 Hz – 3 kHz	1000 km-100 km	EDV, extrémně dlouhé v.	hkm, hektokilometrické,
4	VLF	3 kHz – 30 kHz	100 km-10 km	VDV, velmi dlouhé vlny	Mam, myriametrové v.
5	LF	30 kHz – 300 kHz	10 km-1 km	DV, dlouhé vlny	km, kilometrové vlny
6	MF	300 kHz – 3 MHz	1 km-100 m	SV, střední vlny	Hm, hektometrové v.
7	HF	3 MHz – 30 MHz	100 m-10 m	KV, krátké vlny	Dm, dekametrové v.
8	VHF	30 MHz – 300 MHz	10 m-1 m	VKV, velmi krátké vlny	m, metrové vlny
9	UHF	300 MHz – 3 GHz	1 m-10 cm	UKV, ultra krátké vlny	dm, decimetrové vlny
10	SHF	3 GHz – 30 GHz	10 cm-1 cm	SKV, super krátké vlny	cm, centimetrové vlny
11	EHF	30 GHz- 300 GHz	1 cm-1 mm	EKV, extrémně krátké vlny	mm, milimetrové vlny

Rozptyl (*scattering*)



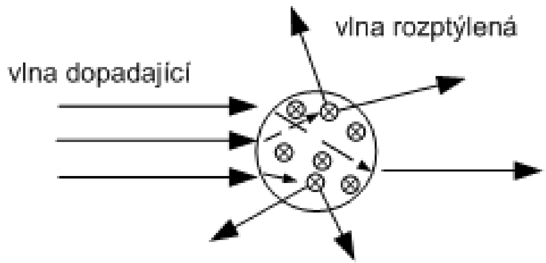
a) Rayleighův rozptyl na velmi malé částici; b) Mieův rozptyl na menší částici; c) Mieův rozptyl na větší částici

Rozptylová funkce
scattering function

$$E_s = E_i f(\mathbf{k}_i, \mathbf{k}_s) \frac{e^{-\mathrm{j}\frac{2\pi}{\lambda}d}}{d}$$

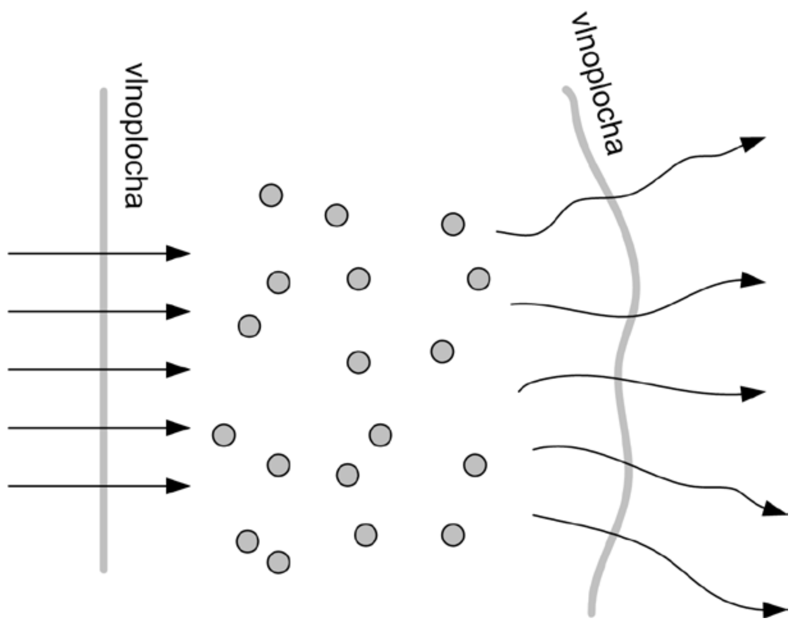
Efektivní plocha odrazu
radar cross section

$$P_s = w_i \sigma(\mathbf{k}_i, \mathbf{k}_s)$$



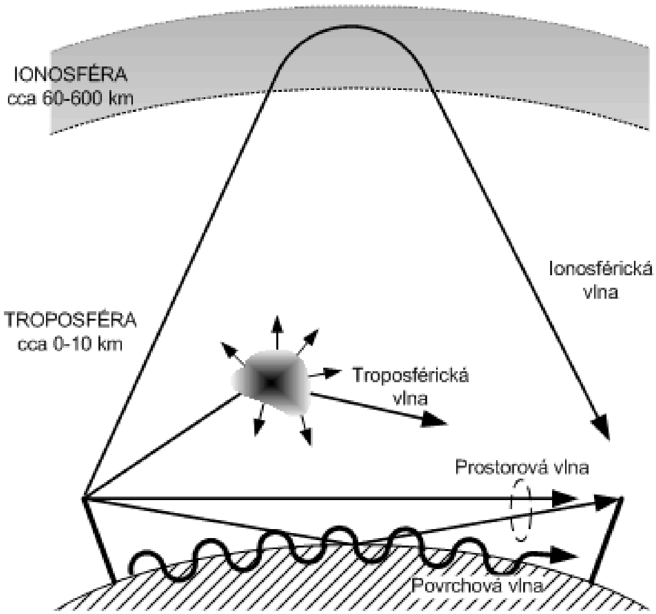
Šíření vlny v turbulentním médiu

- Troposféra = turbulentní médium
  - nerovnoměrné ohřátí zemského povrchu a povětrnostní děje = stoupající a klesající proudy a víry
  - na jednotlivých rozhraních vznikají větší či menší víry (turbulence) s odlišnou rychlostí pohybu vzdušných mas než je střední hodnota rychlosti proudu
  - => vznik malých nesourodostí (i velmi malých ~mm) s odlišnou teplotou (odlišným indexem lomu) než je střední hodnota okolí
- Důsledky na šíření rádiové vlny.
  - rozptyl (*scattering*) vlny
  - scintilace (*scintillation*)
    = rychlé kolísání amplitudy a fáze vlny
    => i deformaci vlnoplochy

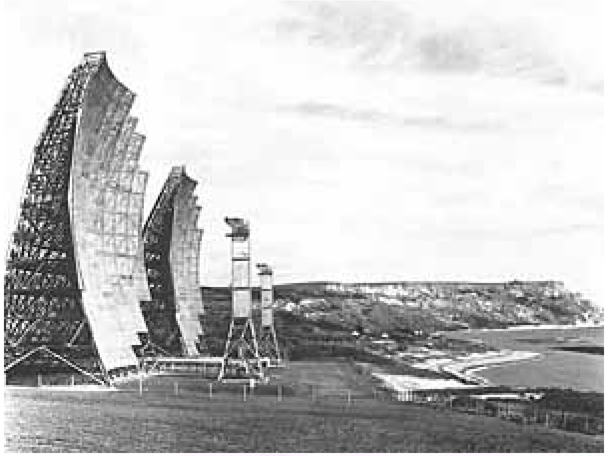


Troposférická vlna

- Jednotlivé nesourodosti ~ (kulové) částice s malým rozměrem ve srovnání s vlnovou délkou
- Rozptyl do všech směrů
  - rozptylová funkce
  - efektivní plocha odrazu
- Integrace přes celý objem
  = energii rozptýlená do daného směru
  => troposférická vlna
- Spojení za horizont; f > 30 MHz
  - (Družicový spoj)
  - (Ionosférická vlna; f < 30 MHz)
  - Anomální stavy (vlnovodný kanál, vrstva Es, rozptyl v ionosféře a na stopách meteoritů)
  - Prostorová vlna (velké ztráty difrakcí)
  - **Troposférická vlna**
    - značné ztráty šířením
      => velké vysílací výkony, ostře směrové antény, citlivé přijímače
    - spolehlivé spojení na cca 100 – 800 km; 200 MHz - 10 GHz
      (níže – problém s konstrukcí antén, výše – neúnosný útlum)
    - mechanizmus vzniku interferencí

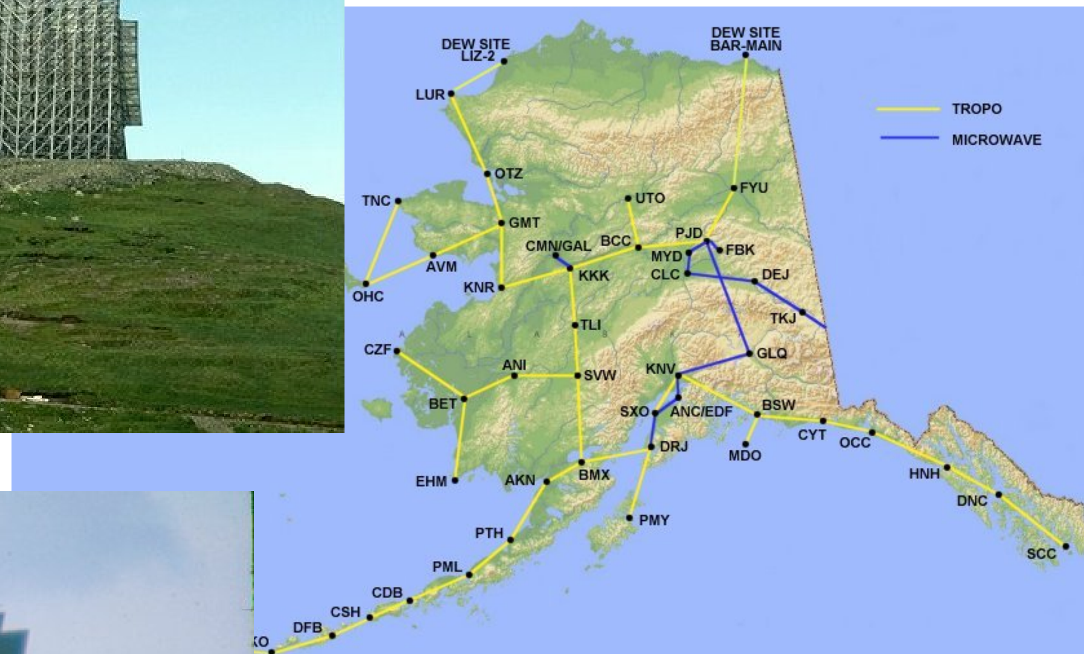


ACE High



Systém NATO 1956 – 80’
- 82 stanic
- **49 troposférických spojů**
- 40 LOS mw spojů
- frek. 832,56 – 959,28 MHz
- výkon až 10 kW

White Alice (WACS)



- Frekvence cca 900 MHz
- Prostorová a frekvenční diverzita
  (2 antény, 4 přijímače - *quad diversity*)
- Vždy pár 10, **20** nebo 40 m
  parabolických antén
- Výkon 1, **10** nebo 50 kW
  (dle délky skoku)

The World Leader in Digital Troposcatter Systems.

Troposcatter Equipment & Systems

Fixed site or transportable troposcatter systems with 16 Mbps or 4 E1 capacity over very long distances.

Microwave Equipment & Systems

Microwave terminals for line of sight applications with 34 Mbps capacity for fixed site or transportable requirements. Comtech Systems' microwave terminals are designed to complement troposcatter terminals using common equipment modules.

VSAT Equipment & Systems

Complete systems & all the components for a VSAT network chosen to meet your requirements for capacity, cost, & reliability.

Turnkey System Design

Complete telecommunication terminals, integrated, installed, & tested in electronic equipment shelters, ready to be shipped directly to sites for immediate deployment. Shelters can be provided for fixed sites or for truck mounted transportable applications.

Inter-Island Tropo Link

A troposcatter terminal on an island in the Bahamas. This tropo link is used for interisland telecommunications for a civil telecommunications application. This terminal uses a single 9 meter diameter parabolic antenna with a four port angle diversity feed horn.

Offshore Platform Troposcatter Link

An example of a Comtech Systems' supplied troposcatter link for an offshore oil platform. This link is operating in the 4400 MHz to 5000 MHz band. Tropo links for offshore platforms are typically designed for 8 Mb/sec for IP based services. Equipment is also available in the 1800-2400 MHz and 7400-7700 MHz bands.

Offshore Oil Platforms

Comtech Systems provided one of the first troposcatter systems in the North Sea for offshore oil production platforms. The example shown is off the coast of Aberdeen, Scotland, and operates in the 2 GHz band.

AN/TRC-170 Deployed

AN/TRC-170 troposcatter shelter with two antennas mounted on a transportable trailer in a typical field deployment. Comtech Systems is providing an upgrade kit for these tropo terminals to increase the bandwidth from 4 Mb/sec to 16 Mb/sec and to improve the link performance.

Fixed Site Quad Diversity Troposcatter Terminal

Example of a fixed site troposcatter system for military applications. The tropo equipment is in one truck transportable shelter for quick installation and site changes. The antennas are on tripod style masts for quick installation and site changes.

VertexRSI ISO 9001 Registered

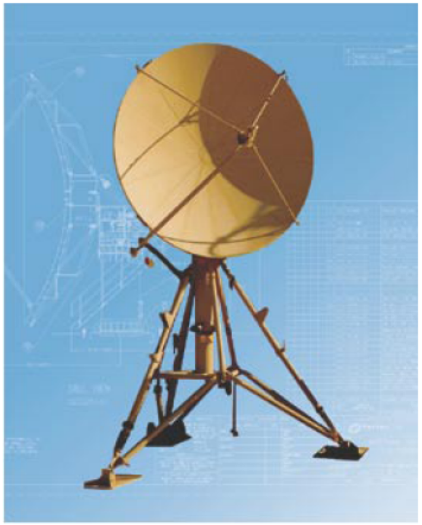
Model 2.4m OE-468/TRC Troposcatter Antenna

VertexRSI Antenna Products - Troposcatter

SATCOM Technologies has designed and produced almost three hundred 2.4-meter quick-deploy tactical antenna systems for military troposcatter and line-of-sight command and control communication. These antenna systems allowed the U.S. Marine Corps t successfully transmit field operations data via troposcatter during Operation Desert Storm.

The all-aluminum, 8-foot diameter parabolic reflector antenna has a dual linear polarized feed and is mounted on a patented collapsible tripod. It is designed to radiate and receive microwave energy as part of a line-of-sight or troposcatter communications system operating in the 4.4 to 5.0 GHz frequency range.

This compact, lightweight and rugged antenna can operate in winds up to 83 mph and survive in winds up to 120 mph. Each antenn: is packed in a lightweight transit frame and can be rapidly assembled or disassembled by two trained people in less than 20 minutes Because of its compact design, the OE-468/TRC Microwave Antenna System can be transported by a modified M116A2 trailer or other conventional flatbed trailers.



Features

- Lightweight transit frame for transportation or storage
- Operational within 20 minutes
- Transportable in M116A2 trailer
- Dual linear polarized feed

VertexRSI ISO 9001 Registered

Model 2.4m OE-468/TRC Troposcatter Antenna

Technical Specifications

*Electrical**	
Frequency (GHz)	4.4 - 5.0
Antenna Gain at 4.4 GHz, dBi	38.5
Antenna Gain at 5.0 GHz, dBi	39.5
VSWR	1.35:1
Power	5 kW CW
Sidelobe Performance (below peak)	
Between ±14°	20 dB
Between 14° and 22°	27.5 dB
All Others	30.5 dB
Isolation Between Ports	30 dB

Mechanical	
Reflector Diameter	8 ft (2.4-meter)
Set-Up Time	20 minutes by 2 trained people
Adjustment Range	
Elevation	-5° to +10°
Azimuth	±15°
Weight	1,250 lbs (570 kg)
Reflector Centerline Height	11 ft (3.4-meter)

Environmental	
Wind Loading	
Operational	23 mph (37 km/h) (no ballast or anchors)
	83 mph (133 km/h) (with ballast or anchors)
Survival	120 mph (193 km/h) (with ballast or anchors)
Temperature	-40° to +154° F (-40° to +68° C)

* Patterns available upon request.

VertexRSI
ISO 9001 Registered

Model LRF-3 9m Long Range Fixed Antenna

VertexRSI Antenna Products - Troposcatter

The VertexRSI Model LRF-3 Long Range Fixed Troposcatter Antenna (LRF-3) is used for troposcatter or high-volume microwave applications. The LRF-3 has a parabolic reflector with a diameter of 29.5 feet (9 meters).

The antenna is comprised of sixteen panels and trusses, interlocked both radially and circumferentially and interconnected at intervals with a system of diagonal braces. The assembly is terminated in the center upon a vertex hub and A-frame that is mounted on the modular steel tower. This creates a rigid, strong antenna that maintains its structural integrity and electrical performance over the broad range of specified conditions.

The process of assembly and deployment is engineered for simplicity. The reflector and feed system are assembled on the ground before being raised for attachment to the support structure.

The feed system is a dual-polarized feed that can operate in various frequency bands. The reflector is prefitted with fixture-controlled attachment points for locating the feed assembly. The position of the focal point for the feed can be restored reliably even after numerous installations and removals of the feed system. This feature also ensures that, if desired, the operating frequency band of the antenna system may be shifted by substituting another feed assembly.

Features

- Sidelobe performance meets all international and domestic specifications
- Easy assembly and deployment
- Meets TIA/EIA-222-F-1996

Options

- Additional frequency bands available
- De-iced feed
- Tower design with 7 ft (2.1 m) incremental height options

Technical Specifications

*Electrical**	
Frequency (GHz)	4.40 - 5.00
Antenna Gain at Feed Flange	
4.4 GHz	49.8 dBi
4.7 GHz	50.4 dBi
5.0 GHz	50.9 dBi
Beamwidth (in degrees at midband)	0.50
Cross Polarization Isolation (on axis)	30.0 dB
VSWR (at feed flange)	1.30:1
Power	5 kW CW
1st Sidelobe Performance	-20 dB minimum
RF Specification	975-1359

Mechanical	
Reflector Material	Aluminum
Antenna Optics	Dual polarized prime focus
Adjustment Range	
Elevation	±2°
Azimuth	±5°
Antenna and Tower Weight	16,000 lbs. (7,300 kg)
Shipping Weight	17,000 lbs. (7,700 kg)
Tower Cross Section	8 ft x 10 ft (2.4 m x 3 m)
Height to Center of Reflector (nominal)	24.6 ft (7.5 m)
Reflector RMS	0.060 in (1.5 mm)
Estimated Installation Time	5 days (3-person crew, excluding foundation)

Environmental	
Wind Loading (no ice)	
Operational	100 mph (161 km/h)
Survival	125 mph (201 km/h)
Temperature Range	+14° to +140° F (-10° to +60° C)
Atmospheric Conditions	Salt, pollutants and contaminants as encountered in coastal and industrial areas
Solar Radiation	360 BTU/h/ft² (1000 Kcal/h/m²)
Rain	4.0 in/h (100 mm/h) @ 40 mph (65 km/h) wind speed
Altitude	
Operating	10,000 ft (3,000 m)
Non-Operating	40,000 ft (12,000 m)
Sand and Dust	1.1 ± 0.3 g/m³ with wind speed 59 ft/s (18 m/s) with particle sizes ranging from 150 to 850 micrometers

* Patterns available upon request.

Troposférický spoj

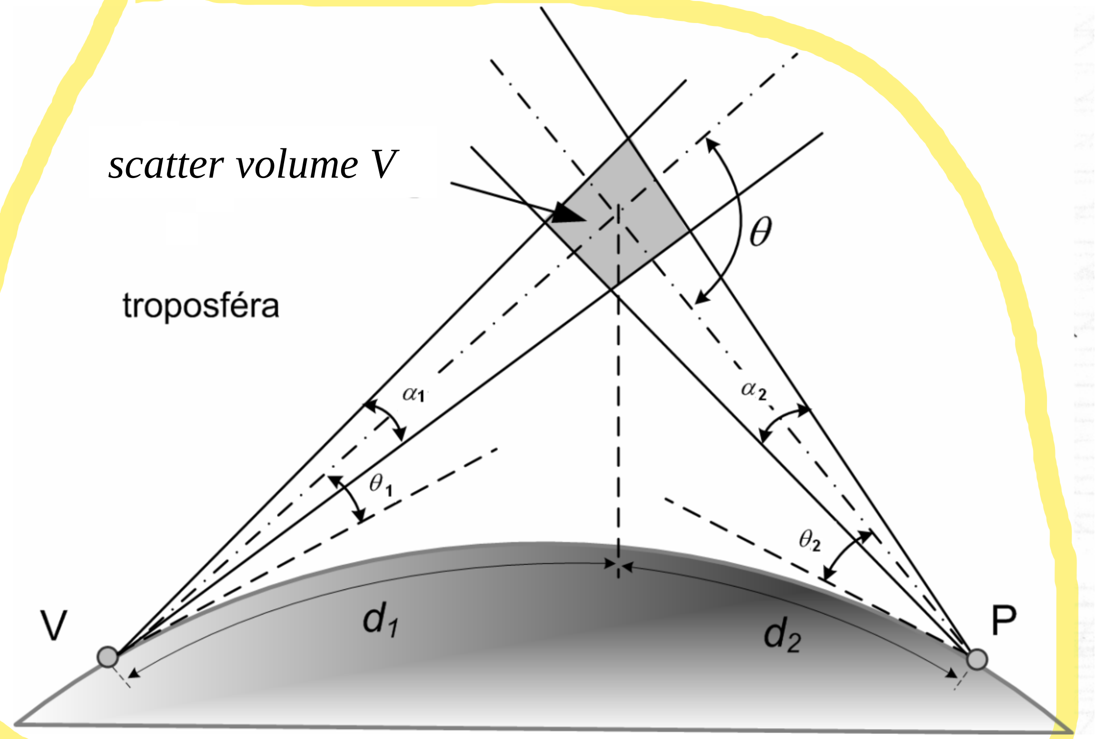
Maximální dosah (symetrický spoj)

$$d_1 = d_2 = \frac{d}{2}$$

Úhel rozptylu (*scatter angle*)

$$\theta = \theta_d + \theta_1 + \theta_2$$

úhlová vzdálenost $\theta_d = \dfrac{d}{R_e}$



maximální teoretický dosah > 800 km

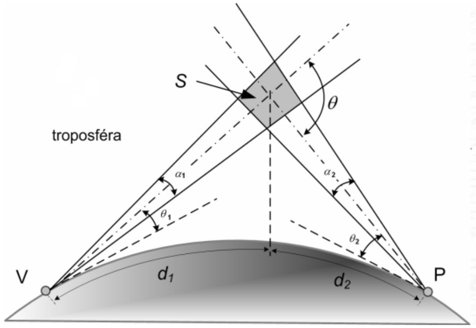
$$\theta_1 = \theta_2 = 0$$

- rozptyl v 10 km (horní hranice troposféry)

reálný dosah menší

- rozptyl v menších výškách (turbulence ubývají s výškou)
- terénní nerovnosti omezují nasměrování antén s malou elevací.

Troposférický spoj

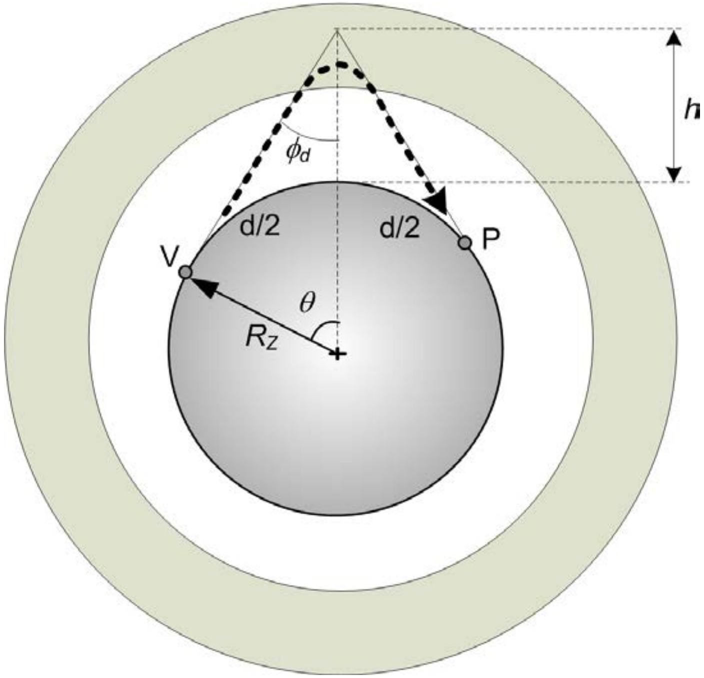


Maximální dosah (symetrický spoj)

$$d_1 = d_2 = \frac{d}{2}$$

Úhel rozptylu (*scatter angle*)

$$\theta = \theta_d + \theta_1 + \theta_2$$



úhlová vzdálenost $\theta_d = \dfrac{d}{R_e}$

maximální teoretický dosah > 800 km

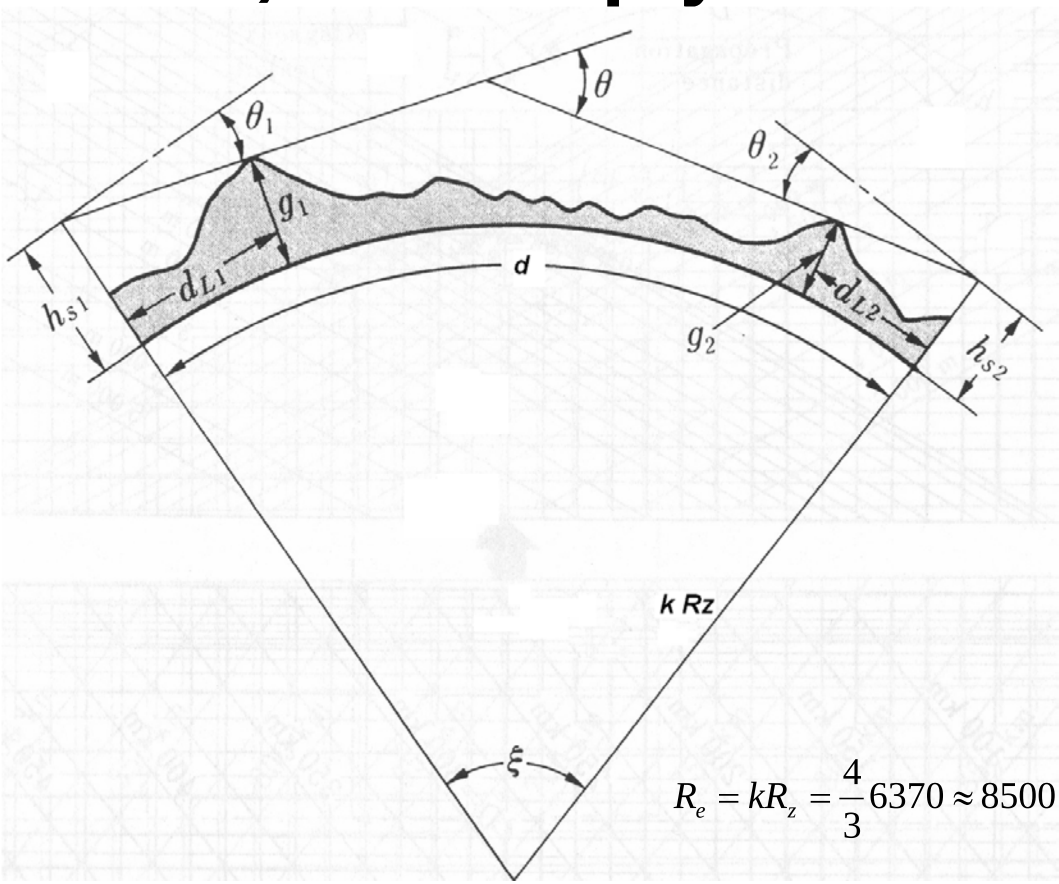
$$\theta_1 = \theta_2 = 0$$

- Nulové elevace
- rozptyl v 10 km (horní hranice troposféry)

$$d_{\max} = 2R_Z \arccos \frac{R_Z}{R_Z + h} =$$

$$= 2 \cdot 8500 \arccos \frac{8500}{8500 + 10} = 824 \text{ km}$$

Elevace, úhel rozptylu



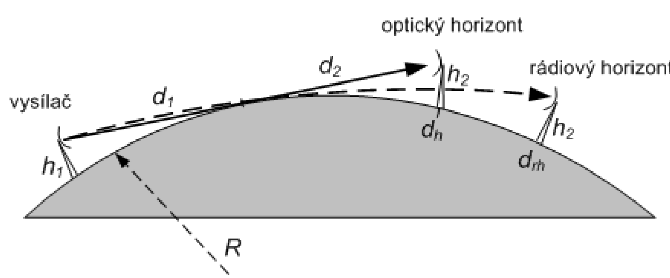
$$\theta_1 = -\left(\frac{h_{s1} - g_1}{d_{L1}} + \frac{d_{L1}}{2kR_z} \right)$$

$$\theta_2 = -\left(\frac{h_{s2} - g_2}{d_{L2}} + \frac{d_{L2}}{2R_e} \right)$$

$$\theta = \frac{d}{R_e} + \theta_1 + \theta_2$$

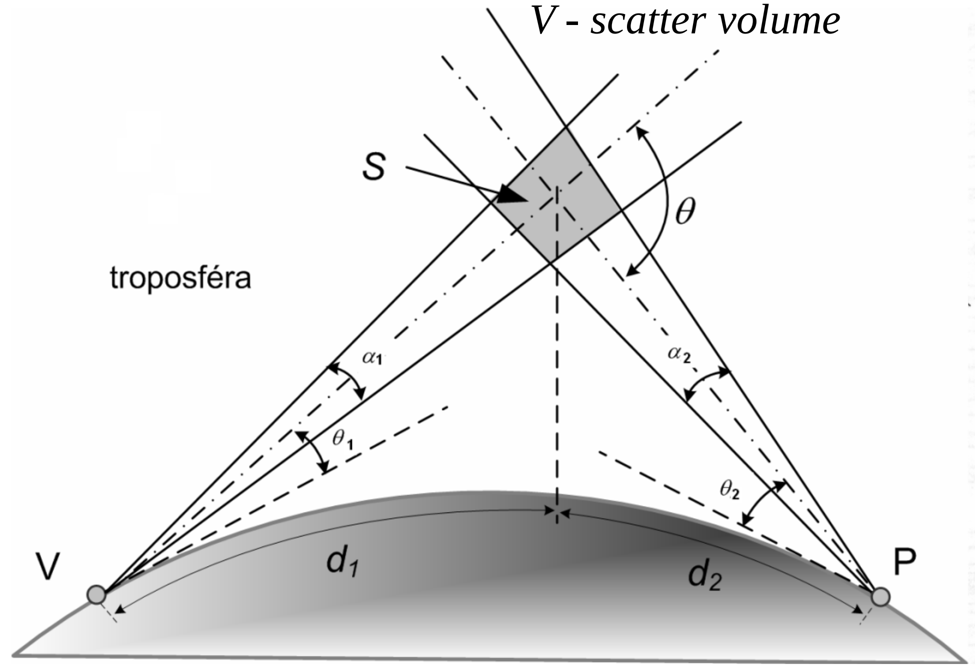
$$R_e = kR_z = \frac{4}{3} 6370 \approx 8500 \text{ km}$$

Pro hladkou kulovou Zemi:
$g_1 = g_2 = 0$
$d_{L1,2}$ = optický horizont



$$d_1 = \sqrt{(R + h_1)^2 - R^2} \approx \sqrt{2Rh_1}$$

Troposférický spoj



$$d_1 = d_2 = \frac{d}{2}$$

$$\theta_1 = \theta_2 = 0 \qquad \theta = \theta_d = \frac{d}{R_e}$$

Stejné antény

- α_V a α_H šířky sv. ve vertik. a horiz. směru

Objem V rozhodující pro rozptyl
= rovnoběžnostěn

- základna S = průnik anténních svazků (a – délka strany) $a = \dfrac{\frac{d}{2}\alpha_V}{\sin\theta}$
- výška v daná horizontální šířkou svazků antén $v = \frac{d}{2}\alpha_H$

$$\sin\theta \approx \frac{d}{R_e} \quad => \quad a \approx \frac{\alpha_V R_e}{2} \quad => \quad S = a^2 \sin\theta \approx \left(\frac{\alpha_V R_e}{2}\right)^2 \frac{d}{R_e}$$

$$V = Sv = \left(\frac{\alpha_V R_e}{2}\right)^2 \frac{d}{R_e}\frac{d}{2}\alpha_H = \frac{d^2 \alpha_V^2 \alpha_H R_e}{8}$$

$$\sigma = \sigma_V V = \sigma_V \frac{d^2 \alpha_V^2 \alpha_H R_e}{8}$$

σ - efektivní plocha odrazu v m^2

σ_V - měrná efektivní plocha odrazu na jednotku objemu v m^{-1} (získaná např. experimentálně).

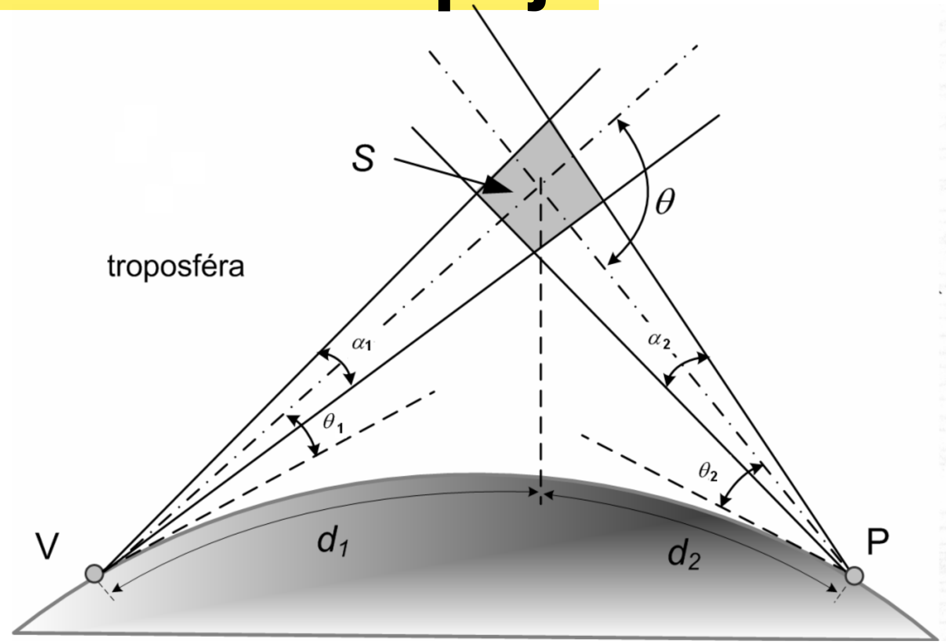
Výkonová bilance troposférického spoje

Výkonová hustota dopadající na objem V

$$w_1 = \frac{P_V G_V}{4\pi d_1^2}$$

Výkonová hustota odražené vlny v místě příjmu

$$w_2 = \frac{w_1 V \sigma_V}{4\pi d_2^2} = \frac{P_V G_V V \sigma_V}{16\pi^2 d_1^2 d_2^2}$$



Přijatý výkon (radiolokační rovnice)

$$P_P = \frac{\lambda^2}{4\pi} G_p w_2 = \frac{\lambda^2 P_V G_V G_P V \sigma_V}{64\pi^3 d_1^2 d_2^2}$$

Pro $G = G_P = G_V$ a $d_1 = d_2 = d/2$: $\dfrac{P_P}{P_V} = \dfrac{\lambda^2 G^2 V \sigma_V}{4\pi^3 d^4}$

$$V = \frac{d^2 \alpha_V^2 \alpha_H R_e}{8} \quad \Uparrow$$

$$\frac{P_P}{P_V} = \frac{\lambda^2 G^2}{4\pi^3 d^4} \frac{d^2 \alpha_V^2 \alpha_H R_e}{8} \sigma_V = \frac{\lambda^2 G^2 \alpha_V^2 \alpha_H R_e}{32\pi^3 d^2} \sigma_V$$

Pro parabolické antény je přibližně $\alpha_V = \alpha_H = \sqrt{\dfrac{2\pi}{G}}$ => $\dfrac{P_P}{P_V} = \dfrac{\lambda^2 \sqrt{2\pi G} R_e}{16\pi^2 d^2} \sigma_V$

Empirický model mediánu ztrát šířením

$$L = 135{,}8 + 30\log(f) + 30\log(\theta) + 10\log d + 0{,}34\theta d$$

θ v rad
frekvence f v MHz
d vzdálenost v km

Podmínky platnosti:
v nulové nm.výšce uprostřed trasy: N = 301 N.

$$\theta d < 10$$

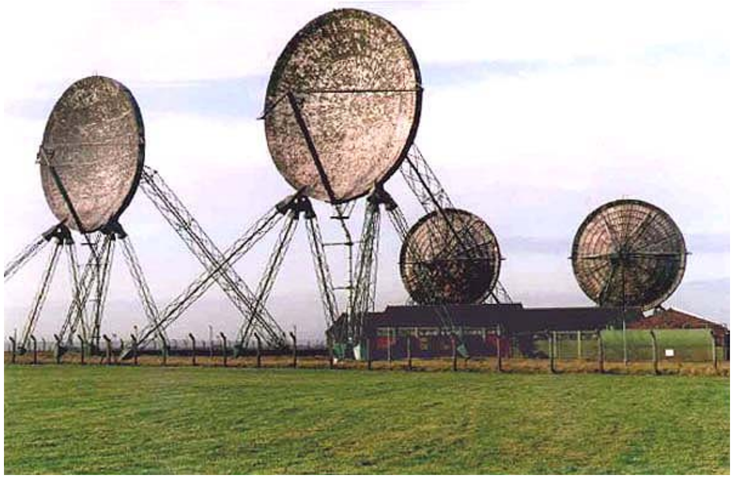
- Průměrné ztráty v jednotlivých měsících se podle klimatu a konkrétní konfigurace mohou lišit i až o 15 – 20 dB
- Rozdíly mezi zimou/létem obvykle 2 – 10 dB
- Kolísání průměrných ztát během dne až 5 – 15 dB

NBS Technical Note 101 (Revised). National Institute of Standards and Technology, USA, 1967

Úniky

- Pomalé i rychlé úniky
  - Např. na 2 GHz pozorováno 20 – 30 úniků/min
  - Frekvenční závislost úniků omezuje šířku pásma
  - Pro 5 min. interval Rayleighovo rozložení úniků
  - Pro interval > 1 hod. Logaritmicko-normální rozložení

- Diverzita
  - Prostorová
  - Frekvenční
  - Úhlová



  - *Polarizační nelze použít*

RECOMMENDATION ITU-R P.617-1*

PROPAGATION PREDICTION TECHNIQUES AND DATA REQUIRED FOR THE DESIGN OF TRANS-HORIZON RADIO-RELAY SYSTEMS

(Question ITU-R 205/3)

(1986-1992)

The ITU Radiocommunication Assembly,

considering

a) that for the proper planning of trans-horizon radio-relay systems it is necessary to have appropriate propagation prediction methods and data;

b) that methods have been developed that allow the prediction of most of the important propagation parameters affecting the planning of trans-horizon radio-relay systems;

c) that as far as possible these methods have been tested against available measured data and have been shown to yield an accuracy that is both compatible with the natural variability of propagation phenomena and adequate for most present applications in system planning,

recommends

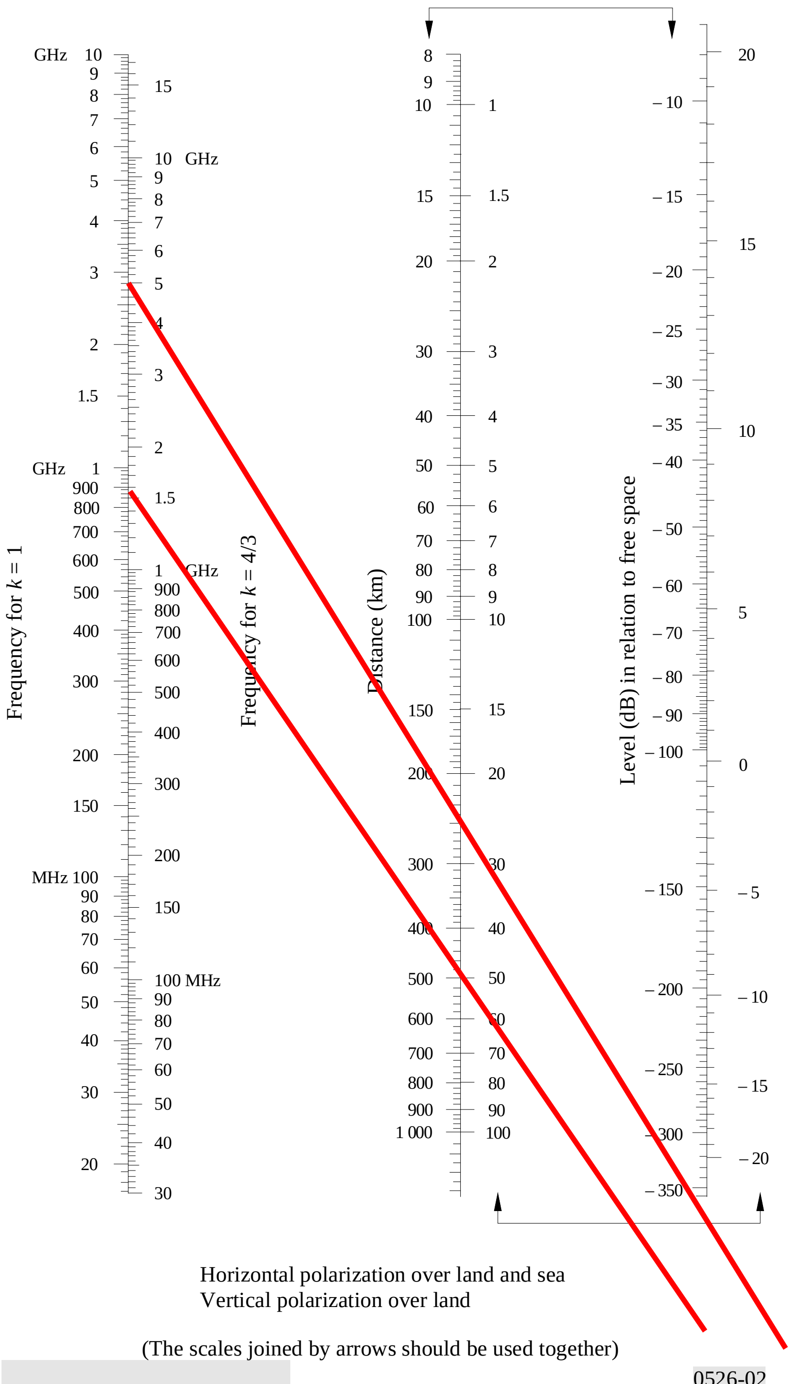
that the prediction methods and other techniques set out in Annex 1 be adopted for planning trans-horizon radio-relay systems in the respective ranges of parameters indicated.

• • •

3.1 Average annual median transmission loss distribution for time percentages greater than 50%

The following step-by-step procedure is recommended for estimating the average annual median transmission loss $L(q)$ not exceeded for percentages of the time q greater than 50%. The procedure requires the link parameters of great-circle path length d (km), frequency f (MHz), transmitting antenna gain G_t (dB), receiving antenna gain G_r (dB), horizon angle θ_t (mrad) at the transmitter, and horizon angle θ_r (mrad) at the receiver:

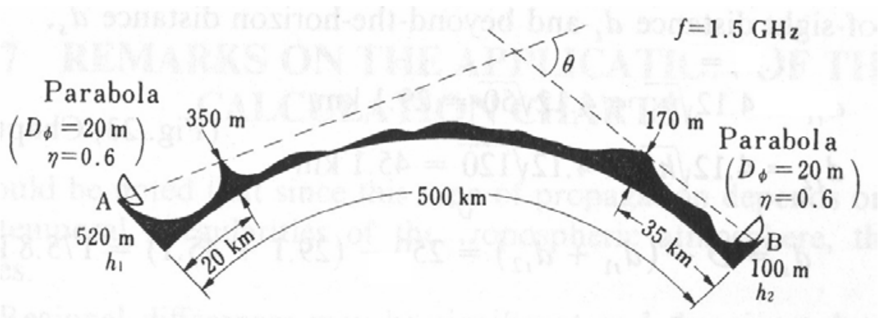
Diffraction by a spherical earth – effect of distance



Porovnání s příklady troposférického spoje

- f = 5 GHz
- d = 250 km
- h = 6 m

- L = 229 dB



- L = 236 dB

Další způsoby šíření vln

- Další způsoby šíření vln
  - Vlnovod Země-Ionosféra
  - Šíření pod vodou
  - Odrazy od stop meteorů
  - Šíření v tunelech
  - …