Základní osnova přednášek

- Úvod a sjednocení pojmů
- Mechanizmy šíření elmag vln v atmosféře a základní postupy pro:
  - I. Návrh pevného směrového spoje
  - II. Plánování pokrytí mobilního spoje
  - III. Analýzu rušení pevného spoje
  - IV. Výpočet výkonové bilance družicového spoje
  - V. Návrh HF spoje
  - VI. Návrh LF/MF spoje
  - VII. Návrh bezdrátového optického spoje
  - VIII. Návrh troposférického a dalších typů spojení
- V rámci projektů
  - Návrh radioreléového spoje dle doporučení ITU-R P.530
  - Měření pomalých a rychlých úniků mobilního spoje

Frekvenční spektrum

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

Označení frekvenčních pásem pro rádiový přenos
dle ČSN IEC 60050-713 a ITU-R V.431

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CPM19-2

Second session of the 2019 Conference Preparatory Meeting (CPM19-2)

18-28 FEBRUARY 2019 GENEVA, SWITZERLAND

Entities | Highlights | Free Resources | FAQs

- World Radiocommunication Conferences (WRC)
- Radiocommunication Assemblies (RA)
- Regional Radiocommunication Conferences (RRC)
- Radio Regulations Board (RRB)
- Radiocommunication Study Groups
- Radiocommunication Advisory Group (RAG)

Space Services

BRIFIC | SNL | SNS | Space Plans

International coordination, notification and recording

Terrestrial Services

BRIFIC | GLAD | MARS | WISFAT

International coordination, notification and recording

Events | Conferences & Meetings | Seminars & Workshops

CPM19-2 - Confirmed
2019-02-18 - 2019-02-28 GENEVA, SWITZERLAND

RRB-19.1 - Confirmed
2019-03-18 - 2019-03-22 GENEVA, SWITZERLAND

WP 6C - Confirmed
2019-03-25 - 2019-03-29 GENEVA, SWITZERLAND

WP 6A - Confirmed
2019-03-26 - 2019-04-03 GENEVA, SWITZERLAND

WP 6B - Confirmed
2019-04-01 - 2019-04-04 GENEVA, SWITZERLAND

1 - 5

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The ITU-R Study Groups

The ITU-R Study Groups develop the technical bases for decisions taken at World Radiocommunication Conferences and develop global standards (Recommendations), Reports and Handbooks on radiocommunication matters. More than 5 000 specialists, from administrations, the telecommunications industry as a whole and academic organizations throughout the world, participate in the work of the Study Groups on topics such as efficient management and use of the spectrum/orbit resource, radio systems characteristics and performance, spectrum monitoring and emergency radiocommunications for public protection and disaster relief.

More >

Study Groups

- **Study Group 1 (SG 1) Spectrum management**
- **Study Group 3 (SG 3) Radiowave propagation**
- **Study Group 4 (SG 4) Satellite services**
- **Study Group 5 (SG 5) Terrestrial services**
- **Study Group 6 (SG 6) Broadcasting service**
- **Study Group 7 (SG 7) Science services**

Related Groups

- **Coordination Committee for Vocabulary (CCV)**
- **Conference Preparatory Meeting (CPM)**
- ***Disbanded Groups***

Meetings and Events | Related Meetings | Highlights

- ITU-R Meeting schedule - Meeting sessions
- ITU-R Event Registration and Practical Information
- CCIR/ITU-R Study Groups 90th anniversary
- 90th Anniversary of CCIR/ITU-R Study Groups and 45th Anniversary of digital TV/HDTV studies, Geneva, ITU, Room Popov, 3 October 2017, 16:45-18:00 hours

References | Related ITU-R Texts | Circulars

- Radio Regulations
- Working methods (Resolution ITU-R 1)
- Guidelines for the working methods
- Format of ITU-R Recommendations
- ITU Style Guides
- ITU Terms and Definitions Database
- Structure of Radiocommunication Study Groups (Resolution ITU-R 4)
- Liaison and collaboration with other relevant organizations (Resolution ITU-R 9)

Contacts | Intellectual Property Rights

Study Group 3 (SG 3)

Radiowave Propagation

Propagation of radio waves in ionized and non-ionized media and the characteristics of radio noise, for the purpose of improving radiocommunication systems.

More >

Structure

- **Working Party 3J (WP 3J) - Propagation fundamentals**
- **Working Party 3K (WP 3K) - Point-to-area propagation**
- **Working Party 3L (WP 3L) - Ionospheric propagation and radio noise**
- **Working Party 3M (WP 3M) - Point-to-point and Earth-space propagation**

Next meeting

- Friday 2019-05-24
- Place : **Switzerland [Geneva]**
- Status : **Confirmed** - Add to Calendar
- Invitation
- List of Registered Participants TIES
- Registration
- SG3 meetings Sharepoint site TIES
- Contributions submission: rsg3@itu.int
- Meeting sessions
- Captioning TIES ***New***
- Webcast TIES

Documents

- Contributions "as received" TIES
- Contributions TIES - Template
- Study Group 3 Summary Record TIES (Meeting: 2017-09-01)
- Administrative Documents (ADM) TIES
- Information Documents (INFO) TIES
- Temporary Documents (DT)
- Informal documents on Sharepoint TIES
- ITU-R Documents Search Tool
- **ITU-R Study Group Sync Applications**
- Status of texts
- Circular Letters (LCCE)
- Administrative Circulars (CA)
- Administrative Circulars (CACE)

Meetings and Events | Related activities | Highlights

- ITU-R Meeting schedule
- Meeting sessions
- ITU-R Event Registration and Practical Information
- SG 3 Workshop: Overview and Activities
- CCIR/ITU-R Study Groups 90th anniversary

References | Related ITU-R Texts | Circulars

- Radio Regulations
- Working methods (Resolution ITU-R 1)
- Guidelines for the working methods
- Format of ITU-R Recommendations
- ITU Style Guides
- ITU Terms and Definitions Database
- Structure of Radiocommunication Study Groups (Resolution ITU-R 4)
- Liaison and collaboration with other relevant organizations (Resolution ITU-R 9)

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- SG 3 Chairman and Vice-Chairmen
- SG 3 Working Party Chairmen and Vice-Chairmen
- Counsellor for SG 3

ITU-R Recommendations

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The ITU-R Recommendations constitute a set of international technical standards developed by the Radiocommunication Sector (formerly CCIR) of the ITU. They are the result of studies undertaken by Radiocommunication Study Groups on:

- the use of a vast range of wireless services, including popular new mobile communication technologies:
- the management of the radio-frequency spectrum and satellite orbits;
- the efficient use of the radio-frequency spectrum by all radiocommunication services ;
- terrestrial and satellite radiocommunication broadcasting;
- radiowave propagation;
- systems and networks for the fixed-satellite service, for the fixed service and the mobile service;
- space operation, Earth exploration-satellite, meteorological-satellite and radio astronomy services.

The ITU-R Recommendations are approved by ITU Member States. Their implementation is not mandatory; however, as they are developed by experts from administrations, operators, the industry and other organizations dealing with radiocommunication matters from all over the world, they enjoy a high reputation and are implemented worldwide.

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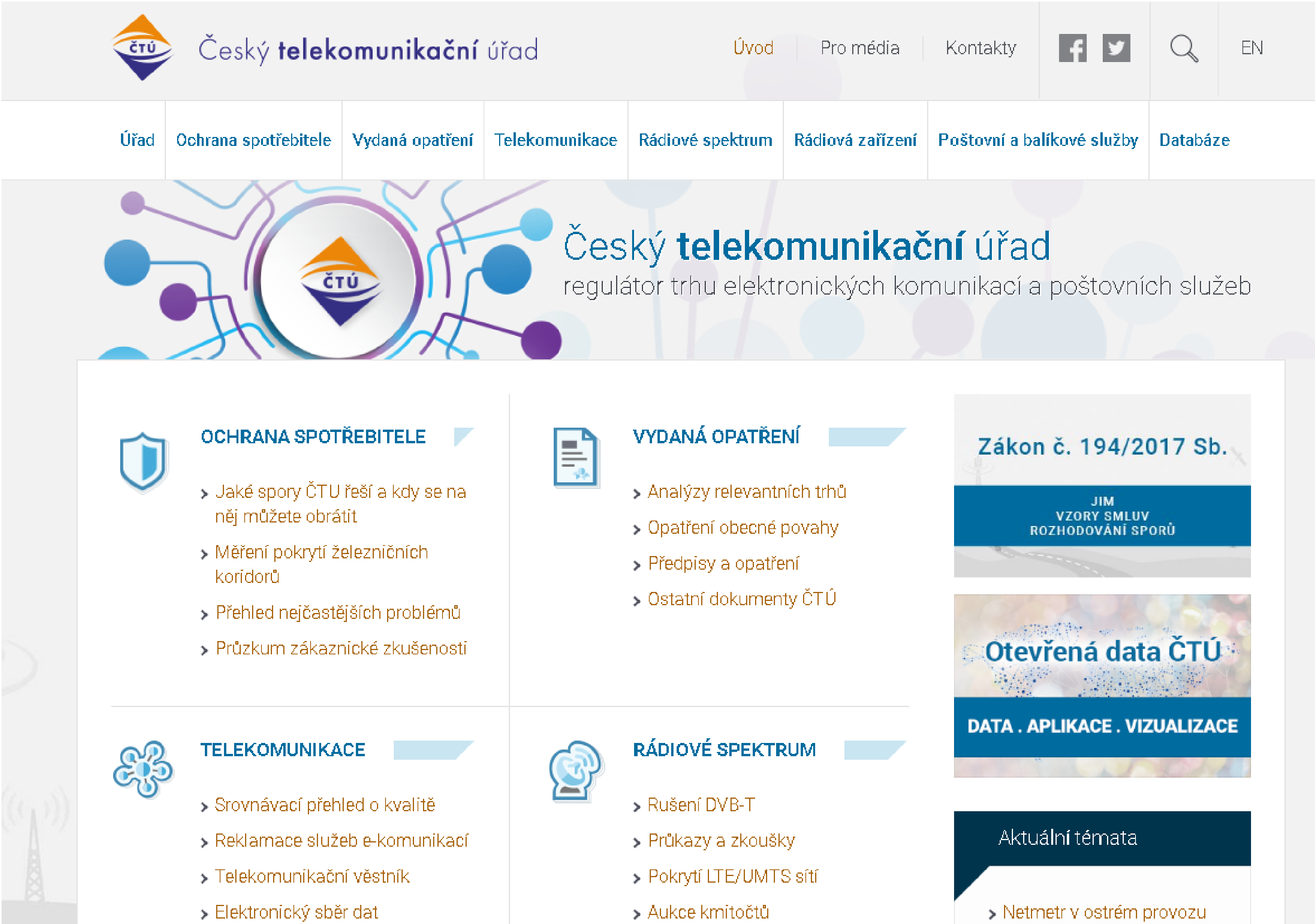
Individual Recommendations (Direct download)	
BO	Satellite delivery
BR	Recording for production, archival and play-out; film for television
BS	Broadcasting service (sound)
BT	Broadcasting service (television)
F	Fixed service
M	Mobile, radiodetermination, amateur and related satellite services
P	Radiowave propagation
RA	Radio astronomy
RS	Remote sensing systems
S	Fixed-satellite service
SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management
SNG	Satellite news gathering
TF	Time signals and frequency standards emissions

Radiowave propagation

XML RSS Feed ?

P.310	Definitions of terms relating to propagation in non-ionized media
P.311	Acquisition, presentation and analysis of data in studies of tropospheric propagation
P.313	Exchange of information for short-term forecasts and transmission of ionospheric disturbance warnings
P.341	The concept of transmission loss for radio links
P.368	Ground-wave propagation curves for frequencies between 10 kHz and 30 MHz
P.369	Reference atmosphere for refraction Note - Suppressed on 24/10/97 (RA-97) - This Recommendation has been replaced by Rec. ITU-R P.453-6
P.370	VHF and UHF propagation curves for the frequency range from 30 MHz to 1 000 MHz. Broadcasting services Note - Suppressed on 22/10/01 (CACE/233)
P.371	Choice of indices for long-term ionospheric predictions
P.372	Radio noise
P.373	Definitions of maximum and minimum transmission frequencies
P.434	ITU-R reference ionospheric characteristics and methods of basic MUF, operational MUF and ray-path prediction Note – Suppressed on 24/10/97 (RA-97)
P.435	Sky-wave field-strength prediction method for the broadcasting service in the frequency range 150 to 1600 kHz Note - Suppressed on 20/10/95 (RA-95)
P.452	Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz
P.453	The radio refractive index: its formula and refractivity data Note - This Recommendation replaces Rec. ITU-R P.369-6
P.525	Calculation of free-space attenuation
P.526	Propagation by diffraction
P.527	Electrical characteristics of the surface of the Earth

ČTÚ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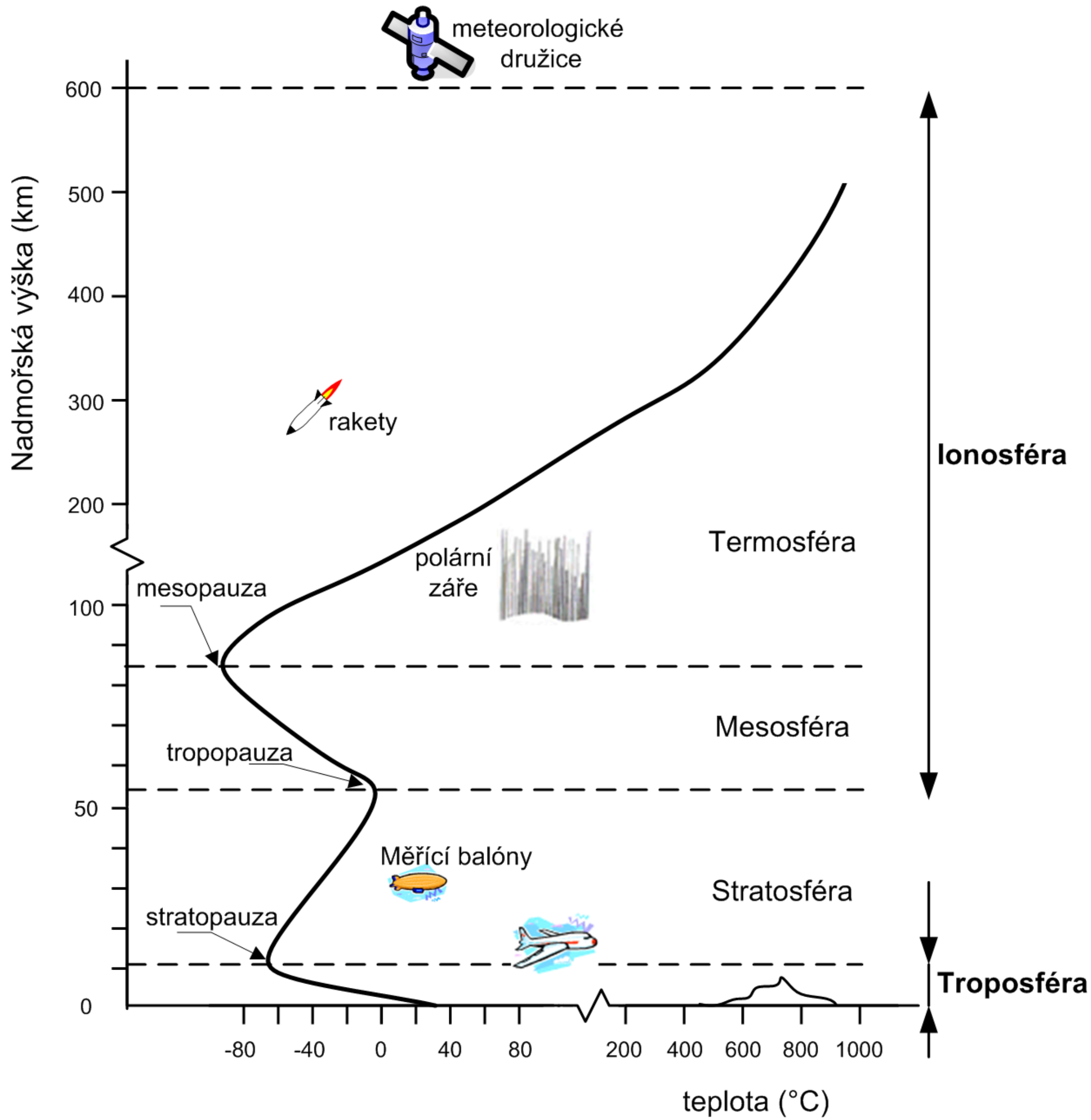
Elektronický sběr dat
RÁDIOVÉ SPEKTRUM
Rušení DVB-T
Průkazy a zkoušky
Pokrytí LTE/UMTS sítí
Aukce kmitočtů
Aktuální témata
Netmetr v ostrém provozu

Radiokomunikační služby a modely „šíření“

- Základní radiokomunikační služby
  - Pevná služba (pevný spoj „bod-bod“) - radiokomunikační služba mezi stanovenými pevnými body (pozemními rádiovými stanicemi).
  - Pozemní pohyblivá službu (mobilní spoj) - služba mezi základnovými stanicemi a pozemními pohyblivými stanicemi nebo mezi pozemními pohyblivými stanicemi navzájem.
  - Rozhlasová službu (spoj „bod-plocha“) - radiokomunikační služba, jejíž vysílání jsou určena k přímému příjmu širokou veřejností (rozhlas, televize, aj.).
  - Družicové služby – pevná, pohyblivá, rozhlasová
- => geometrie spoje

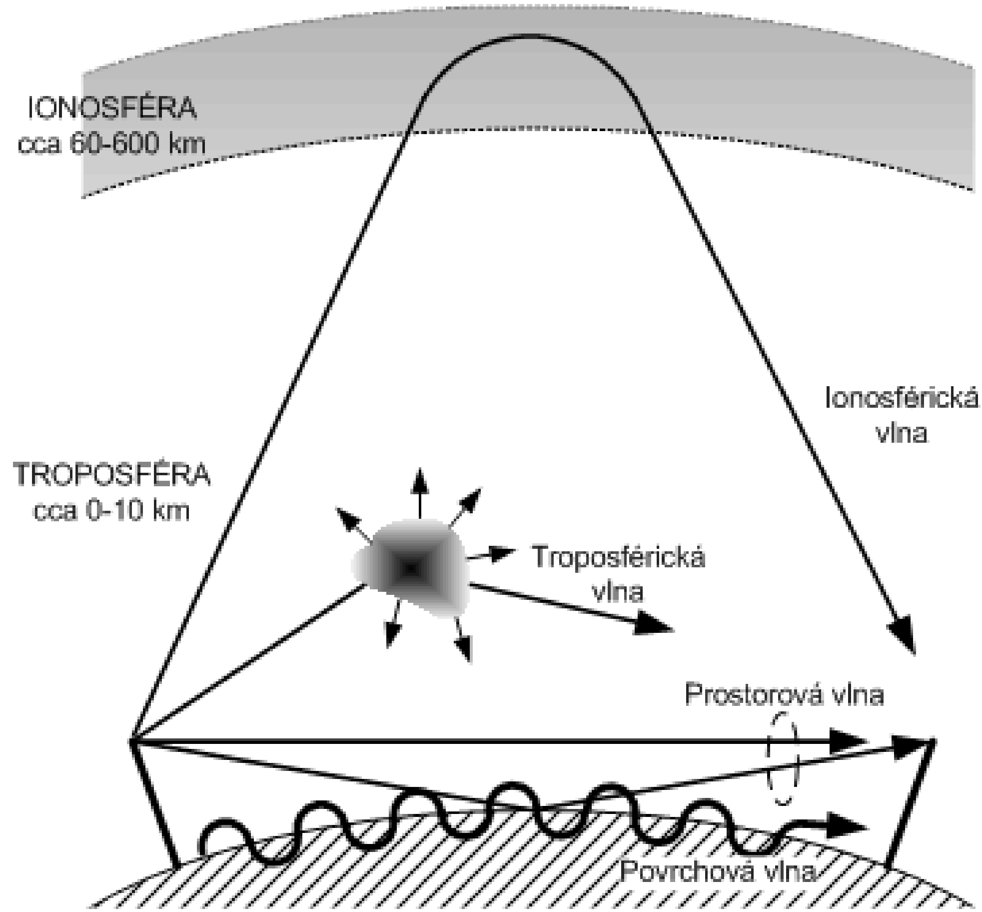
- Z hlediska mechanismů šíření signálu jsou zásadní
  - frekvence
  - geometrie/prostředí
  - antény
- Z hlediska modelování/predikce šíření dále
  - typ signálu (užitečný/rušivý)
  - typ služby (požadovaná kvalita a spolehlivost)

Zemská atmosféra



Způsoby šíření vln pro pozemní rádiové spoje

- Přízemní povrchová vlna
  ground wave – surface w.
- Přízemní prostorová vlna
  ground wave – space w.
- (šíření vlnovodným kanálem – *ducting*)
- Troposférická vlna
  tropospheric wave
- Ionosférická vlna
  sky wave, ionospheric w.
- …



Parametry prostředí

- Prostředí s nenulovou vodivostí

$$\varepsilon_{\mathrm{kr}} = \varepsilon_{\mathrm{r}} - \mathrm{j}\frac{\sigma}{\omega\varepsilon_0} = \varepsilon_{\mathrm{r}} - \mathrm{j}60\lambda\sigma$$

$$\alpha = \omega\sqrt{\frac{\mu\varepsilon}{2}\left(\sqrt{1+\left(\frac{\sigma}{\omega\varepsilon}\right)^2}-1\right)}$$

$$\mathbf{k} = \beta - \mathrm{j}\alpha = \sqrt{-\mathrm{j}\omega\mu\left(\mathrm{j}\omega\varepsilon + \sigma\right)}$$

$$\beta = \omega\sqrt{\frac{\mu\varepsilon}{2}\left(\sqrt{1+\left(\frac{\sigma}{\omega\varepsilon}\right)^2}+1\right)}$$

$$n_k = n - \mathrm{j}\,p = \sqrt{\varepsilon_{kr}} = \sqrt{\varepsilon_r - j\frac{\sigma}{\omega\varepsilon_0}}$$

$$n = \frac{c}{v} = \sqrt{\frac{1}{2}\left(\varepsilon_{\mathrm{r}} + \sqrt{\varepsilon_{\mathrm{r}}^2 + \left(60\lambda\sigma\right)^2}\right)}$$

$$p = \sqrt{\frac{1}{2}\left(-\varepsilon_{\mathrm{r}} + \sqrt{\varepsilon_{\mathrm{r}}^2 + \left(60\lambda\sigma\right)^2}\right)}$$

Ideální dielektrikum (bezeztrátové prostředí)

$$\alpha = 0$$

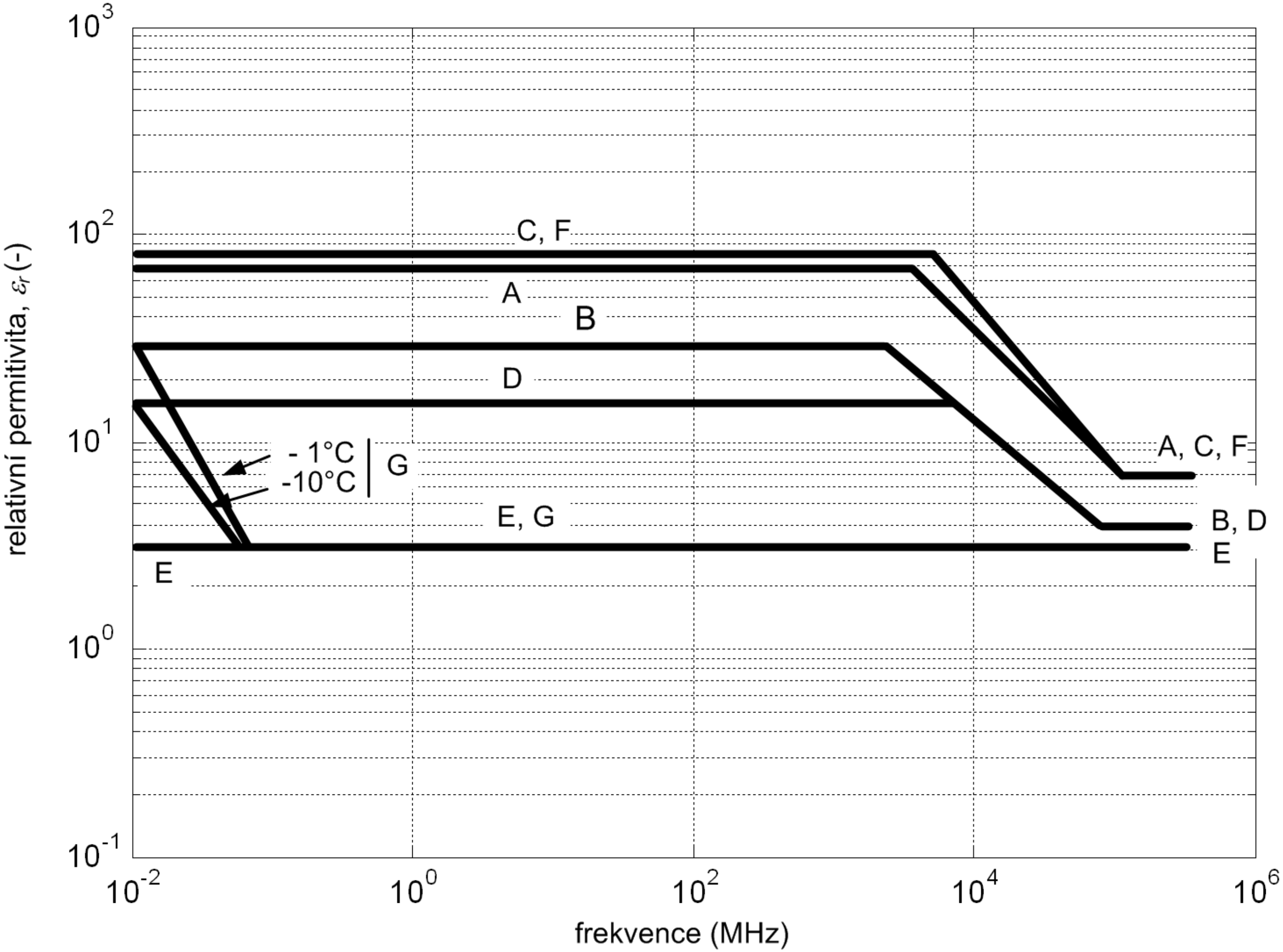
$$\lambda = \frac{2\pi}{\beta} = \frac{c}{f}\frac{1}{\sqrt{\varepsilon_r}} = \frac{c}{f}\frac{1}{n}$$

$$\mathbf{k} = \beta = \omega\sqrt{\mu\varepsilon} = \frac{\omega}{c}\sqrt{\varepsilon_r} = \frac{\omega}{c}n$$

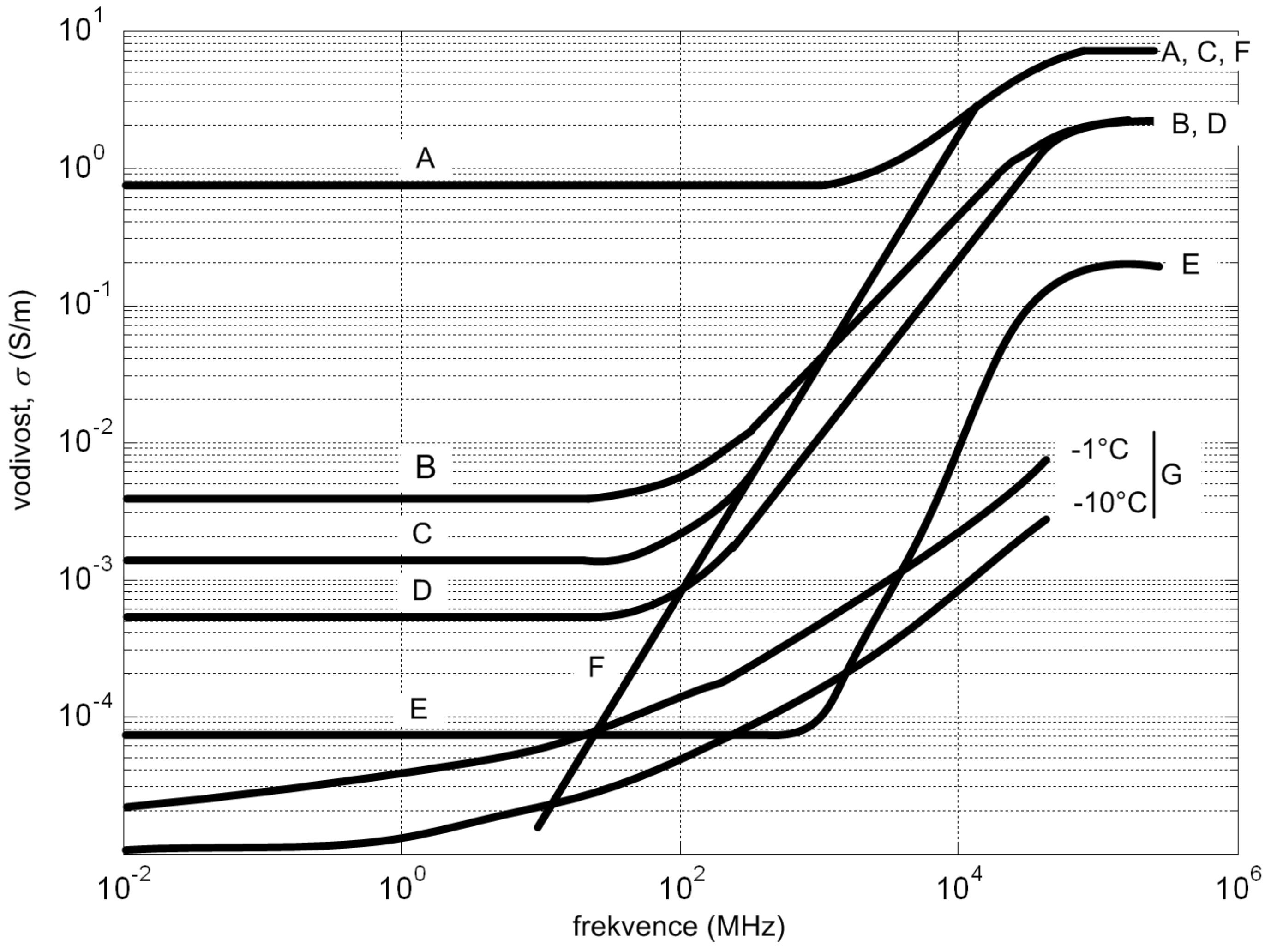
$$Z = \sqrt{\frac{\mu}{\varepsilon}}$$

$$n = \sqrt{\varepsilon_r}$$

Frekvenční závislost rel. permitivity různých povrchů A – mořská voda, B – vlhká zem, C – voda, D – středně suchá půda, E – velmi suchá půda, F – dest. voda, G – led (podle ITU-R P.527)



Frekvenční závislost vodivosti různých povrchů A – mořská voda, B – vlhká zem, C – voda, D – středně suchá půda, E – velmi suchá půda, F – destil. voda, G – led (podle ITU-R P.527)



Světový atlas vodivostí země (ITU-R P.832)

efektivní vodivost země v mS/m; VLF (do 30 kHz), MF (1 MHz)

FIGURE 6

Europe

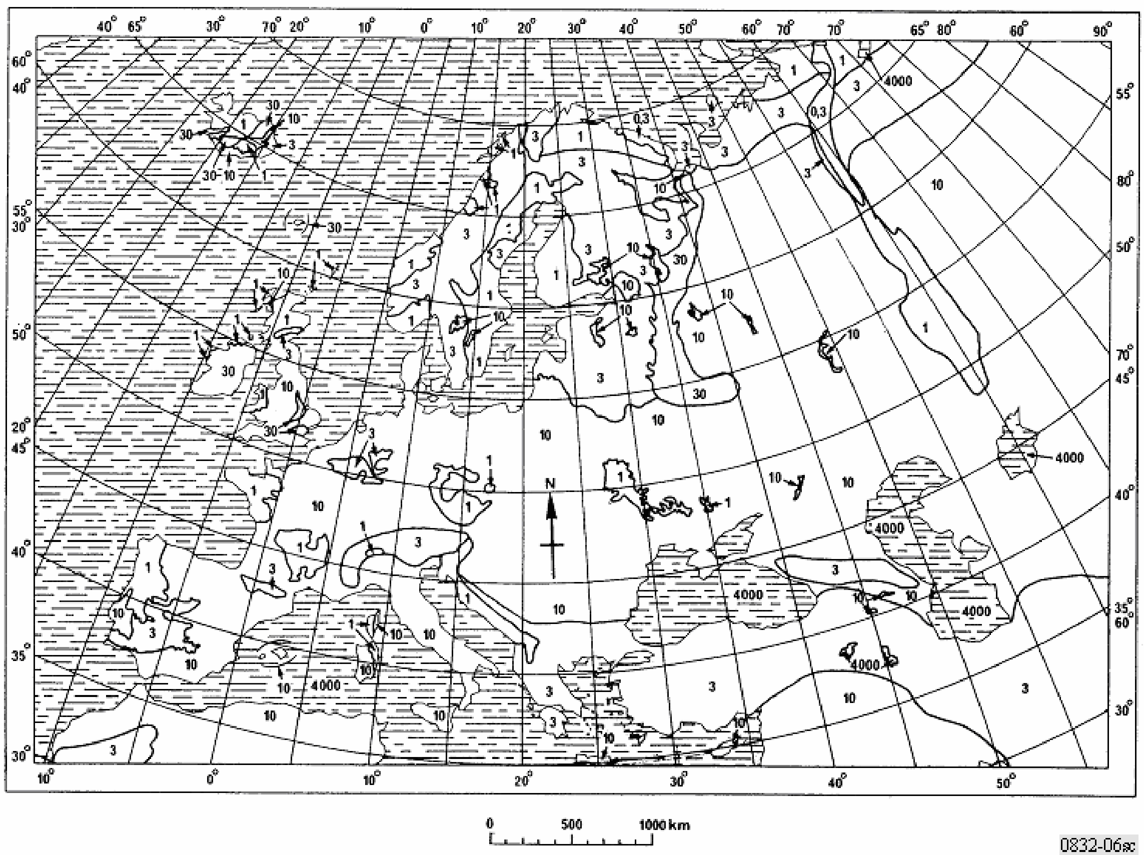
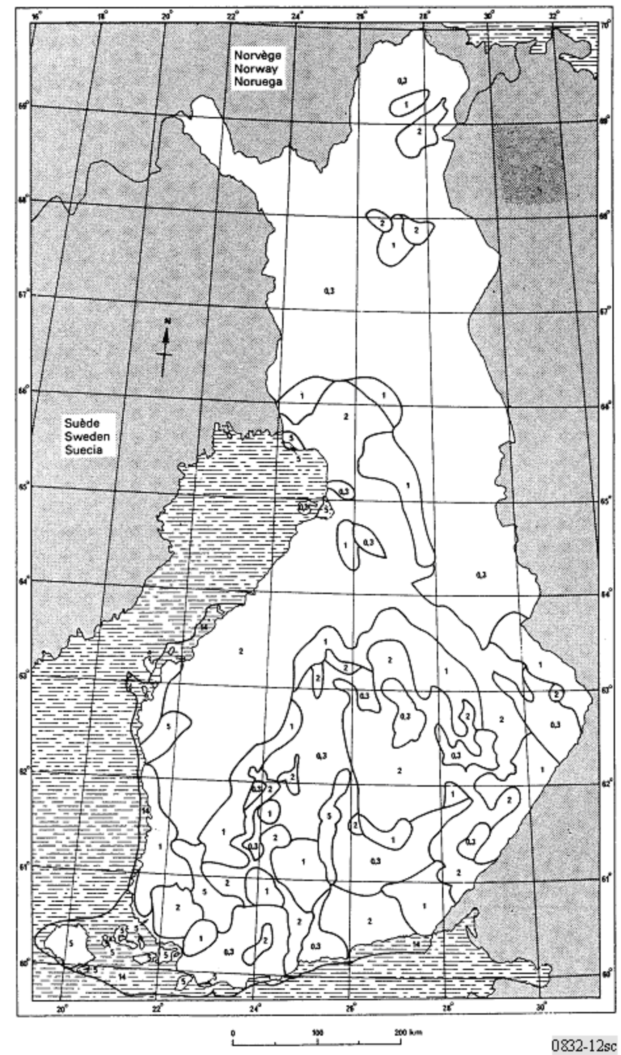


FIGURE 12

Finland

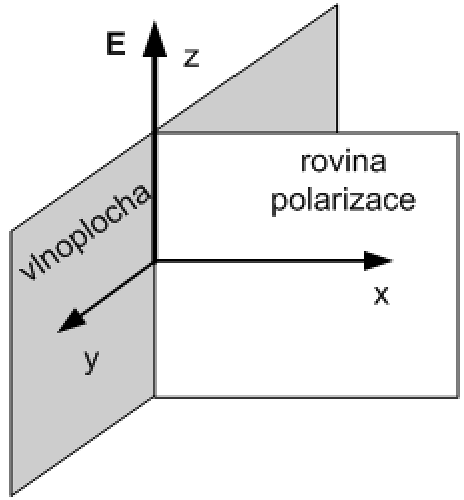


Komplexní permitivita stavebních materiálů pro 1 GHz (ITU-R P.1238)

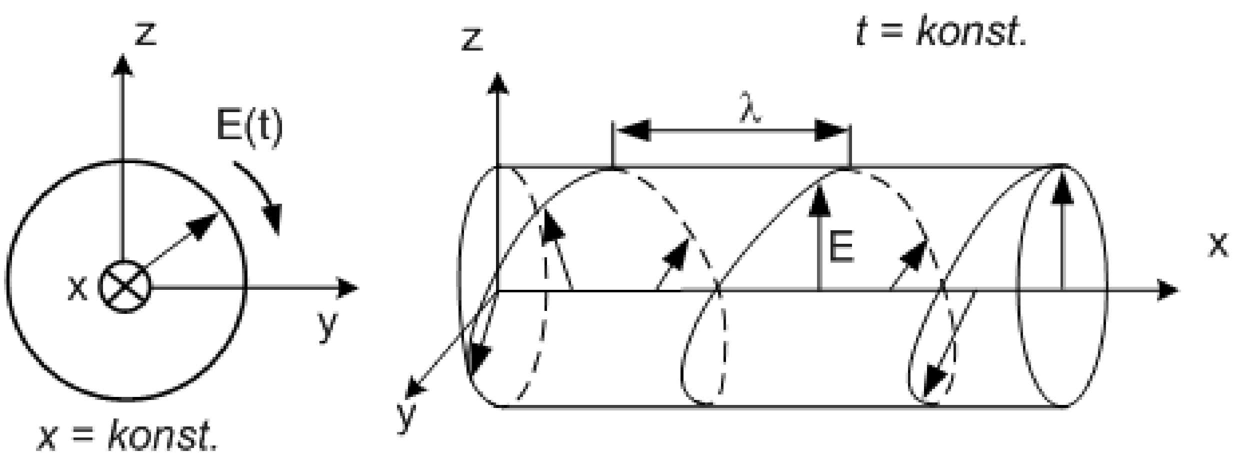
materiál	komplexní permitivita
beton	7,00 – 0,85j
odlehčený beton	2,00 – 0,50j
sklo	7,00 – 0,10j
plexisklo	1,20 – 0,10j

Polarizace

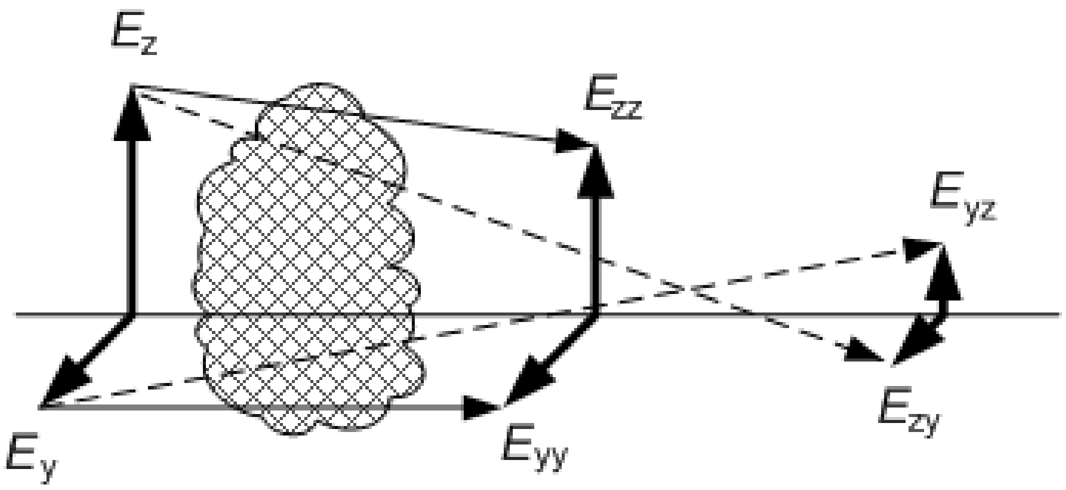
- Lineární



- Kruhová ($E_z = E_y$ a $\varphi = \pm\pi/2$)



Depolarizace



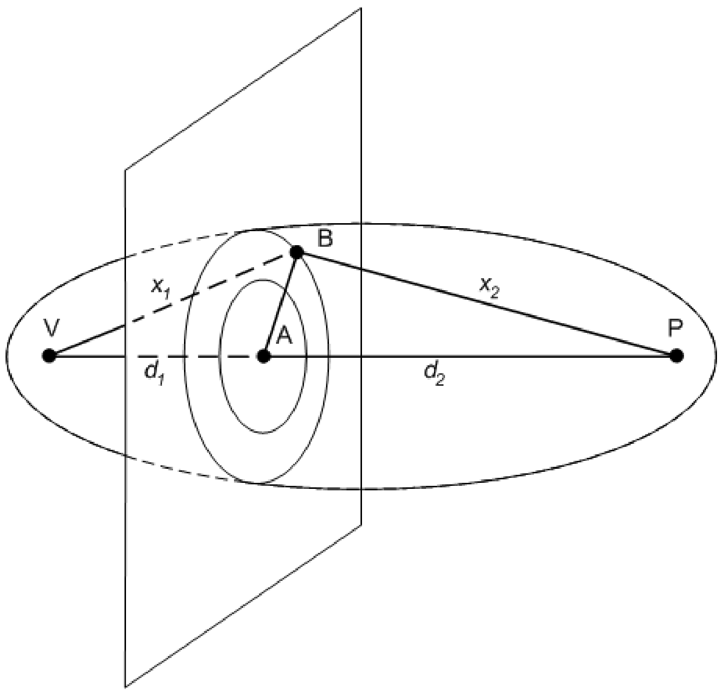
- rozlišovací poměr
  cross-polar discrimination

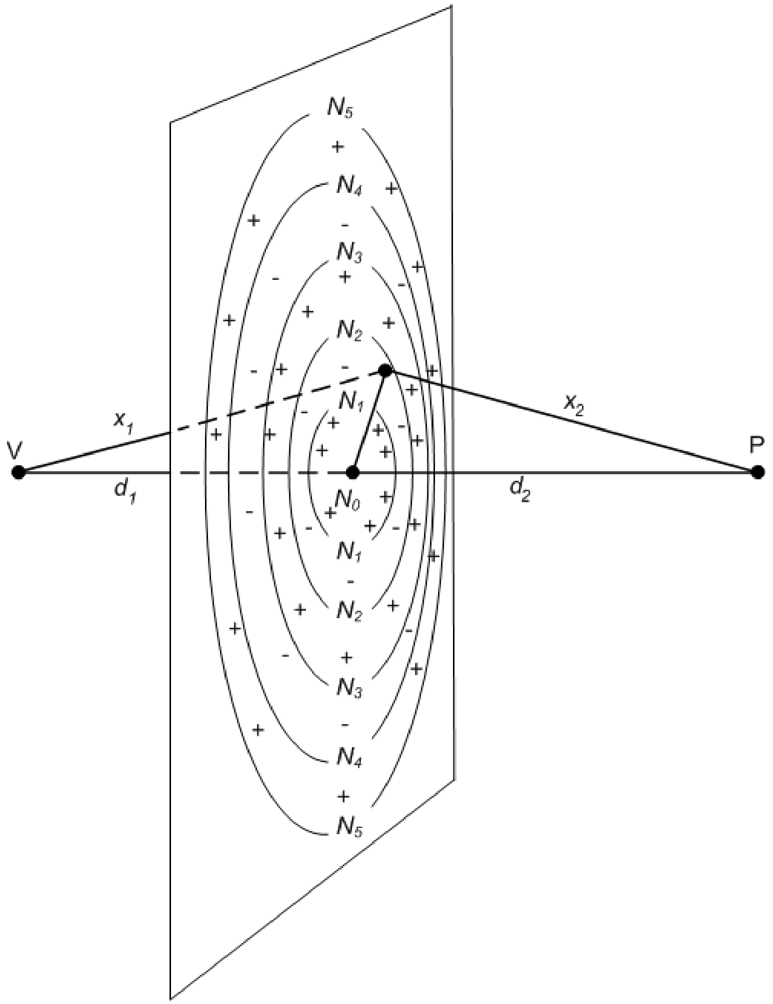
$$xpd = \frac{|E_{zz}|^2}{|E_{zy}|^2}$$

- izolační poměr
  cross-polar isolation

$$xpi = \frac{|E_{zz}|^2}{|E_{yz}|^2}$$

Fresnelovy zóny





$$\left(x_1 + x_2\right) - \left(d_1 + d_2\right) = \mathrm{n}\frac{\lambda}{2}$$

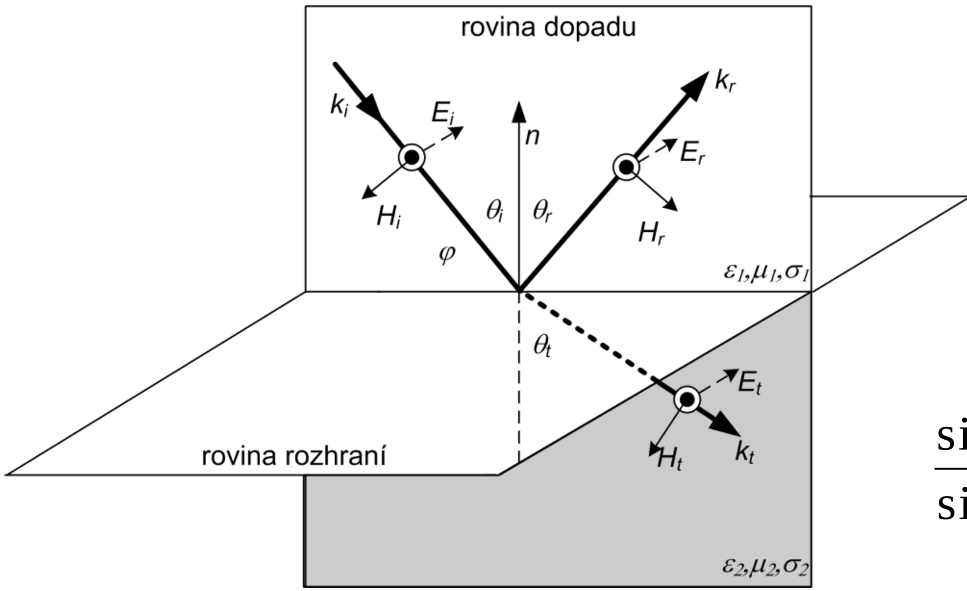
$$\sqrt{d_1^2 + b_\mathrm{n}^2} + \sqrt{d_2^2 + b_\mathrm{n}^2} - d_1 - d_2 = \mathrm{n}\frac{\lambda}{2}$$

$$\sqrt{d_{1,2}^2 + b_\mathrm{n}^2} \approx d_{1,2} + \frac{b_\mathrm{n}^2}{2d_{1,2}}$$

$$b_\mathrm{n} = \sqrt{\frac{d_1 d_2 n\lambda}{d_1 + d_2}}$$

$$b_1 = \sqrt{\frac{d_1 d_2 \lambda}{d_1 + d_2}}$$

Odraz a lom vlny (Snellův zákon)



$$\theta_i = \theta_r$$

$$k_1 \sin\theta_i = k_2 \sin\theta_t$$

$$\frac{\sin\theta_t}{\sin\theta_i} = \frac{k_1}{k_2} = \frac{\sqrt{\mu_1\varepsilon_1}}{\sqrt{\mu_2\varepsilon_2}} = \sqrt{\frac{\varepsilon_{r1}}{\varepsilon_{r2}}} = \frac{n_1}{n_2} = \frac{v_2}{v_1} = \frac{Z_2}{Z_1}$$

$$R_\perp = \frac{E_r}{E_i} = \frac{Z_2\cos\theta_i - Z_1\cos\theta_t}{Z_2\cos\theta_i + Z_1\cos\theta_t} = \frac{Z_2\cos\theta_i - Z_1\sqrt{1-(k_1/k_2)^2\sin^2\theta_i}}{Z_2\cos\theta_i + Z_1\sqrt{1-(k_1/k_2)^2\sin^2\theta_i}}$$

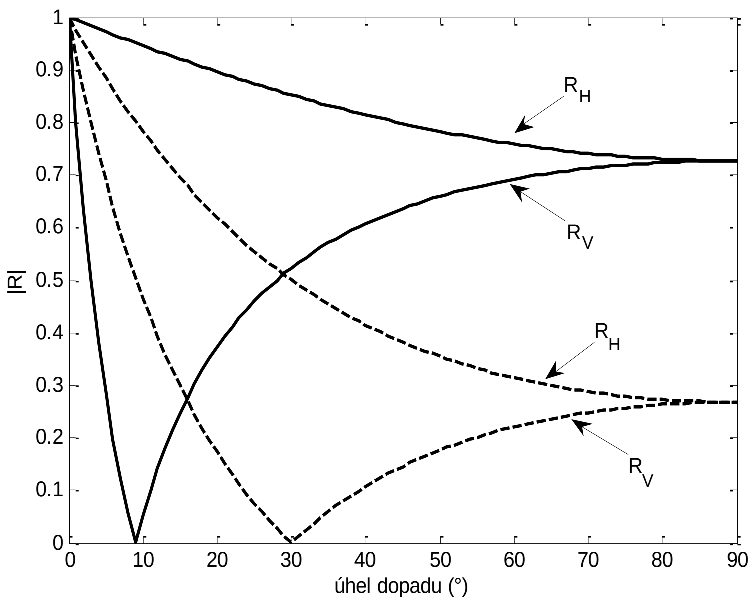
$$R_\parallel = \frac{E_r}{E_i} = \frac{Z_2\cos\theta_t - Z_1\cos\theta_i}{Z_2\cos\theta_t + Z_1\cos\theta_i} = \frac{Z_2\sqrt{1-(k_1/k_2)^2\sin^2\theta_i} - Z_1\cos\theta_i}{Z_2\sqrt{1-(k_1/k_2)^2\sin^2\theta_i} + Z_1\cos\theta_i}$$

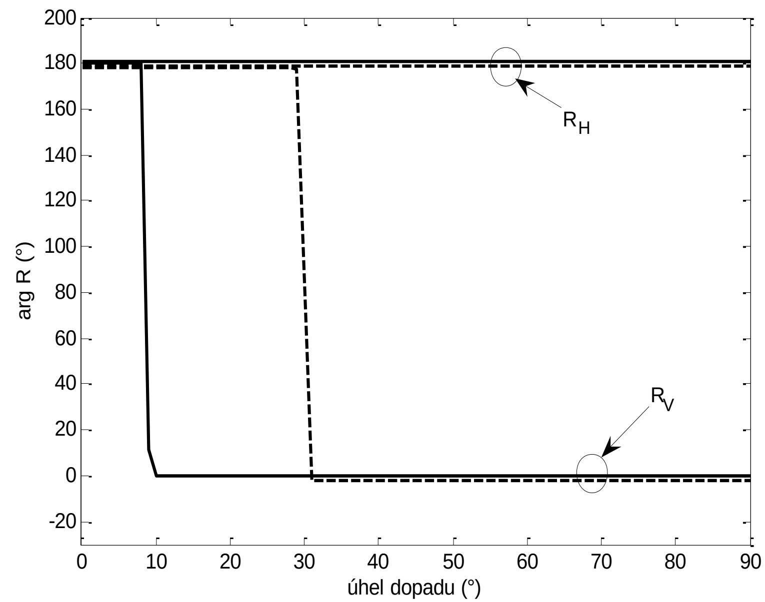
$$T_\perp = \frac{E_t}{E_i} = \frac{2Z_2\cos\theta_i}{Z_2\cos\theta_i + Z_1\cos\theta_t} = \frac{2Z_2\cos\theta_i}{Z_2\cos\theta_i + Z_1\sqrt{1-(k_1/k_2)^2\sin^2\theta_i}}$$

$$T_\parallel = \frac{E_t}{E_i} = \frac{2Z_2\cos\theta_i}{Z_2\cos\theta_t + Z_1\cos\theta_i} = \frac{2Z_2\cos\theta_i}{Z_2\sqrt{1-(k_1/k_2)^2\sin^2\theta_i} + Z_1\cos\theta_i}$$

Odraz od země

$$R_H = \frac{\sin\varphi - \sqrt{\varepsilon_{kr} - \cos^2\varphi}}{\sin\varphi + \sqrt{\varepsilon_{kr} - \cos^2\varphi}} \qquad R_V = \frac{\varepsilon_{kr}\sin\varphi - \sqrt{\varepsilon_{kr} - \cos^2\varphi}}{\varepsilon_{kr}\sin\varphi + \sqrt{\varepsilon_{kr} - \cos^2\varphi}}$$

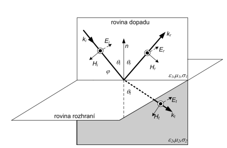




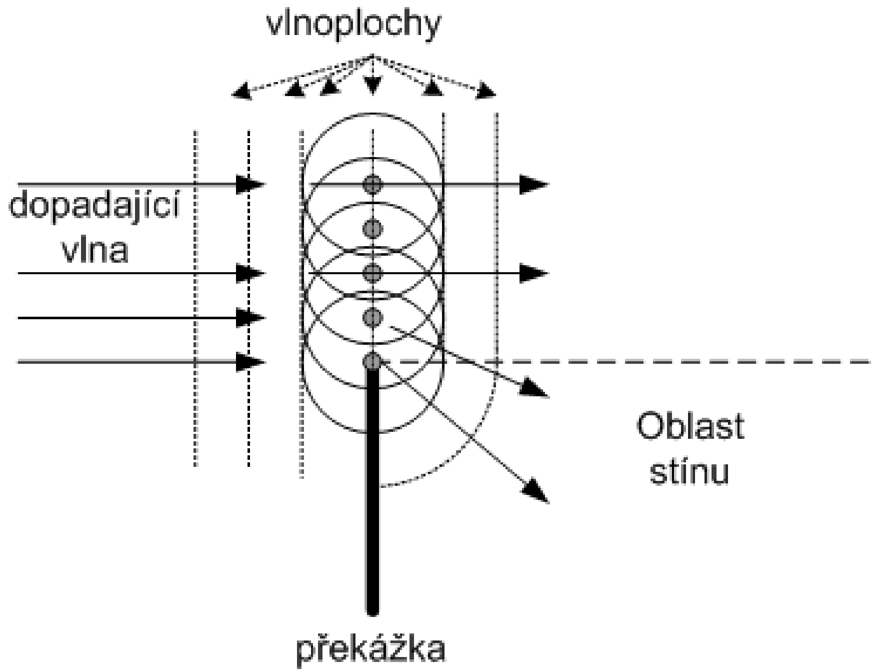
Závislost a) amplitudy; b) fáze koeficientu odrazu na úhlu dopadu pro dobře vodivou zem (σ = 0,03 Sm^{-1}, ε_r = 40; plná čára) a špatně vodivou zem (σ = 0,0001 Sm^{-1}, ε_r = 3; přerušovaná křivka); frekvence 450 MHz

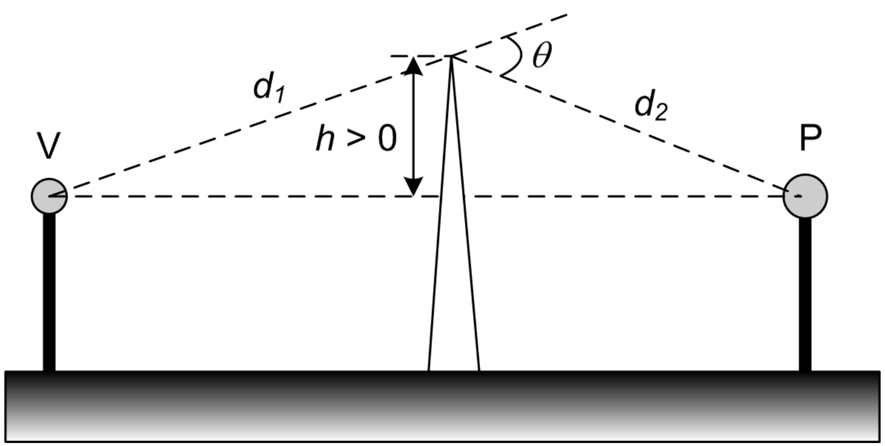
---

Brewsterův polarizační úhel $$\sin\theta_{\mathrm{iBR}} = \frac{1}{\sqrt{1 + \dfrac{\varepsilon_1}{\varepsilon_2}}}$$



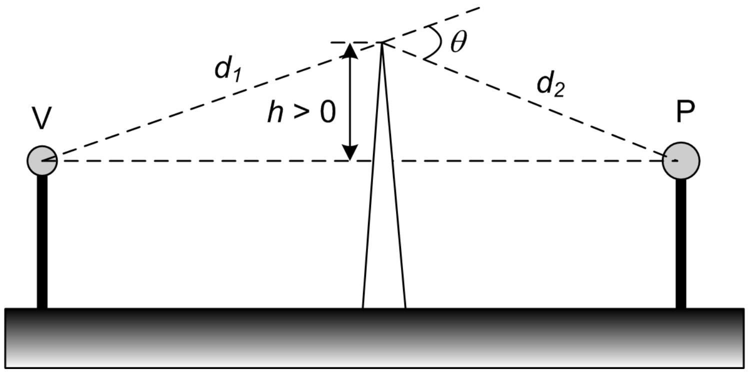
Difrakce



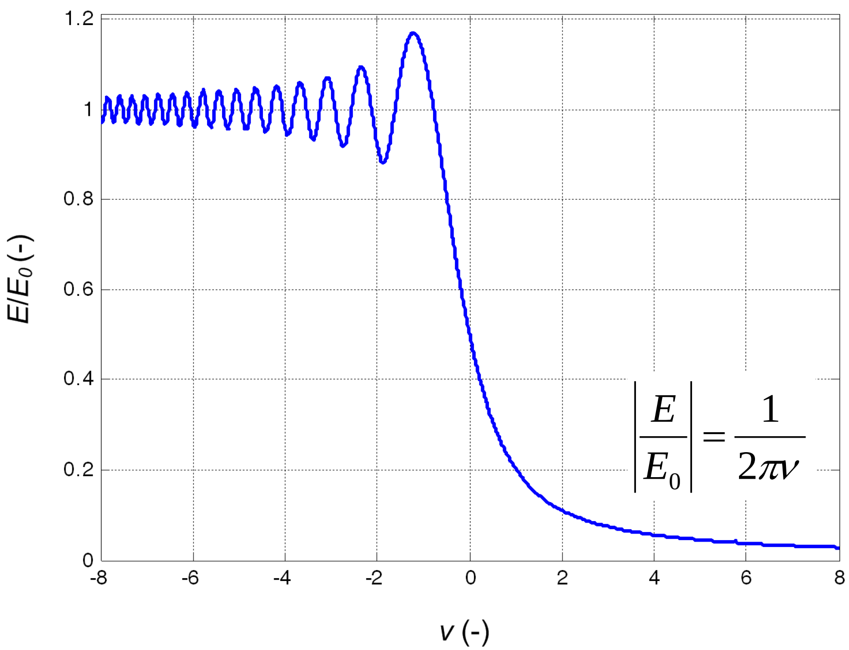


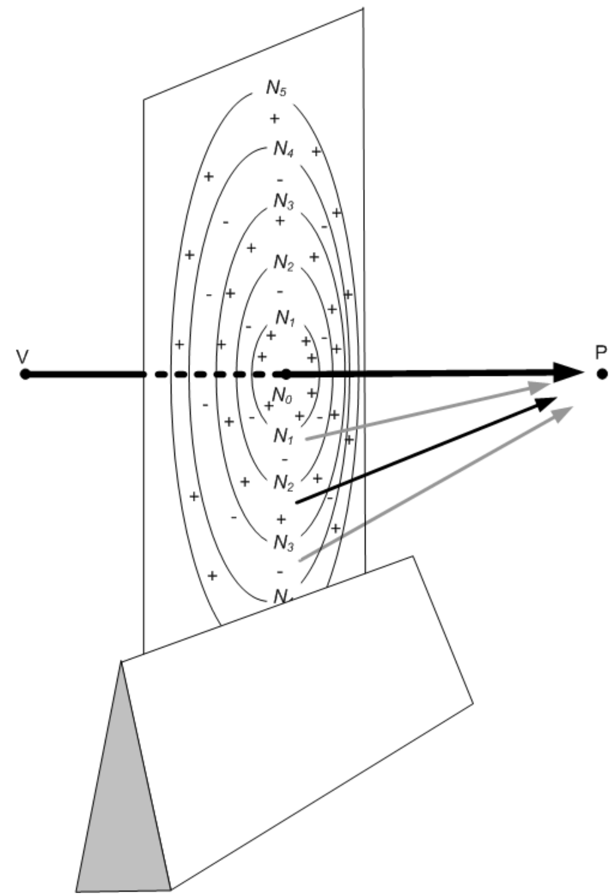
$$\nu = h\sqrt{\frac{2}{\lambda}\left(\frac{1}{d_1}+\frac{1}{d_2}\right)} = \theta\sqrt{\frac{2}{\lambda\left(\frac{1}{d_1}+\frac{1}{d_2}\right)}}$$

Difrakce na ostré překážce, *knife edge diffraction*

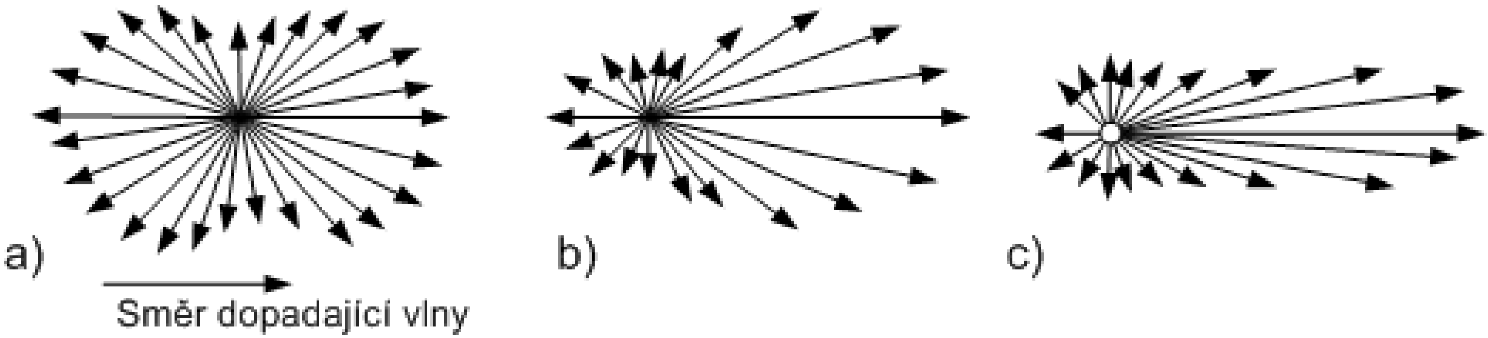


$$\nu = h\sqrt{\frac{2}{\lambda}\left(\frac{1}{d_1}+\frac{1}{d_2}\right)} = \theta\sqrt{\frac{2}{\lambda\left(\frac{1}{d_1}+\frac{1}{d_2}\right)}}$$





Rozptyl (*scattering*)



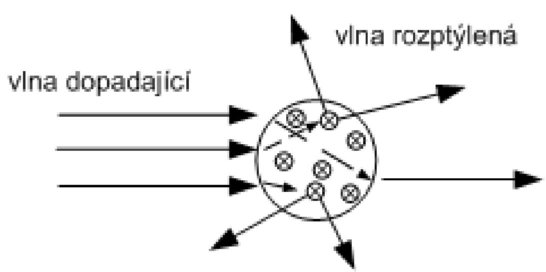
a) Rayleighův rozptyl na velmi malé částici; b) Mieův rozptyl na menší částici; c) Mieův rozptyl na větší částici

Rozptylová funkce
scattering function

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

Efektivní plocha odrazu
radar cross section

$$P_s = P_i \sigma\left(\mathbf{k}_i, \mathbf{k}_s\right)$$



Decibely

$$10\log\frac{P_1}{P_2} \qquad 10\log\frac{U_1^2}{U_2^2} = 20\log\frac{U_1}{U_2}$$

Veličina	Referenční veličina	Zápis jednotky	Převod ze základních jednotek
Výkon *P*	1 mW	dB(1 mW), dBm	$10\log\frac{P}{10^{-3}}$
Výkon *P*	1 W	dB(1 W), dBW	$10\log\frac{P}{1}$
Intenzita el. pole *E*	1 μV/m	dB(1 μV/m), dBμ, dBu	$20\log\frac{E}{10^{-6}}$

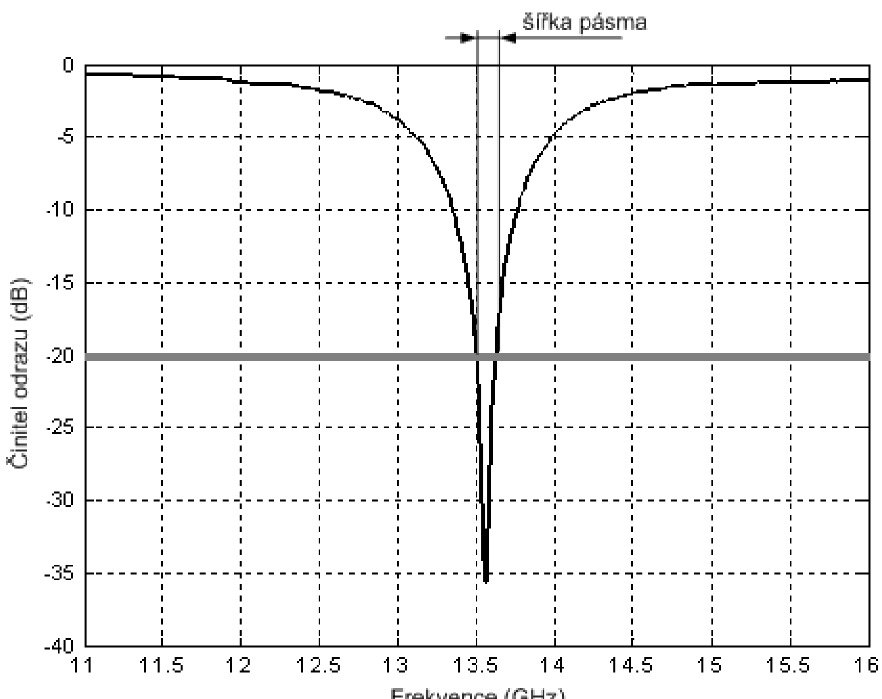
Základní parametry antén

- Vstupní impedance

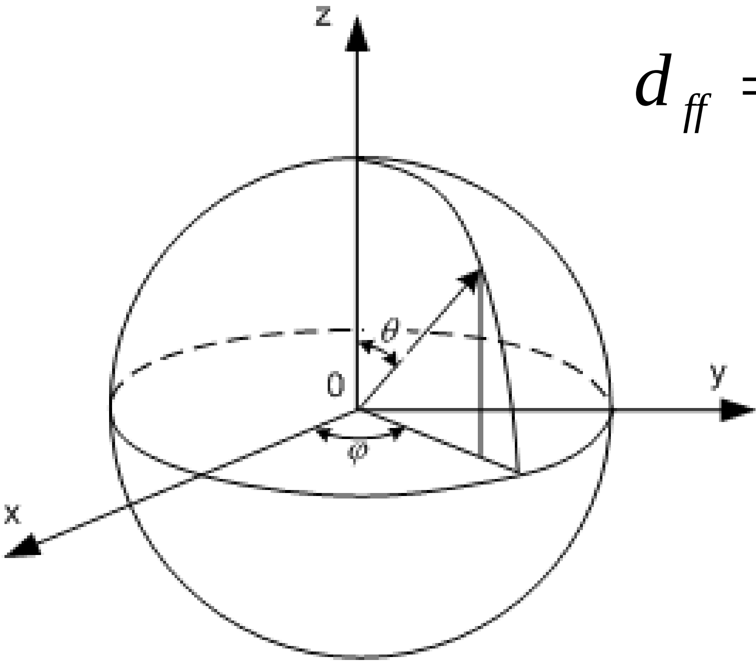
$$R = \frac{Z_A - Z_o}{Z_A + Z_o} \qquad PSV = \frac{U_{\max}}{U_{\min}} = \frac{1+|R|}{1-|R|} \qquad |R| = \frac{PSV-1}{PSV+1}$$

$$RL = -10\log\left(|R|^2\right) = -20\log|R| \qquad L_I = -10\log\left(1-|R|^2\right)$$

- Šířka pásma



Vyzařování antén



$$d_{ff} = \frac{2D^2}{\lambda}$$

$$w = E \cdot H$$

$$H = \frac{E}{120\pi}$$

$$P_{vyz} = \oiint_S w \, dS$$

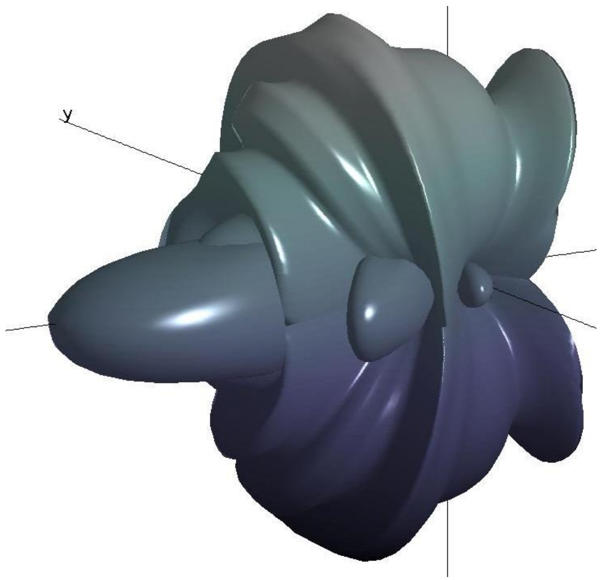
- Isotropický zářič

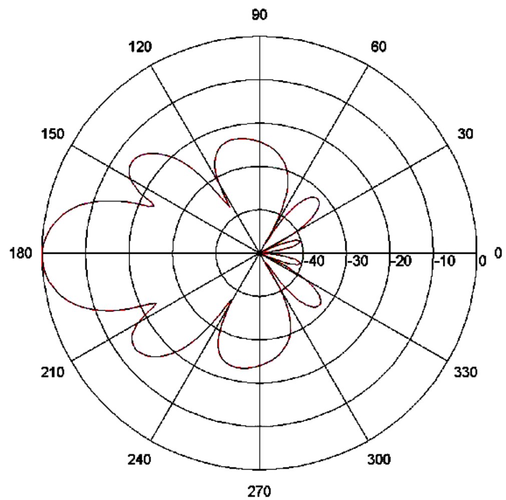
$$w = \frac{P_{vyz}}{4\pi d^2} \qquad U = d^2 w = \frac{P_{vyz}}{4\pi}$$

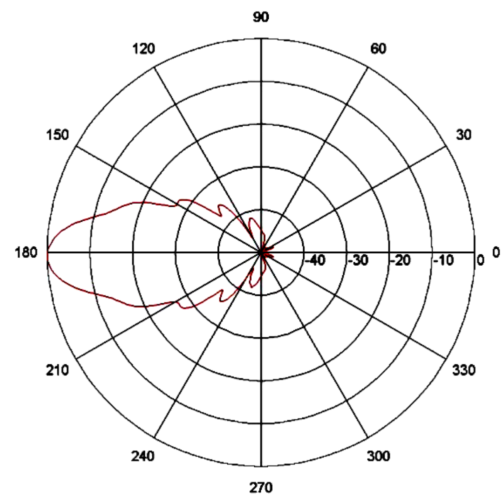
- Směrová anténa

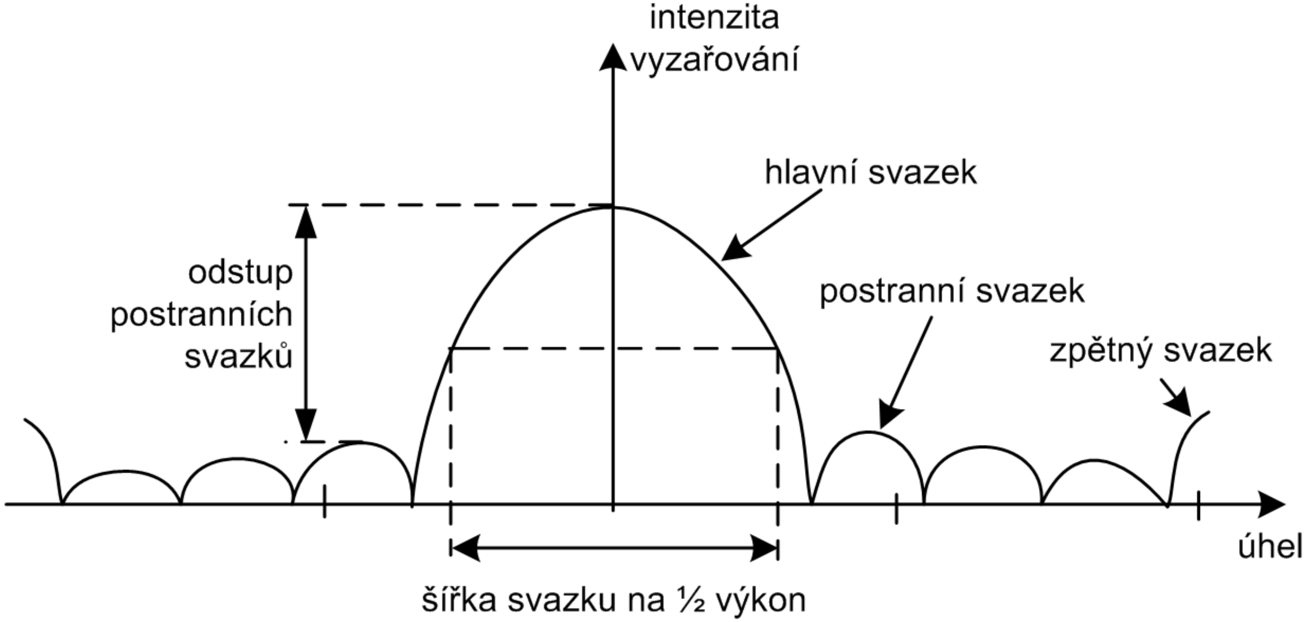
$$\mathbf{E} = C \, e^{j\psi} \mathbf{a}_0 \; F(\vartheta, \varphi) \, \frac{\mathrm{e}^{-\mathrm{j}kd}}{d}$$

Směrová/vyzařovací charakteristika









Směrovost, zisk, efektivní plocha antény

$$F_n(\vartheta,\varphi)=\frac{F(\vartheta,\varphi)}{\max\left[F(\vartheta,\varphi)\right]}$$

$$D(\vartheta,\varphi)=\frac{U(\vartheta,\varphi)}{U_o}$$

$$D_{\max}=D=\frac{U_{\max}}{U_o}=\frac{4\pi U_{\max}}{P_{vyz}}=\frac{4\pi}{\int\limits_0^{2\pi}\int\limits_0^{\pi}\left|F_n^2(\vartheta,\varphi)\right|\sin\vartheta\, d\vartheta\, d\varphi}$$

$$G=\eta D=\frac{4\pi U}{P_v}$$

$$G_{dB}=10\log G$$

Anténa	G (-)	G (dBi)
Izotropický zářič	1	0
Elementární dipól	1,5	1,75
Půlvlnný dipól	1,64	2,15
Elementární monopól/dipól na dokonale vodivé zemi	3	4,8
Čtvrtvlnný monopól na dokonale vodivé zemi	3,3	5,2

$$P_V=w_{dop}A_{ef}$$

$$A_{ef}=\left(\frac{\lambda^2}{4\pi}\right)G$$

$$G=\frac{4\pi}{\lambda^2}\eta S$$

Rádiový přenos ve volném prostoru

$$w_v = \frac{P_V G_V}{4\pi d^2}$$

$$w_v = \left|\mathbf{E}\times\mathbf{H}\right| = \frac{\left|E\right|^2}{120\,\pi}$$

$$\Longrightarrow$$

$$E = \frac{\sqrt{30\,P_V G_V}}{d}$$

$$P_P = w_V A_P = \frac{P_V G_V}{4\pi d^2} G_P \frac{\lambda^2}{4\pi} = P_V G_V G_P \left(\frac{\lambda}{4\pi d}\right)^2$$

$$L_{FSL} = 20\log\left(\frac{4\pi d}{\lambda}\right) = 32{,}4 + 20\log\left(f_{MHz}\right) + 20\log\left(d_{km}\right)$$

$$P_P = P_V + G_V + G_P - L_{FSL} - L$$

Příklad – FSL (dB)

$$L_{FSL} = 20\log\left(\frac{4\pi d}{\lambda}\right) = 32{,}4 + 20\log\left(f_{MHz}\right) + 20\log\left(d_{km}\right)$$

d (m) / f (MHz)	**450**	**900**	**1800**	**2500**	**5000**	**10000**	**20000**	**40000**
1	26	32	38	40	46	52	58	64
10	46	52	58	60	66	72	78	84
100	66	72	78	80	86	92	98	104
1000	86	92	98	100	106	112	118	124
5000	99	106	112	114	120	126	132	138
10000	106	112	118	120	126	132	138	144
30000	115	121	127	130	136	142	148	154
750000	143	149	155	158	164	170	176	182
36000000	177	183	189	192	198	204	210	216

+20 dB

+6 dB

+34 dB

+6 dB

RECOMMENDATION ITU-R P.525-2*

CALCULATION OF FREE-SPACE ATTENUATION

(1978-1982-1994)

The ITU Radiocommunication Assembly,

considering

a) that free-space propagation is a fundamental reference for radio-engineering,

recommends

1. that the methods in Annex 1 be used for the calculation of attenuation in free space.

ANNEX 1

1. Introduction

As free-space propagation is often used as a reference in other texts, this Annex presents relevant formulae.

2. Basic formulae for telecommunication links

Free-space propagation may be calculated in two different ways, each of which is adapted to a particular type of service.

2. Basic formulae for telecommunication links

Free-space propagation may be calculated in two different ways, each of which is adapted to a particular type of service.

2.1 Point-to-area links

If there is a transmitter serving several randomly-distributed receivers (broadcasting, mobile service), the field is calculated at a point located at some appropriate distance from the transmitter by the expression:

$$e = \frac{\sqrt{30p}}{d} \tag{1}$$

where:

e : r.m.s. field strength (V/m) (see Note 1)

p : equivalent isotropically radiated power (e.i.r.p.) of the transmitter in the direction of the point in question (W) (see Note 2)

d : distance from the transmitter to the point in question (m).

Equation (1) is often replaced by equation (2) which uses practical units:

$$e_{mV/m} = 173 \frac{\sqrt{p_{kW}}}{d_{km}} \tag{2}$$

2.2 Point-to-point links

With a point-to-point link it is preferable to calculate the free-space attenuation between isotropic antennas, also known as the free-space basic transmission loss (symbols: L_{bf} or A_0), as follows:

$$L_{bf} = 20 \log \left(\frac{4\pi\, d}{\lambda} \right) \qquad \text{dB} \tag{3}$$

where:

L_{bf}: free-space basic transmission loss (dB)

d: distance

λ: wavelength, and

d and λ are expressed in the same unit.

Equation (3) can also be written using the frequency instead of the wavelength.

$$L_{bf} = 32.4 + 20 \log f + 20 \log d \qquad \text{dB} \tag{4}$$

where:

f: frequency (MHz)

d: distance (km).

2.3 Relations between the characteristics of a plane wave

There are also relations between the characteristics of a plane wave (or a wave which can be treated as a plane wave) at a point:

$$s = \frac{e^2}{120\,\pi} = \frac{4\pi\, p_r}{\lambda^2} \tag{5}$$

where:

s: power flux-density (W/m^2)

e: r.m.s. field strength (V/m)

p_r: power (W) available from an isotropic antenna located at this point

λ: wavelength (m).

3. The free-space basic transmission loss for a radar system (symbols: L_{br} or A_{0r})

Radar systems represent a special case because the signal is subjected to a loss while propagating both from the transmitter to the target and from the target to the receiver. For radars using a common antenna for both transmitter and receiver, a radar free-space basic transmission loss, L_{br}, can be written as follows:

$$L_{br} = 103.4 + 20 \log f + 40 \log d - 10 \log \sigma \qquad \text{dB} \tag{6}$$

where:

σ: radar target cross-section (m^2)

d: distance from the radar to the target (km)

f: frequency of the system (MHz).

The radar target cross-section of an object is the ratio of the total isotropically equivalent scattered power to the incident power density.

4. Conversion formulae

On the basis of free-space propagation, the following conversion formulae may be used.

Field strength for a given isotropically transmitted power:

$$E = P_t - 20 \log d + 74.8 \tag{7}$$

Isotropically received power for a given field strength:

$$P_r = E - 20 \log f - 167.2 \tag{8}$$

Free-space basic transmission loss for a given isotropically transmitted power and field strength:

$$L_{bf} = P_t - E + 20 \log f + 167.2 \tag{9}$$

Power flux-density for a given field strength:

$$S = E - 145.8 \tag{10}$$

where:

P_t: isotropically transmitted power (dB(W))

P_r: isotropically received power (dB(W))

E: electric field strength (dB(μV/m))

f: frequency (GHz)

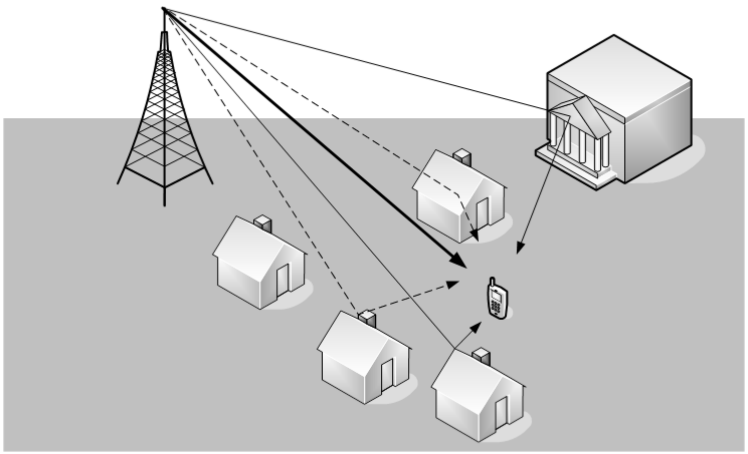
d: radio path length (km)

L_{bf}: free-space basic transmission loss (dB)

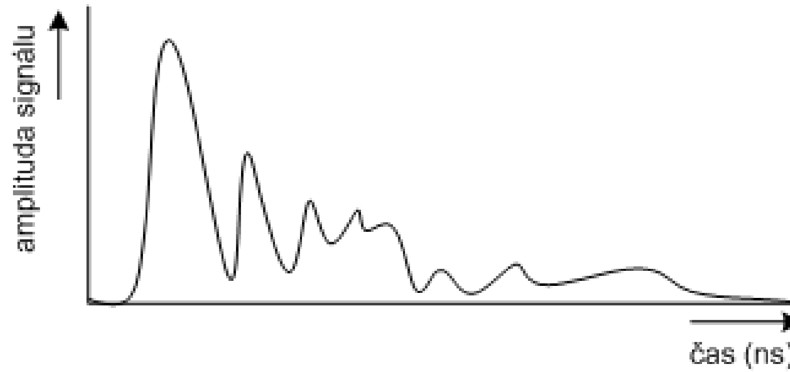
S: power flux-density (dB(W/m^2)).

Note that equations (7) and (9) can be used to derive equation (4).

Vícecestné šíření (*multipath propagation*)



$$\mathbf{E} = \sum_i \mathbf{E}_i$$



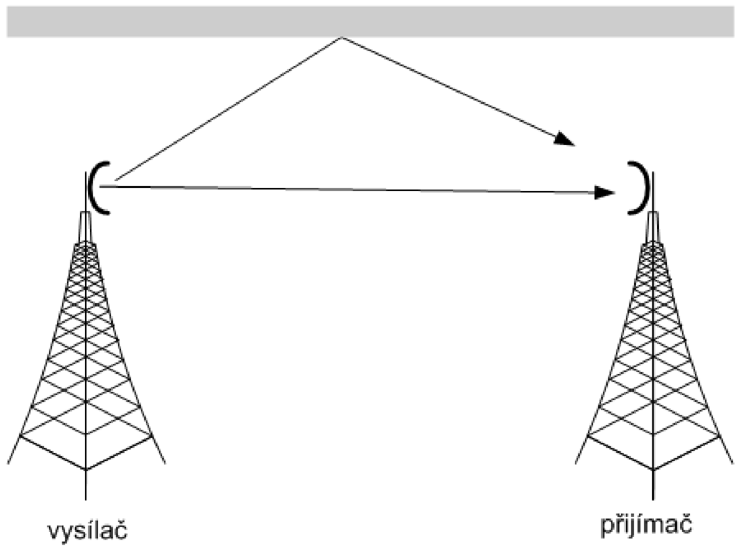
- časovému zpoždění (*time delay*)
- impulzová odezva (*impulse response*)
- rozptyl dob zpoždění (*RMS Delay Spread*)
- úhel dopadu (*AOA, Angle of Arrival*)
- úhel odchodu paprsku (*AOD, Angle of Departure*)

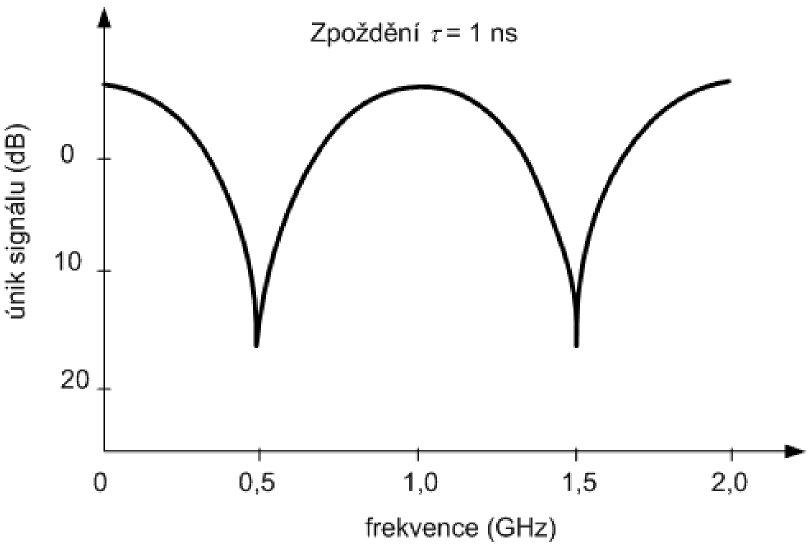
Typ spoje	Typická hodnota rozptylu dob zpoždění
Mikrovlnný radioreléový spoj	~ 3 ns
Mobilní spoj v mikrobuňce (zástavba)	~ 500 ns
Mobilní spoje v makrobuňce	~ 4000 ns

Úniky (*fading*)

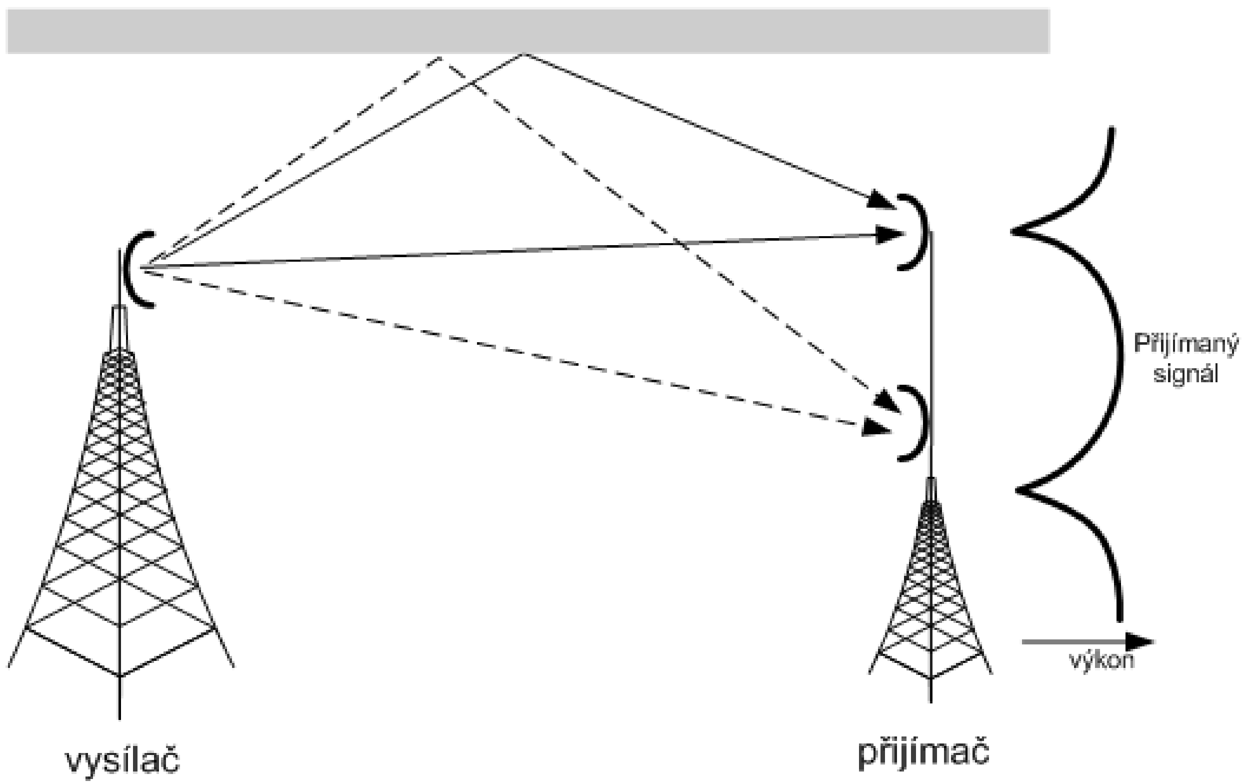
- Ztráty rádiového spoje
  - ztráty volným prostorem
  - difrakční ztráty vlivem zastínění překážkou (terén, vegetace, zástavba,...)
  - útlum atmosférickými plyny
  - ztráty vícecestným šířením
  - ztráty rozptylem vlivem anomální refrakce
  - ztráty vlivem scintilací
  - ztráty vlivem změny úhlu odchodu a dopadu vlny
  - útlum hydrometeory (déšť, kroupy, ...)
  - ztráty v ionosféře, aj.
- Úniky
  - Ploché (pomalé)
  - Frekvenčně selektivní (rychlé)
- Vylepšení úrovně (*enhancement*)

Frekvenčně selektivní únik způsobený vícecestným šířením

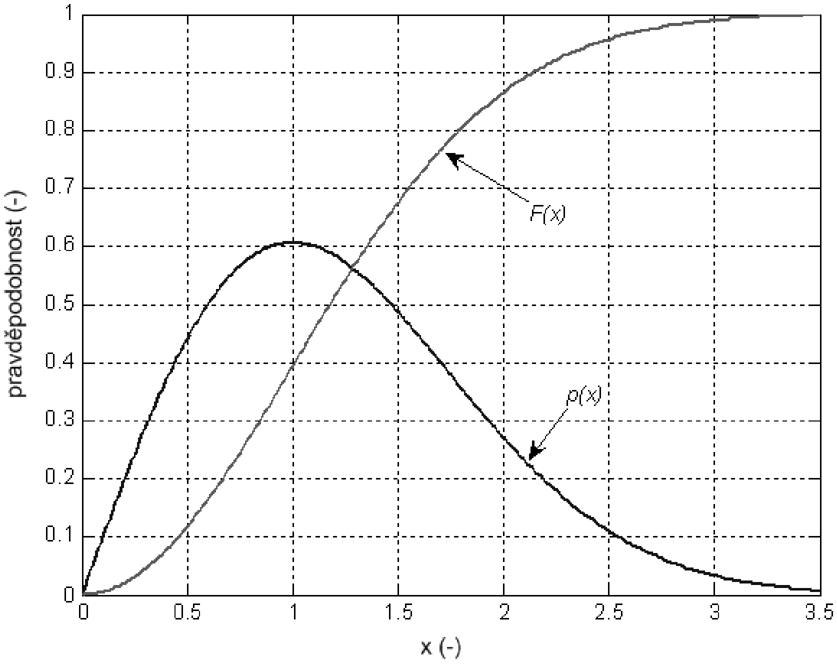




Diverzitní příjem

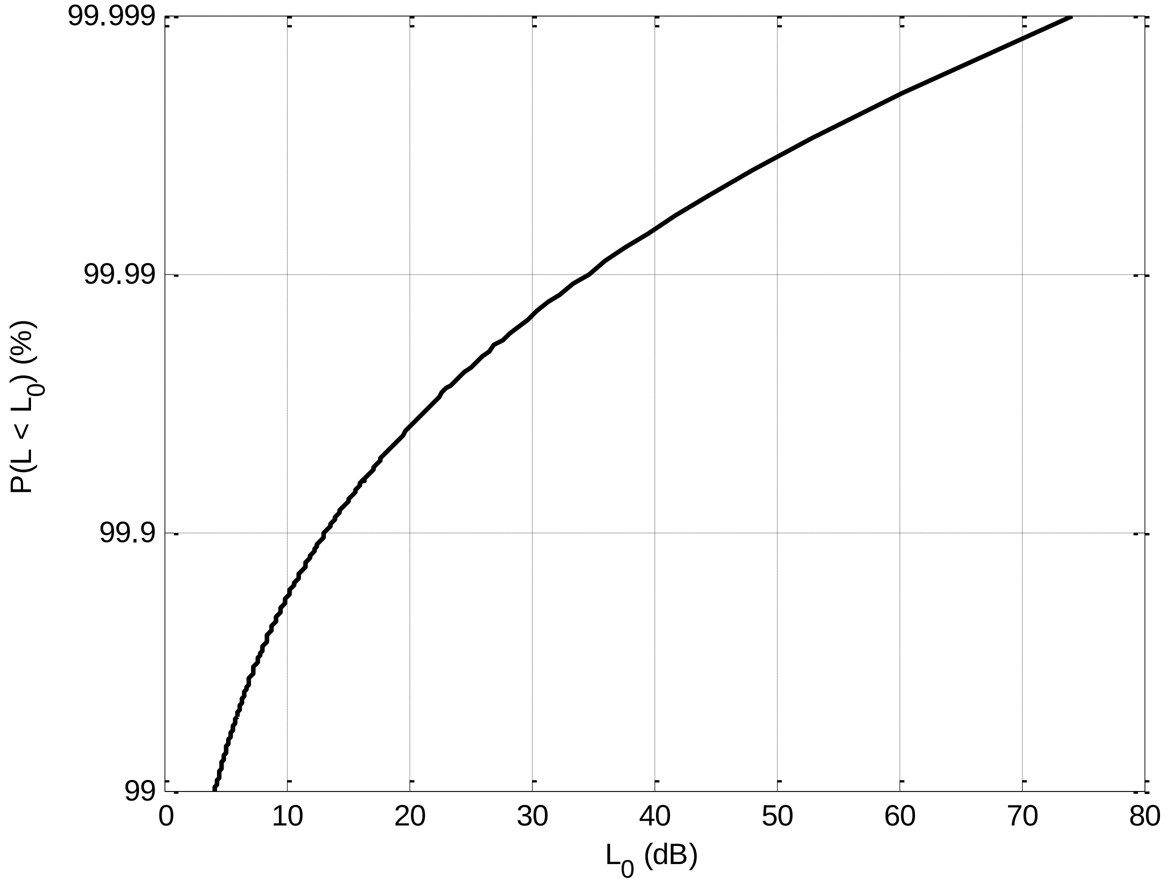


Hustota pravděpodobnosti a distribuční funkce Rayleigho rozdělení

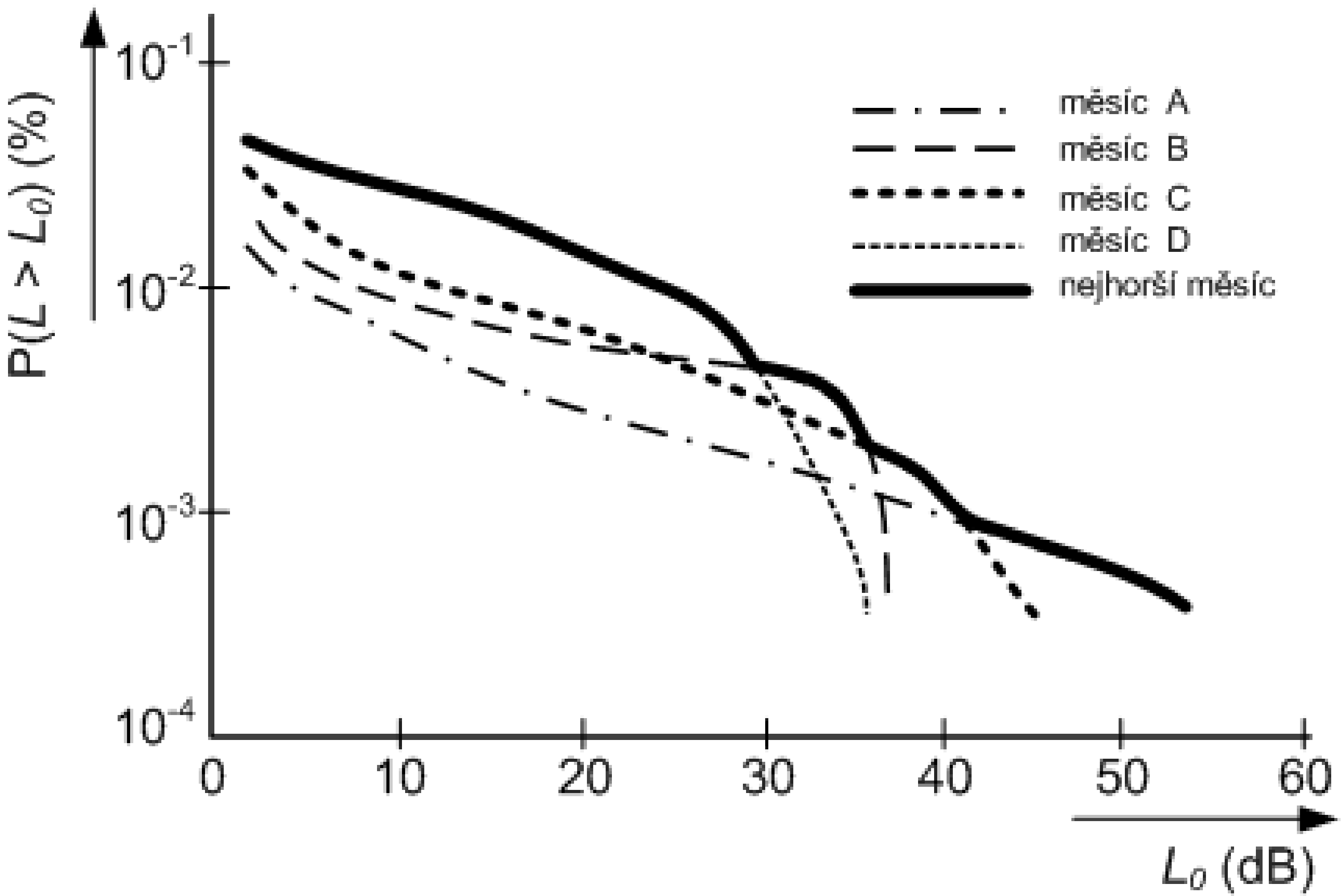


$$F(L) = \mathrm{P}\left(L \le L_0\right)$$

Příklad kumulativní distribuční funkce (CDF) útlumu deštěm



Průměrný rok a nejhorší měsíc



Rádiový šum

- Vyzařování černého tělesa

$$N = kTB$$

- ekvivalentní šumové teploty (*equivalent noise temperature*)

$$T_{ekv} = \frac{N}{kB}$$

- jasová teplota (*brightness temperature*) objektu

$$N = kT_j B = \varepsilon kTB \qquad T_j = \varepsilon T$$

- šumová teploty antény

$$T_\mathrm{A} = \frac{\int_0^{2\pi}\int_0^{\pi} T_\mathrm{j}(\vartheta,\varphi) G(\vartheta,\varphi) \sin\vartheta \,\mathrm{d}\vartheta \,\mathrm{d}\varphi}{\int_0^{2\pi}\int_0^{\pi} G(\vartheta,\varphi) \sin\vartheta \,\mathrm{d}\vartheta \,\mathrm{d}\varphi}$$

Kvalita (jakost) a spolehlivost rádiového spoje (telekomunikační služby)

- **SNR, S/N - odstup signálu a šumu**
- BER - chybovost, *bit error ratio* - relativní četnost chybně přijatých bitů; základní kritéria: BER = 10^{-3} a 10^{-6}
- RBER - minimální (zbytková) chybovost, *residual bit error ratio* - chybovost ve stavu bez úniků a interferencí
- EB - *errored blocks -* rámce s alespoň jedním chybným bitem
- ES - chybové sekundy, *errored seconds* - výskyt aspoň jedné chyby
- SES - silně chybové sekundy, *severly errored seconds* - 30% je EB
- BBE - *background errored block* - ES mimo SES
- ESR, SESR, BBER - ... *ratio*
- ...

Výkonová bilance rádiového spoje

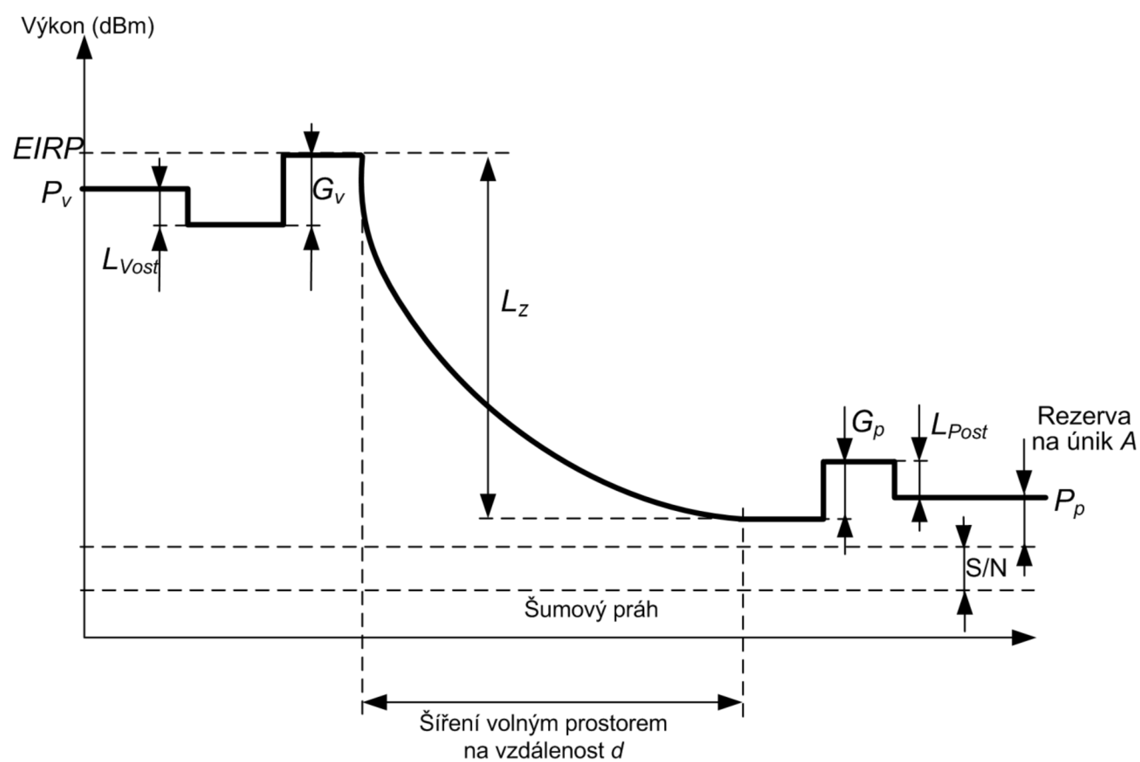
$$P_{P\min} \leq P_p = P_V + G_V + G_P - L_c - L_{ost}$$

$$SNR_{\min} \leq SNR = P_P - 10\log(kTB) = P_V + G_V + G_P - L_c - L_{ost} - 10\log(kTB)$$

$$L_c = L_z + L_f$$

$$A = P_{p0} - P_{p\min}$$

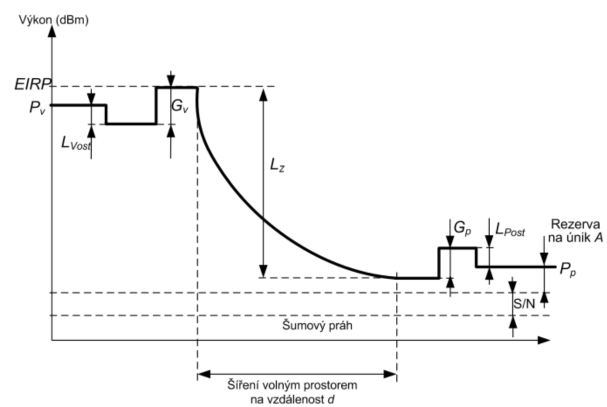
$$P_{P0} = P_V + G_V + G_P - L_z - L_{ost}$$



Příklad výkonové bilance rádiového spoje

spoj na přímou viditelnost v síti bod-mnohobod pro nesymetrický širokopásmový přenos, kdy je na základnové stanici sektorová anténa a na straně uživatele vysoce zisková anténa ideálně nasměrovaná na základnovou stanici

	Downlink (od základnové stanice)	**Uplink (k základnové stanici)**
Frekvence	28 GHz	28 GHz
Šířka pásma	40 MHz	2 MHz
Vysílaný výkon	27 dBm	15 dBm
Zisk vysílací antény	12 dBi	36 dBi
Zisk přijímací antény	36 dBi	12 dBi
Šumový práh	-98 dBm	-111 dBm
Šumové číslo přijímače	8 dB	8 dB
Požadované S/N	13 dB	13 dB
Rezerva na únik	5 dB	5 dB



RECOMMENDATION ITU-R P.341-5*

THE CONCEPT OF TRANSMISSION LOSS FOR RADIO LINKS**

(1959-1982-1986-1994-1995-1999)

The ITU Radiocommunication Assembly,

considering

a) that in a radio link between a transmitter and a receiver, the ratio between the power supplied by the transmitter and the power available at the receiver input depends on several factors such as the losses in the antennas or in the transmission feed lines, the attenuation due to the propagation mechanisms, the losses due to faulty adjustment of the impedances or polarization, etc.;

b) that it is desirable to standardize the terminology and notations employed to characterize transmission loss and its components;

c) that Recommendation ITU-R P.525 provides the free-space reference conditions for propagation,

recommends

that, to describe the characteristics of a radio link involving a transmitter, a receiver, their antennas, the associated circuits and the propagation medium, the following terms, definitions and notations should be employed:

2 System loss (symbols: L_s or A_s)

The ratio, usually expressed in decibels, for a radio link, of the radio-frequency power input to the terminals of the transmitting antenna and the resultant radio-frequency signal power available at the terminals of the receiving antenna.

NOTE 1 – The available power is the maximum real power which a source can deliver to a load, i.e., the power which would be delivered to the load if the impedances were conjugately matched.

NOTE 2 – The system loss may be expressed by:

$$L_s = 10 \log (p_t / p_a) = P_t - P_a \qquad \text{dB} \tag{1}$$

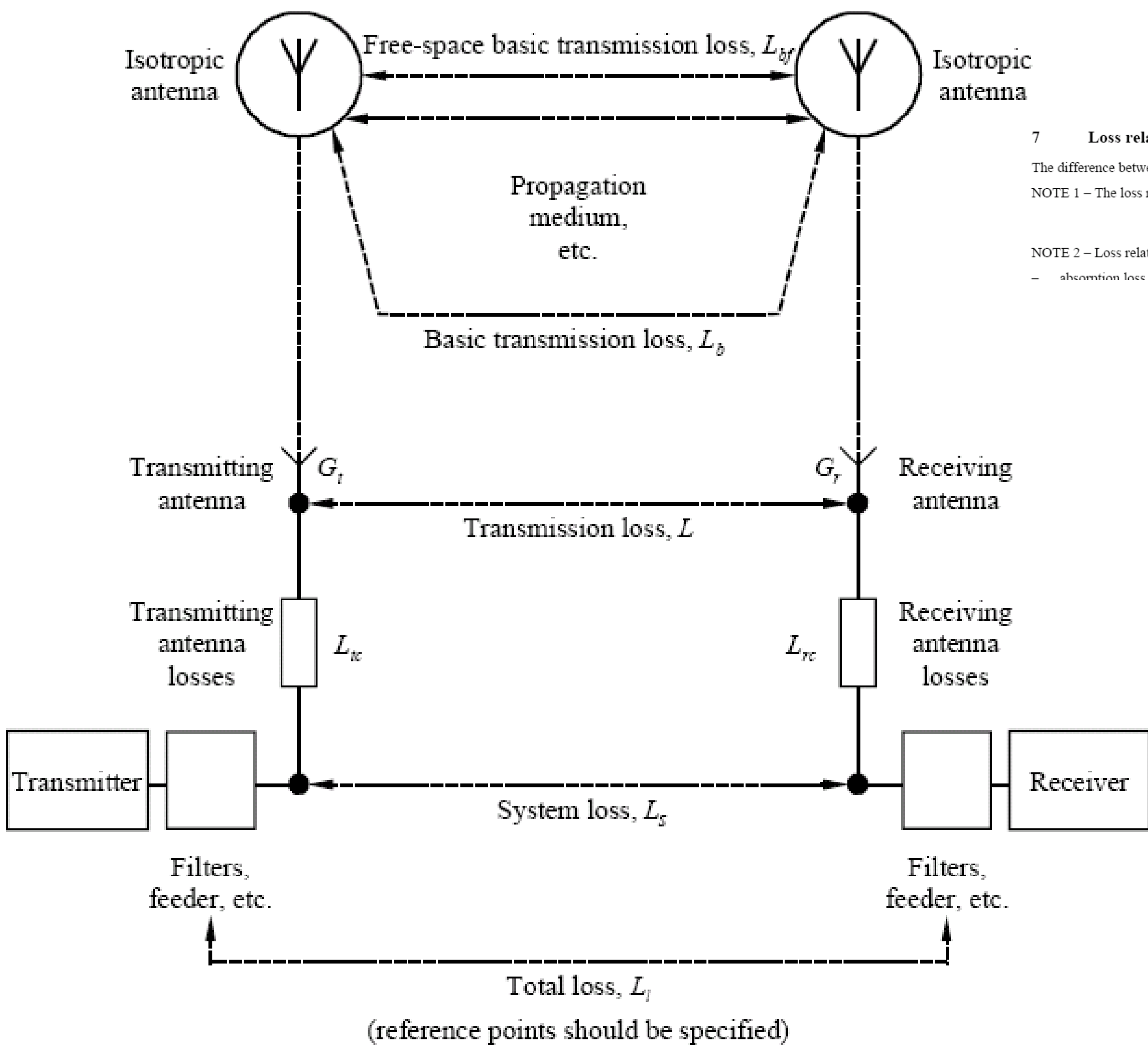
where:

p_t: radio-frequency power input to the terminals of the transmitting antenna

p_a: resultant radio-frequency signal power available at the terminals of the receiving antenna.

FIGURE 1

Graphical depiction of terms used in the transmission loss concept



L_{bf}

7 **Loss relative to free space** (symbols: L_m or A_m)

The difference between the basic transmission loss and the free-space basic transmission loss, expressed in decibels.

NOTE 1 – The loss relative to free space may be expressed by:

$$L_m = L_b - L_{bf} \quad \text{dB} \tag{6}$$

NOTE 2 – Loss relative to free space, L_m, may be divided into losses of different types, such as:

– absorption loss (ionospheric, atmospheric gases or precipitation);

$$L_b = L_{bf} + L_m$$

$$L = L_b - G_t - G_r$$

$$L_s = L + L_{tc} + L_{rc} = P_t - P_a$$

Modelování šíření vln

$$s_P(t) = s_V(t) * h(t) + n(t)$$

- Empirické modely
- Deterministické (teoretické, fyzikální) modely
- Semi-empirické (semi-deterministické) modely