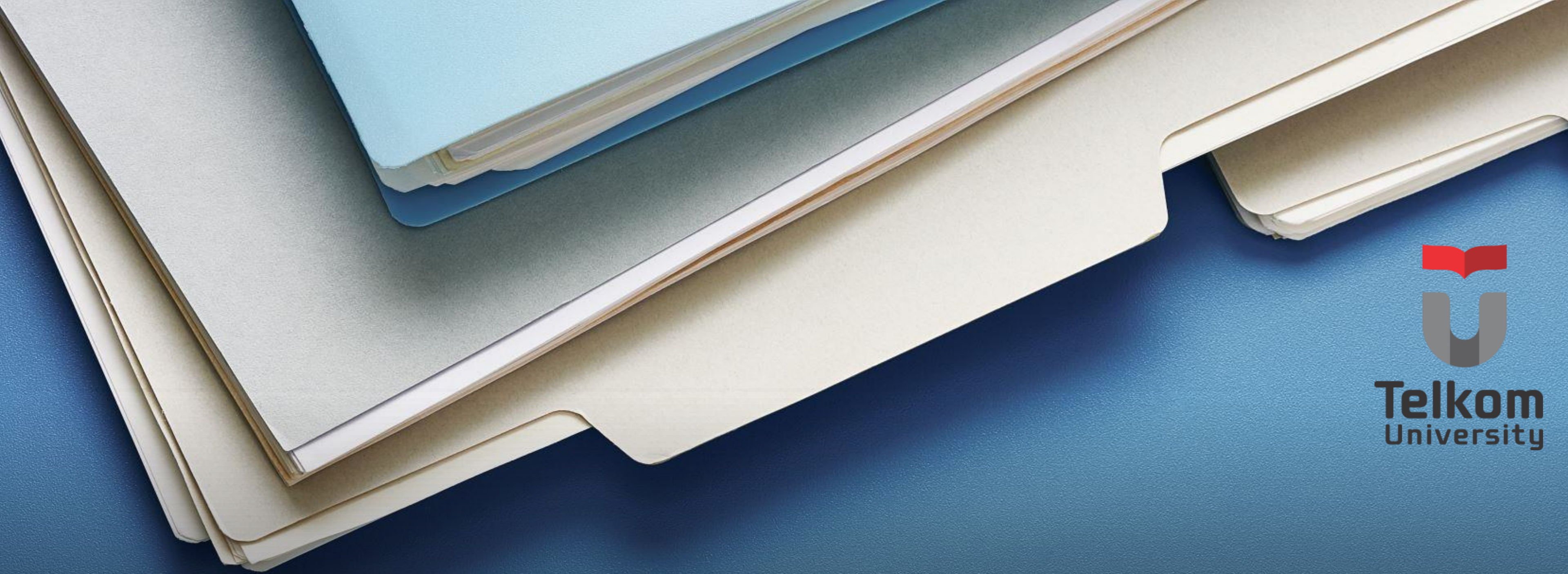


Konfigurasi sistem radio teresterial

A. Adya Pramudita & B. Syihabuddin

Catatan Ajar 6, TTH3G3 – Antena dan Propagasi

S1 Teknik Telekomunikasi, Fakultas Teknik Elektro, Universitas Telkom, 2020

Tujuan pembelajaran

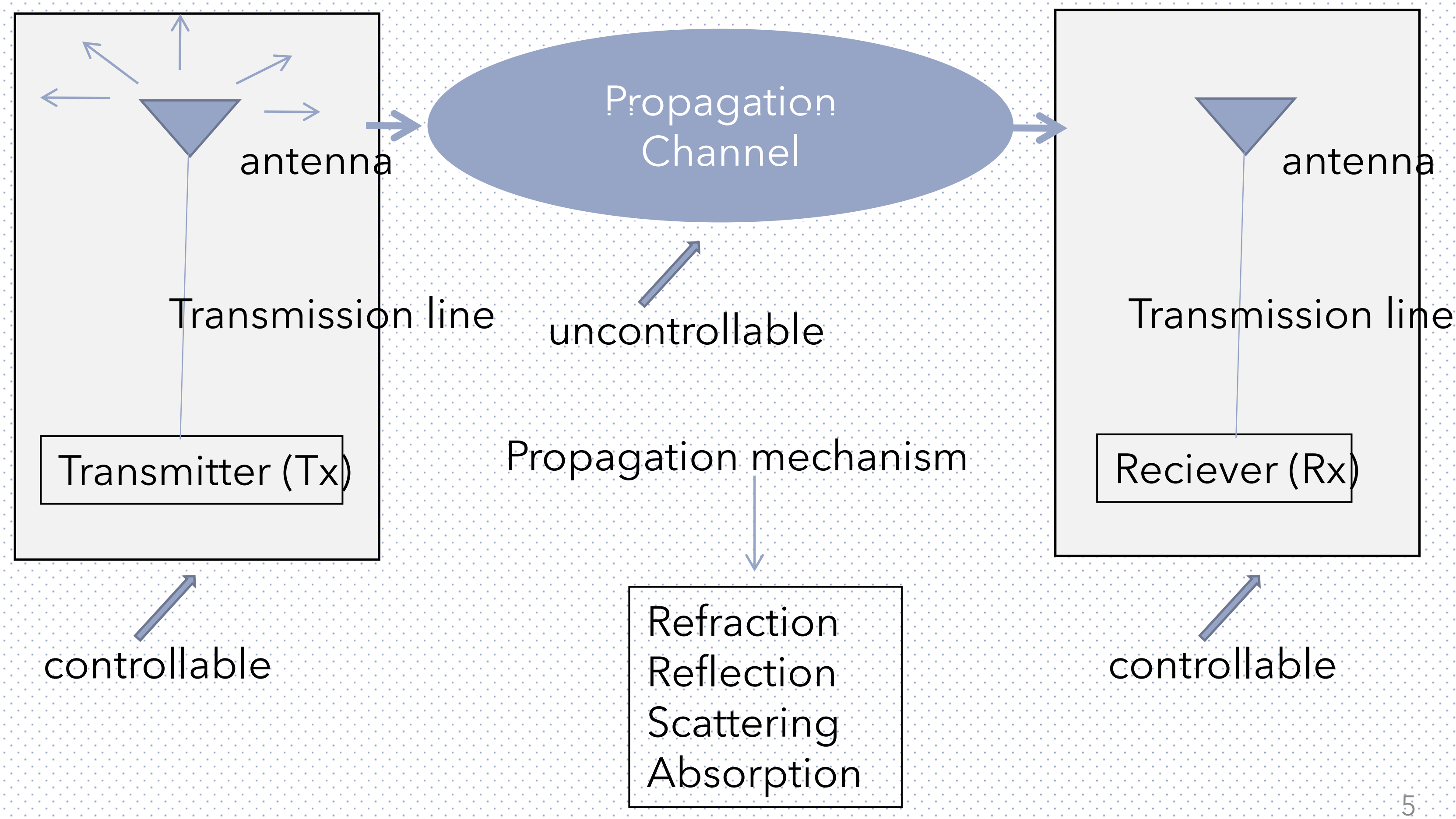
- Peserta mampu merancang link komunikasi radio terestrial mempertimbangkan konsep-konsep propagasi gelombang EM

Pokok bahasan

- Mekanisme propagasi gelombang radio
- Redaman bumi datar
- Rugi-rugi difraksi
- Fresnel zone
- Link budget
- Penentuan kofigurasi sistem radio teresterial

Mekanisme propagasi gelombang radio

Kanal propagasi



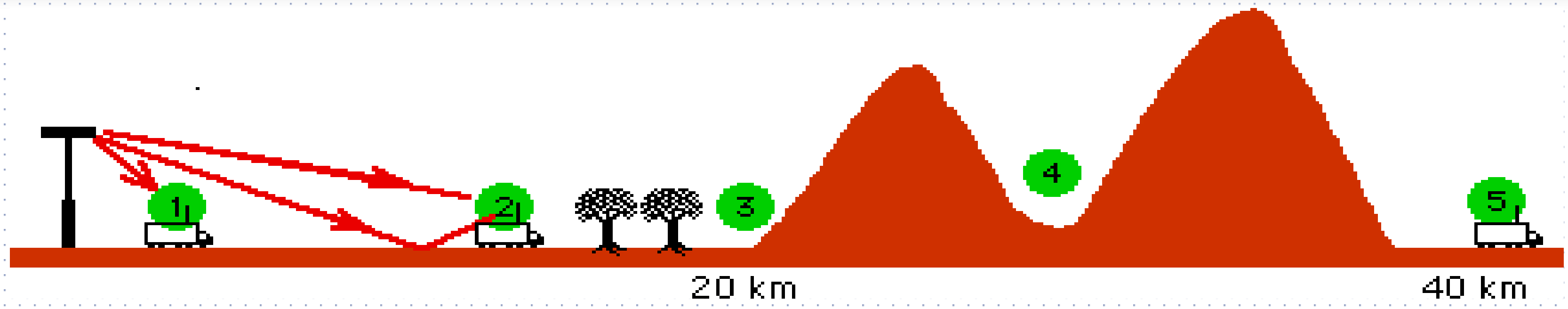
Kanal propagasi

- Propagation Channel : a system between Tx and RX that uncontrollable.
- Channel may causes distortion in transmit signal then potentially degrades the performance of communication system
- Channel modelling is needed to perform a prediction/estimation/anticipation in order to improve the system performance.

Kanal propagasi

- Propagation channel model is determined/depended by several factor :
  - particles condition in propagation medium. Things or structures that may be as obstacle between Tx and Rx.
  - Frequency of EM wave.
  - User behaviour (fix/mobile)

Ilustrasi kanal propagasi



Location-1 : direct wave propagation is dominant component.
(Line of Sight propagation Model)

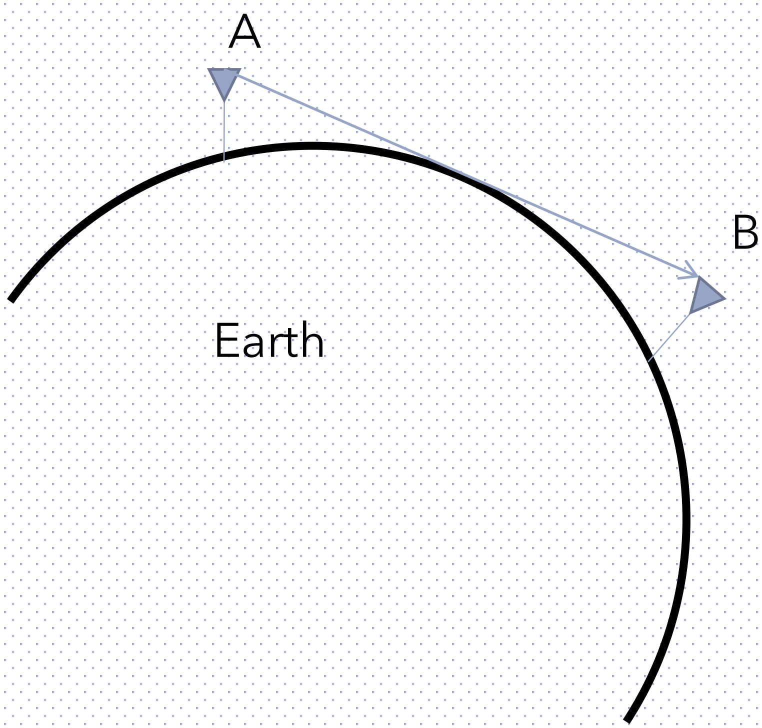
Location- 2 : reflected wave from ground surface must be considered .
(*Plane Earth Propagation Model*)

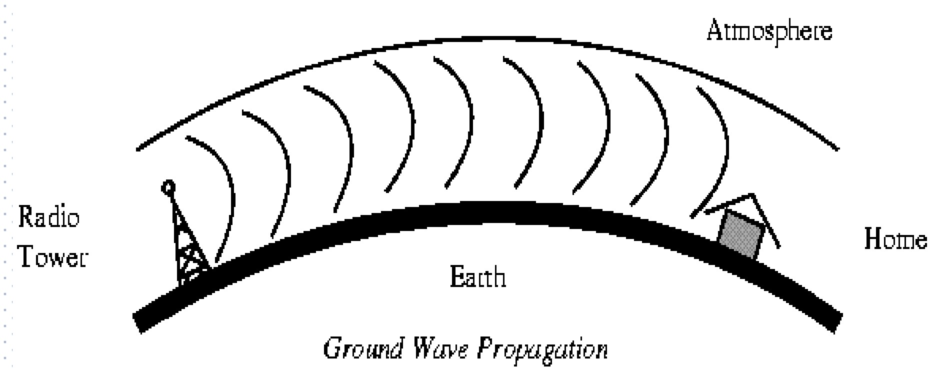
Location-3 : *Plane Earth Propagation Model* should be corrected by trees difraction.

Location-4 : knife edge difraction model

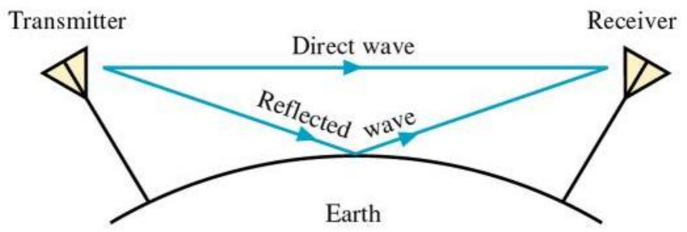
Location-5 : multiple knife edge diffraction

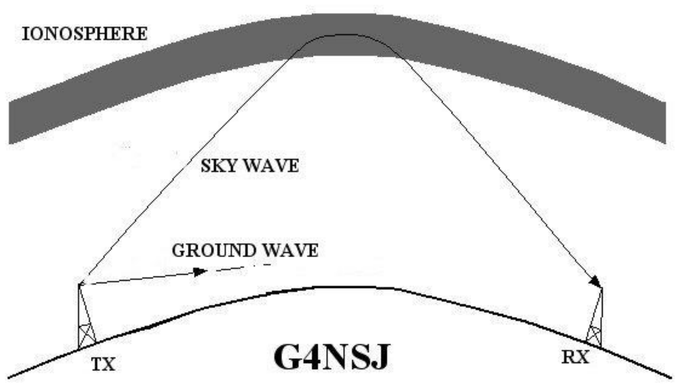
Mekanisme propagasi

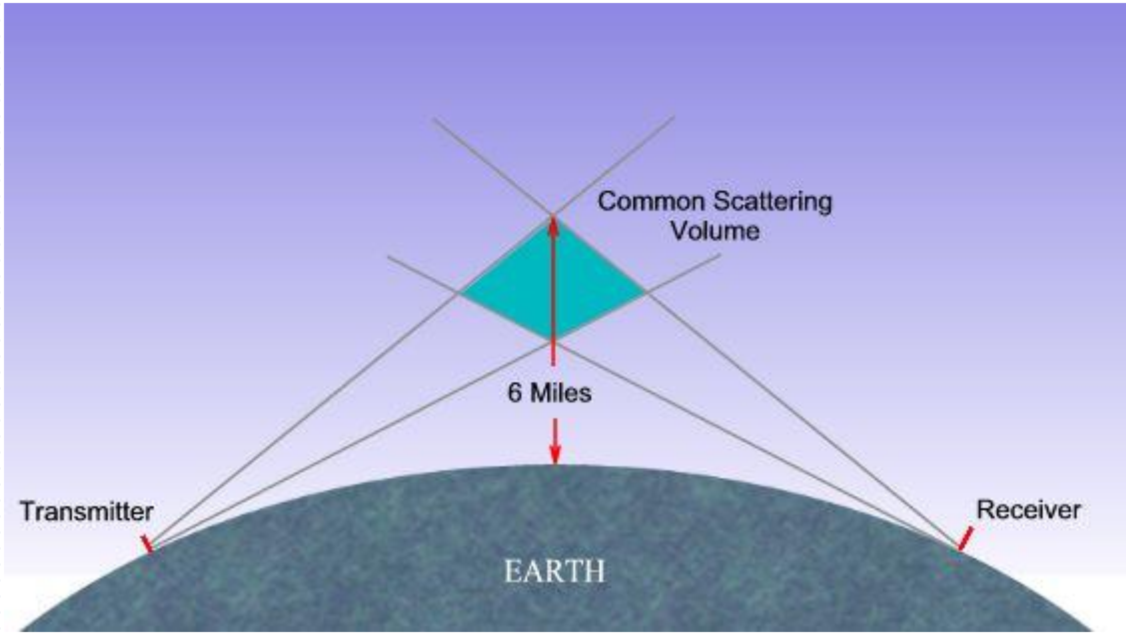




Mekanisme propagasi







Spektrum frekuensi

Frequencies	Band	Characteristics	Services
3 Hz–30 kHz	ELF, VLF	High atmospheric noise, Earth-ionosphere waveguide modes, very inefficient antennas	Submarine, navigation, sonar, long-range navigation
30–300 kHz	LF	High atmospheric noise, Earth-ionosphere waveguide modes, absorption in the ionosphere	Long-range navigational beacons
0.3–3 MHz	MF	High atmospheric noise, good ground wave propagation, Earth magnetic field cyclotron noise	Navigation, maritime communication, AM broadcasting
3–30 MHz	HF	Moderate atmospheric noise, ionosphere reflections that provide long-distance links, affected by solar flux density	International shortwave broadcasting, ship-to-shore, telephone, telegraphy, long-range aircraft communication, amateur radio

Spektrum frekuensi

Frequencies	Band	Characteristics	Services
3–30 MHz	HF	Moderate atmospheric noise, ionosphere reflections that provide long-distance links, affected by solar flux density	International shortwave broadcasting, ship-to-shore, telephone, telegraphy, long-range aircraft communication, amateur radio
30–300 MHz	VHF	Some ionosphere reflections at the lower range, meteor scatter possible, normal propagation basically line of sight	Mobile, television, FM broadcasting, air-traffic control, radio navigation aids, land-mobile communications
0.3–3 GHz	UHF	Basically line-of-sight propagation, efficient portable antennas	Television, radar, land-mobile communications, satellite communications, Global Positioning Satellite (GPS), PCS, wireless local-area networking, mobile phones

Spektrum frekuensi

Frequencies	Band	Characteristics	Services
3–30 GHz	SHF	Line-of-sight propagation, atmospheric absorption at upper frequencies	Radar, microwave links, land-mobile communication, satellite communication, UWB, wireless LANs and PANs, fixed broadband, 3G PCS
30–300 GHz	EHF	Line-of-sight propagation, very subject to atmospheric absorption	Radar, secure and military communication, satellite links, mm-wave personal-area networking
300–10^7 GHz	IR—optics	Line-of-sight propagation, very subject to atmospheric absorption	Optical communications, fiber optical links

Spektrum frekuensi

Band Name	Frequency
L band	1 - 2 GHz
S band	2 - 4 GHz
C band	4 – 8 GHz
X band	8 – 12 GHz
Ku band	12 – 18 GHz
K band	18 – 27 GHz
Ka band	27 – 40 GHz

Aspek propagasi

- Atmosphere Refraction Index
- Reflection from ground surface
- Fading
- Difraction

Indeks bias atmosfer

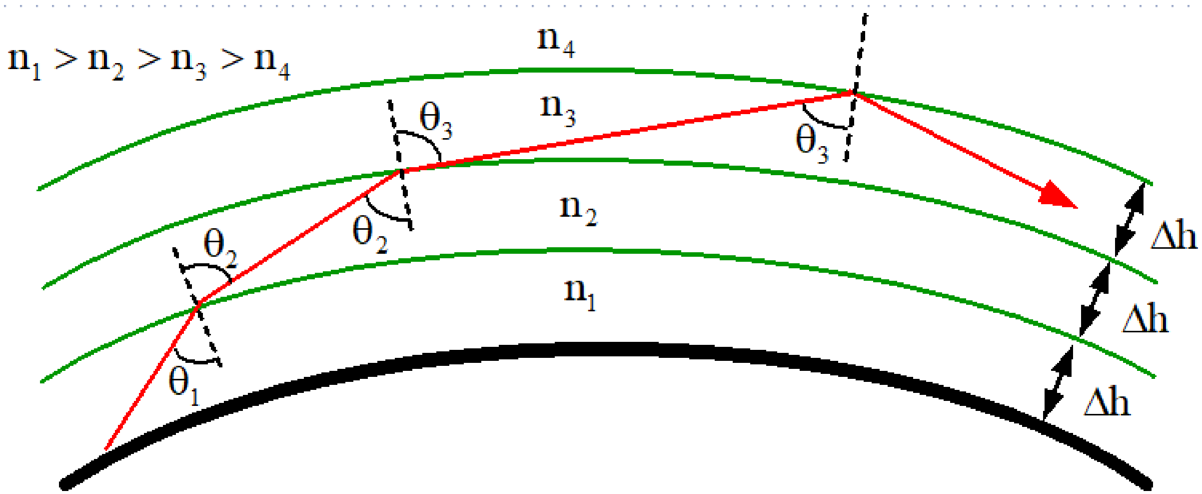
- Untuk f > 30 MHz pengaruh troposfer perlu diperhitungkan(sd ketinggian (h) 18 km di khatulistiwa, 11 km di kutup utara dan 9 km di kutup selatan.
- Udara $\mu_r = 1.0000004 \approx 1, \varepsilon_r = 1.0006$ indek bias n= $\sqrt{\varepsilon_r} = 1.0003$. Namun n akan turun jika h semakin tinggi.
- Sehingga lintasan gelombang menjadi melengkung

Indeks bias atmosfer

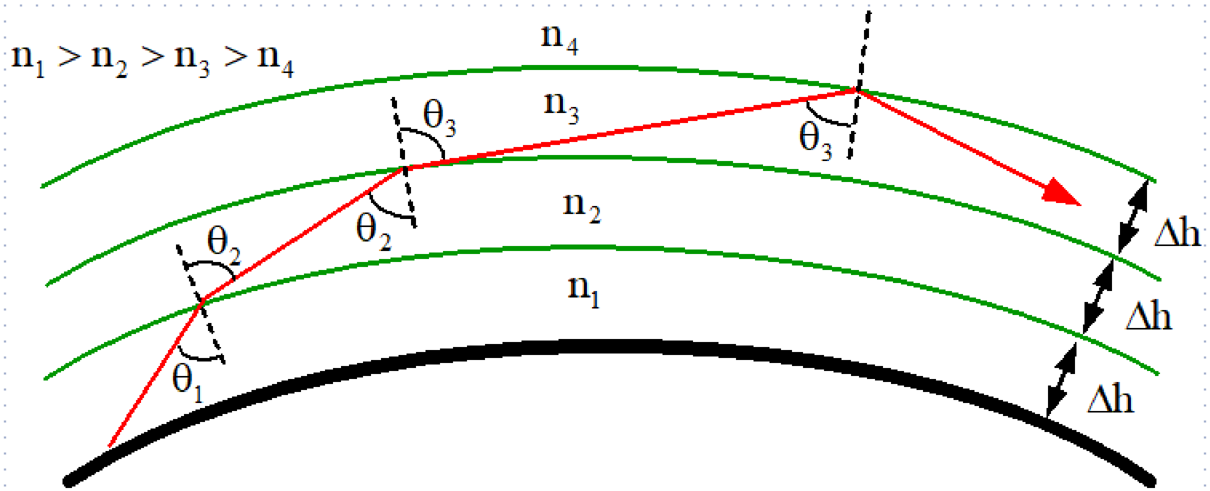
Analisis lintasan gel. Melengkung dilakukan dengan **Hukum Snellius (Kuliah Elmag Tel)**

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 = n_3 \sin\theta_3 = \ldots = n(h)\sin\theta(h) = \text{constant}$$

Jika $\Delta h \rightarrow 0$**,**
maka lengkungan lintasan pada gambar di bawah akan kontinyu



Indeks bias atmosfer



Jika n menurun dengan bertambahnya tinggi, lintasan GEM melengkung mendekati bumi

Jika n bertambah, lintasan GEM melengkung menjauhi bumi

Jika n tetap, lintasan GEM tetap 'lurus' (terhadap ketinggian)

Kadang-kadang GEM terperangkap di antara 2 lapisan (duct)

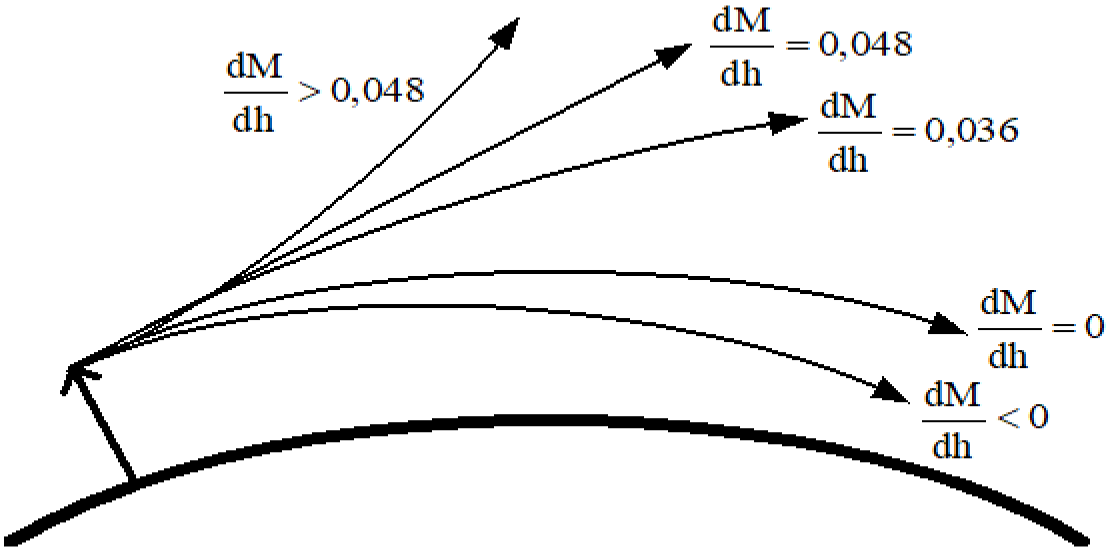
Indeks bias dimodifikasi

Indeks Bias Dimodifikasi (**M**)

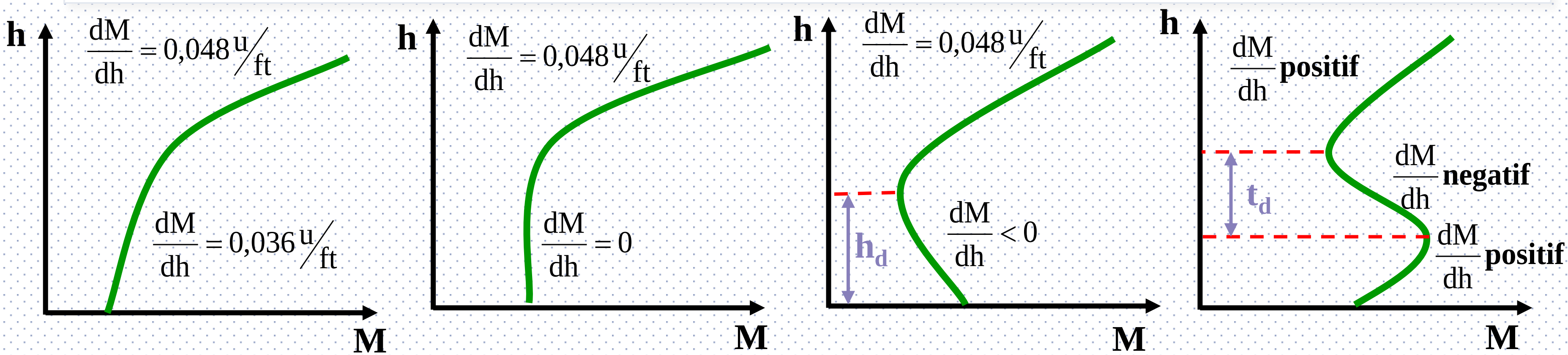
Analisis perubahan indeks bias terhadap ketinggian

$$\boxed{M = \left(n - 1 + \frac{h}{a} \right) 10^6}$$

n = indeks bias pada ketinggian h = 0
h = ketinggian dari permukaan bumi
a = jari-jari bumi = 6,37. 10^6 m



Indeks bias dimodifikasi



(a) Atmosfer standar **(b) ρ = R ; k = ∞** **(c) Duct** **(d) Elevated Duct**

Atmosfer Standar

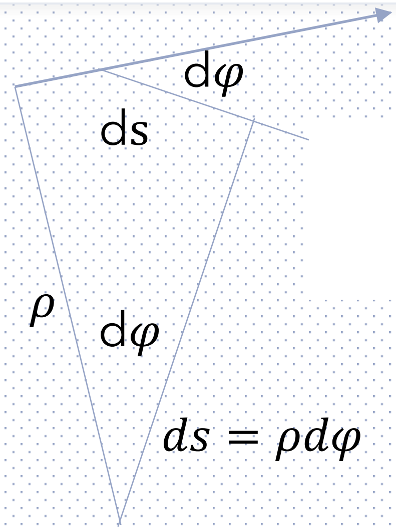
Tujuan : Standarisasi sifat atmosfer dan memudahkan perhitungan

Atmosfer standar memenuhi persamaan berikut :

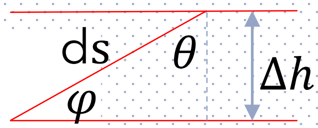
$$N = (n-1)10^6 = 289\,e^{(-0{,}136\,h)}$$

Dimana,
N = co indeks
h = ketinggian dalam km
n = indeks bias sebagai fungsi h

Jari-jari lengkung lintasan gelombang



$$ds = \rho d\varphi$$



$$\varphi = 90 - \theta$$
$$ds\ sin\varphi = dh$$

$$nsin\theta = n(h)sin\theta(h)$$
$$ncos\varphi = n(h)cos\varphi(h)$$
$$\frac{d(ncos\varphi)}{ds} = \frac{d(n(h)cos\varphi(h))}{ds}$$
$$cos\varphi\frac{dn}{ds} = nsin\varphi\frac{d\varphi}{ds}$$
$$\frac{d\varphi}{ds} = \frac{dn}{dssin\varphi}\frac{cos\varphi}{\varphi}$$

Horizontal φ=0 dan dng n=1

$$\frac{d\varphi}{ds} = \frac{dn}{dh}$$
$$\frac{dn}{dh} = \frac{1}{\rho}$$

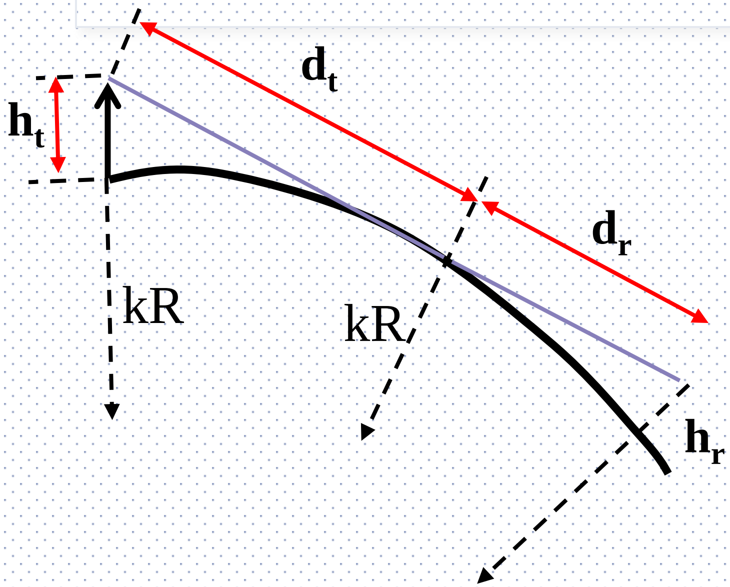
Untuk Atmosfer standar

$$(n-1)10^6 = 289\,e^{(-0,136\,h)}$$
$$\frac{dn}{dh} = d[(n-1)/dh = d[10^{-6}289\,e^{(-0,136\,h)}]/dh$$
$$= -0.136x289x10^{-6}\,xe^{(-0,136\,h)} = -39.3\ 10^{-6}\,e^{(-0,136\,h)}$$

untuk h kecil maka

$$\frac{dn}{dh} = -39.3\ 10^{-6}\ \text{ sehingga } |\rho| = \frac{10^{-6}}{39.3} = 25500km$$

Jarak horizon radio



$$(kR)^2 + d_t^2 = (kR + h_t)^2$$

- Didapatkan, untuk $h_t << R$

$$\boxed{d_t = \sqrt{2kRh_t}}$$

- Jika dt dalam mil dan ht dalam feet,

$$\boxed{d_{t(mi)} = \sqrt{\frac{3}{2} k\, h_{t(ft)}}}$$

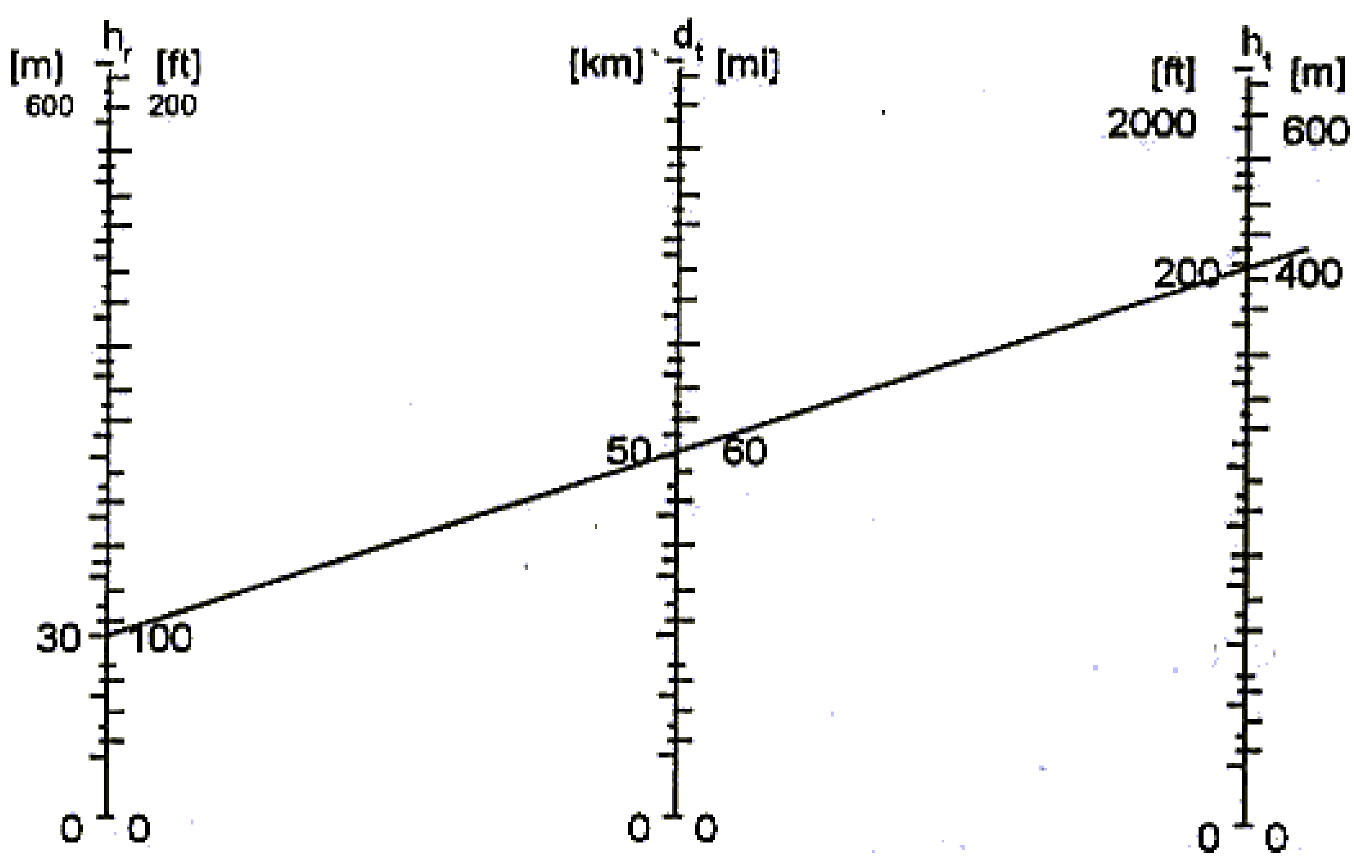
- Jika jarak horison Rx = d_r , maka :

$$\boxed{d_{tot} = d_t + d_r = \sqrt{2kRh_t} + \sqrt{2kRh_r}}$$

Contoh : Atmosfer standar (R=6370, k = 4/3) didapatkan ,

Untuk h_t = 100 m dan h_r = 1,5 meter $\Rightarrow$ d_{tot} = **46,2 km**

Nomogram


[m]
h_r
[ft]
600
200
30
100
0
0
[km]
d_t
[mi]
50
60
0
0
[ft]
h_t
[m]
2000
600
200
400
0
0

Jari-jari efektif bumi

Lengkung lintasan GEM ditransformasikan sebagai **Lintasan Lurus**
Lengkung muka bumi ditransformasikan sama, membentuk lengkungan baru dengan **Jari-Jari Efektif Bumi = kR**

$$\boxed{R_{eff} = k\,R}$$

R_{eff} = Jari-jari lengkung bumi hasil transformasi
k = faktor kelengkungan bumi (dipengaruhi atmosfer)

dan,

$$\boxed{k = \frac{1}{1 + R\dfrac{dn}{dh}}} \quad \textbf{atau} \quad \boxed{k = \frac{1}{1 - R/\rho}}$$

Jari-jari efektif bumi

- Untuk **atmosfer standar,** R = 6370 km dan ρ = 25000 km (perhitungan sebelumnya), didapatkan :

$$k = \frac{1}{1 - R/\rho} = \frac{1}{1 - \dfrac{6370}{25000}} \approx \mathbf{\frac{4}{3}} \quad \text{sehingga} \quad R_{eff} = k\,R = \frac{4}{3}\,6370 = \mathbf{8500\,km}$$

Refleksi permukaan bumi

- Karakteriktik propagasi gelombang tergantung kepada impedansi intrinsik medium
- Refleksi tergantung kepada **sifat bahan** yang dirambati gelombang dan **polarisasi** gelombang
- **Koefisien refleksi** dinyatakan sbb :

$$\overline{R}_{EH} = \frac{\sin\varphi - \sqrt{\overline{n}^2 - \cos^2\varphi}}{\sin\varphi + \sqrt{\overline{n}^2 - \cos^2\varphi}}$$

(Polarisasi horisontal)

$$\overline{R}_{EV} = \frac{\overline{n}^2 \sin\varphi - \sqrt{\overline{n}^2 - \cos^2\varphi}}{\overline{n}^2 \sin\varphi + \sqrt{\overline{n}^2 - \cos^2\varphi}}$$

(Polarisasi vertikal)

Dimana,

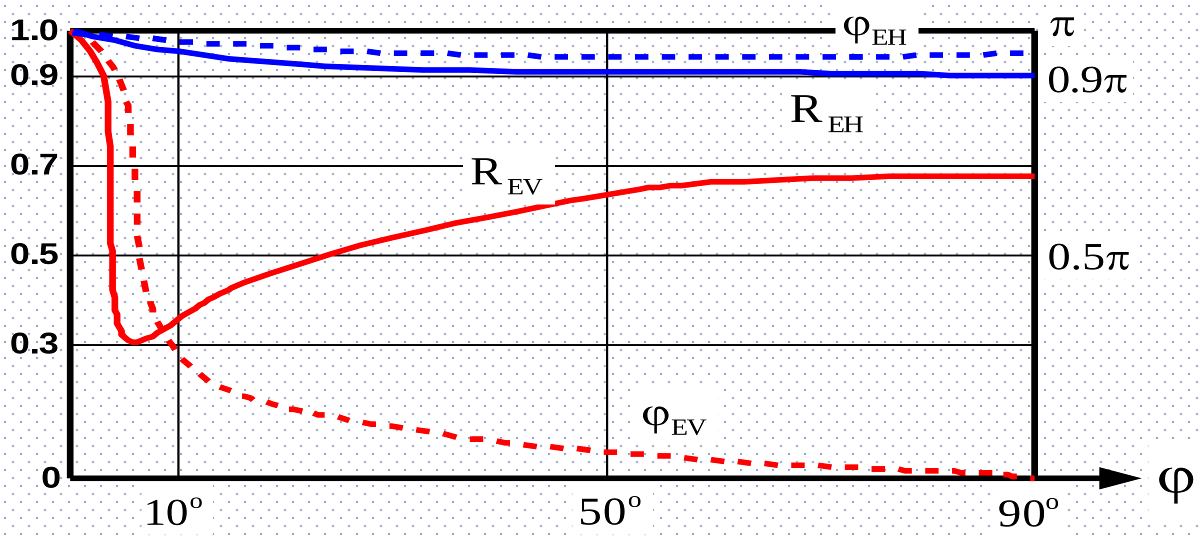
$\varphi = 90^o - \theta$ = sudut vertikal

θ = sudut datang = sudut pantul

$$\overline{n}^2 = \frac{\varepsilon_{r2} - j\dfrac{\sigma_2}{\omega\varepsilon_0}}{\varepsilon_{r1}} = \text{indeks bias relatif}$$

Refleksi permukaan bumi

- Untuk keadaan permukaan bumi dan keadaan udara tertentu, maka grafik koefisien pantul dan sudut datang sebagai fungsi φ diberikan sebagai berikut

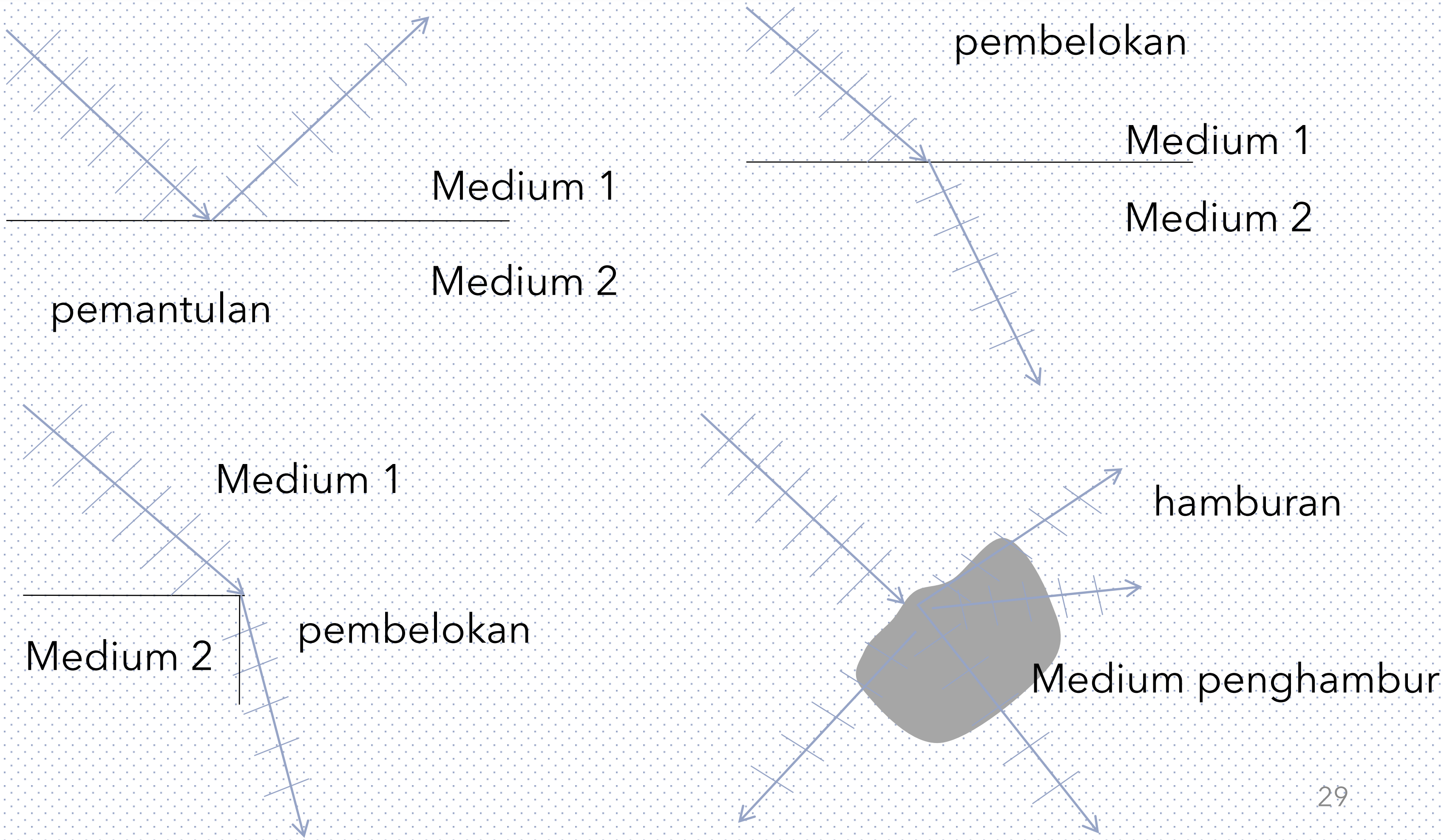


Karena jarak Tx-Rx >> tinggi menara, maka biasa dianggap $R_{EV} = R_{EH} = 1$, dan $\phi_R = \pi$ atau 180^o)

- Untuk suatu kondisi, sudut φ untuk koefisien pantul minimum disebut sebagai sudut Brewster

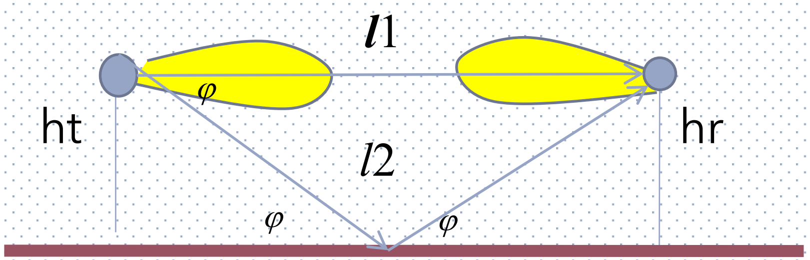
Redaman bumi datar

Mekanisme perambatan GEM



Redaman bumi datar

Polaradiasi antena



Permukaan tanahd

Gelombang ruang terdiri 2 komponen, yaitu gelombang langsung dan gelombang pantul. Nilai masing-masing ditentukan koefisien refleksi permukaan tanah dan polaradiasi antena.

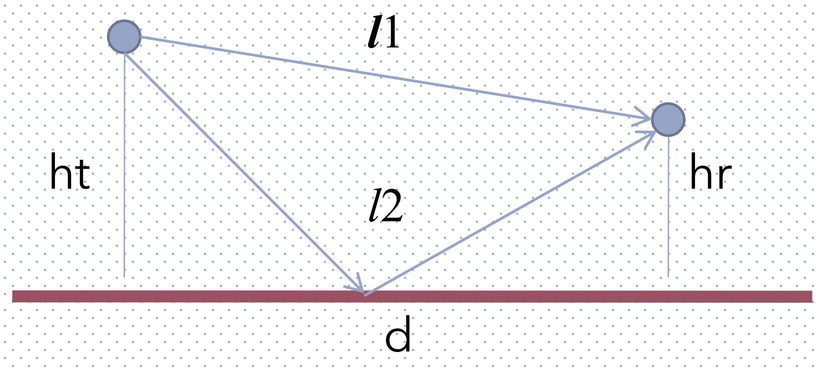
$$G_A = 40 \text{ dB} \;\Rightarrow\; \text{beamwidth} : \quad \theta_1 = \phi_1 = \sqrt{\frac{4\pi}{10^4}} \approx 2{,}1^o$$

$$h_t = h_r = 50 \text{ m} \;;\; d = 25 \text{ km} \quad \Rightarrow \; \text{sudut} \quad \varphi \approx \tan^{-1}\left(\frac{50}{12.10^3}\right) \approx 0{,}12^o$$

Besar koefisien pantul permukaan tanah mendekati 1 dengan bergeser fasa 180 derajat, E pada arah langsung dan pantul hampir sama besar.

Interferensi destruktif

Redaman propagasi bumi datar



$$l_1 = \sqrt{d^2 + (h_t - h_r)^2} \approx d(1 + 0.5\left(\frac{h_t - h_r}{d}\right)^2)$$

$$l_2 = \sqrt{d^2 + (h_t + h_r)^2} \approx d(1 + 0.5\left(\frac{h_t + h_r}{d}\right)^2)$$

$$\Delta l = l_2 - l_1 = \frac{2h_t h_r}{d}$$

$$d >> h_t$$

$$\varphi \approx 0 \quad \text{maka} \;\; R_{EV} \;\&\; R_{EH} = 1e^{j\pi}$$

$$E_t = E_l + E_l e^{j\pi} e^{j(\frac{2\pi}{\lambda}\Delta l)} = E_l(1 + e^{j(\pi + \frac{2\pi}{\lambda}\Delta l)})$$

$$1 + e^{j\psi} = e^{j\psi/2}(e^{-j\psi/2} + e^{j\psi/2}) = 2\cos\frac{\psi}{2} e^{j\psi/2}$$

$$E_t = E_l(1 + e^{j(\pi + \frac{2\pi}{\lambda}\Delta l)}) = 2E_l\left(e^{j(\frac{\pi}{2} + \frac{\pi}{\lambda}\frac{2h_t h_r}{d})}\right)\cos(\frac{\pi}{2} + \frac{\pi}{\lambda}\frac{2h_t h_r}{d})$$

Redaman propagasi bumi datar

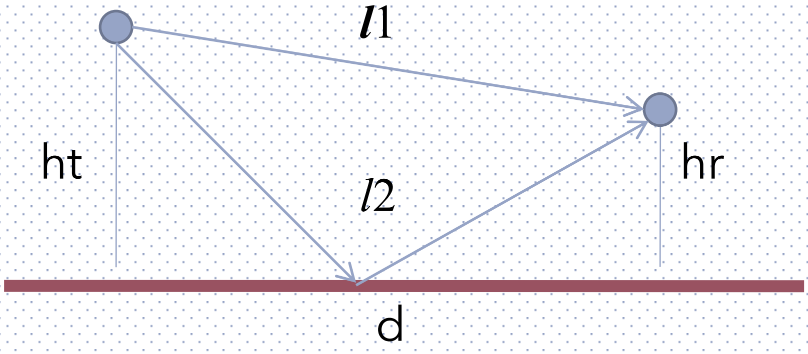
$$E_t = 2E_l \sin\left(\frac{\pi}{\lambda}\frac{2h_t h_r}{d}\right)\left(e^{j\left(\frac{\pi}{2}+\frac{\pi}{\lambda}\frac{2h_t h_r}{d}\right)}\right)$$

$$\frac{|E_t|}{|E_l|} = 2\sin\left(\frac{\pi}{\lambda}\frac{2h_t h_r}{d}\right) \text{ untuk d >> ht}$$

$$\frac{|E_t|}{|E_l|} = \frac{4\pi}{\lambda}\frac{h_t h_r}{d}$$

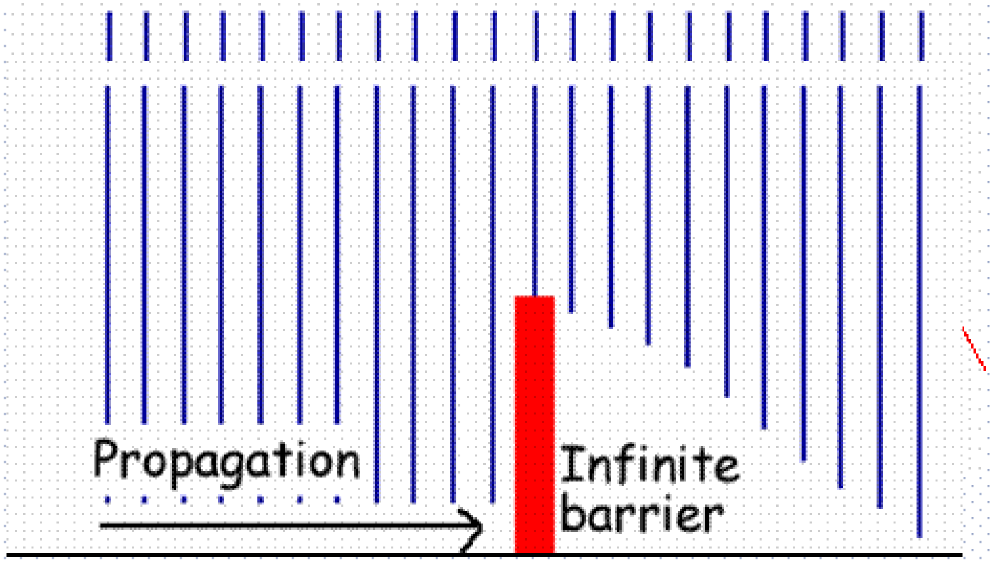
maka untuk redaman propagasi dikoreksi menjadi

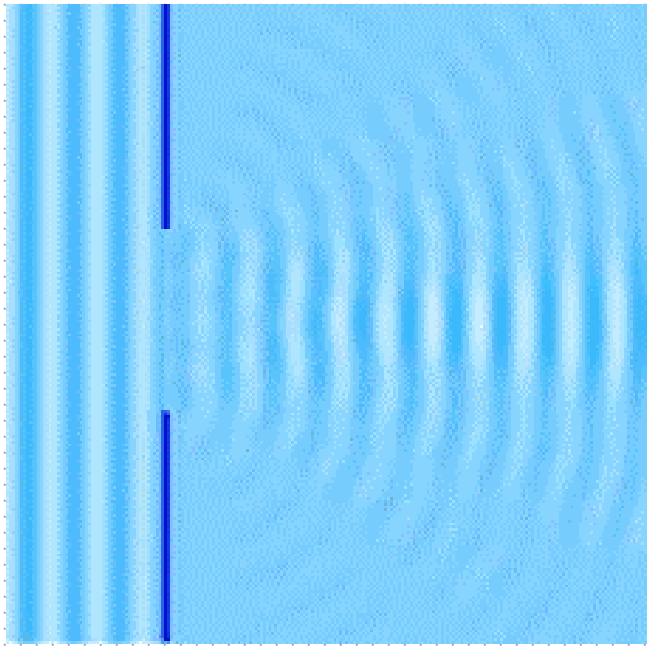
$$L_{bumidatar} = L_{fs} - 20\log\left(\frac{4\pi}{\lambda}\frac{h_t h_r}{d}\right)$$



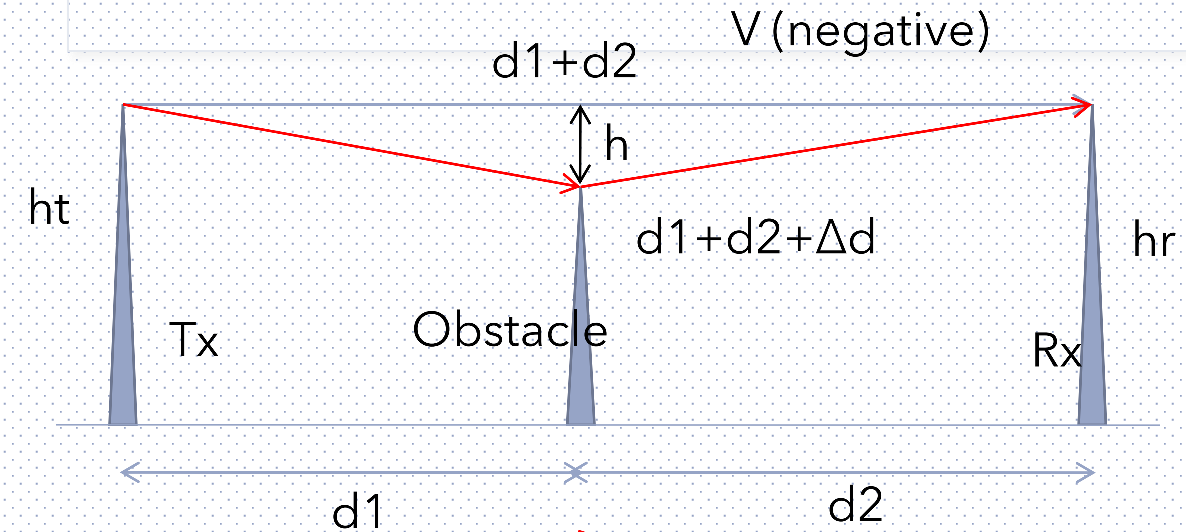
Rugi-rugi difraksi

Difraksi knife edge

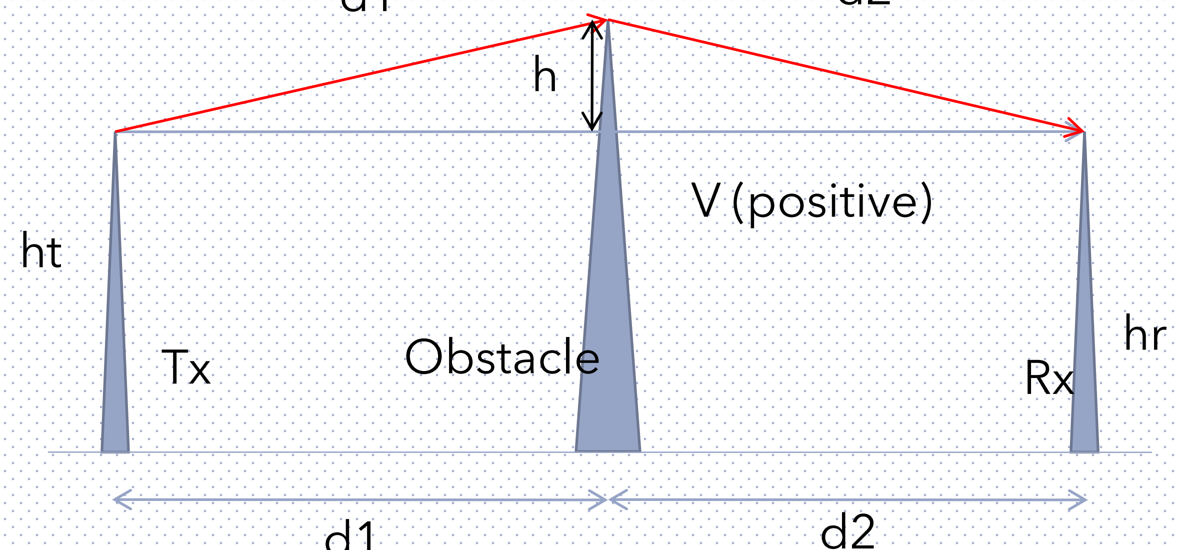




Difraksi knife edge



$$\Delta d \approx h^2 \frac{d_1 + d_2}{2 d_1 d_2}$$



$$|v| = h\sqrt{\frac{2(d_1 + d_2)}{\lambda d_1 d_2}}$$

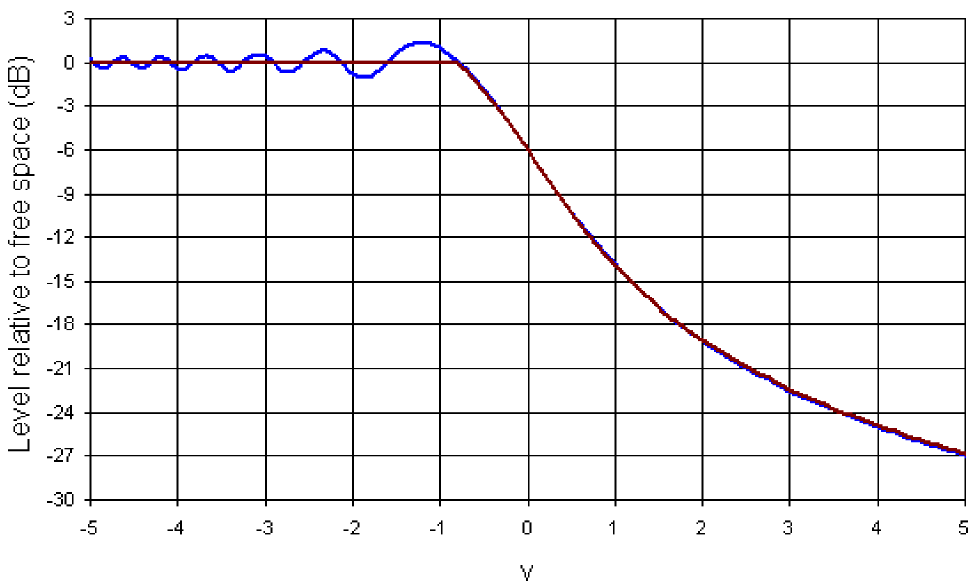
$$|v| = \sqrt{\frac{|\Delta h|}{\lambda}}$$

Redaman difraksi knife edge

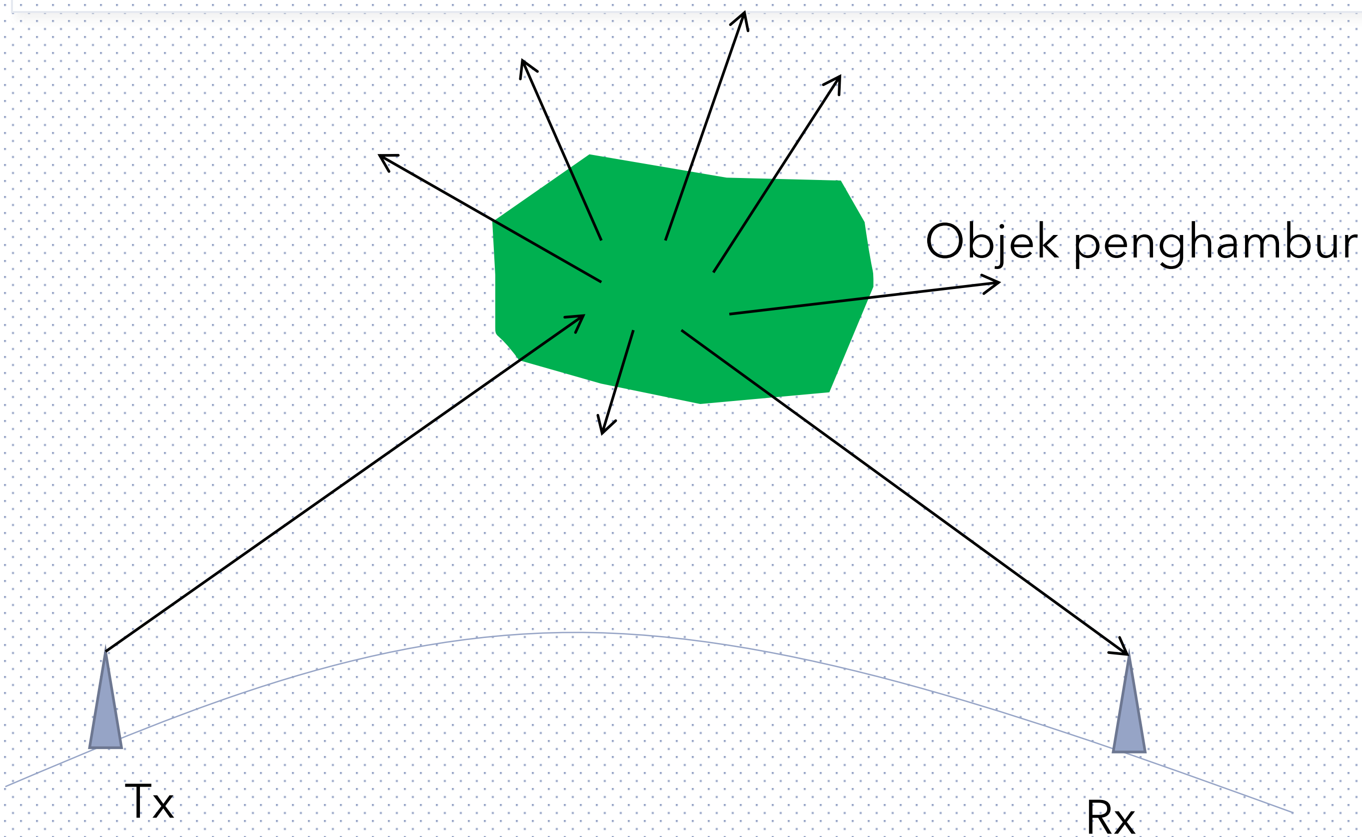
$G_d(dB) = 20 \log|F(v)|$

$$F(v) = \frac{(1+j)}{2}\int_v^{\infty} \exp\left(\frac{-j\pi t^2}{2}\right)dt$$

$$J(v) = 6.9 + 20\log(\sqrt{(v-0.1)^2+1}+v-0.1)$$



Hamburan troposfer



Komunikasi radio memanfaatkan hamburan troposfer disebut Troposcatter

Troposcaters

- Lap. Troposfer membentuk gumpalan-gumpalan gas dengan diameter orde cm sd 50 m. Gumpalan-gumpalan tersebut memiliki indeks bias berbeda-beda dan bergerak acak.
  - Frekuensi 300-30000MHz (UHF/SHF)
  - Ketinggian 18 km (ekuator)
  - Jangkauan 200-800km
  - Fading besar

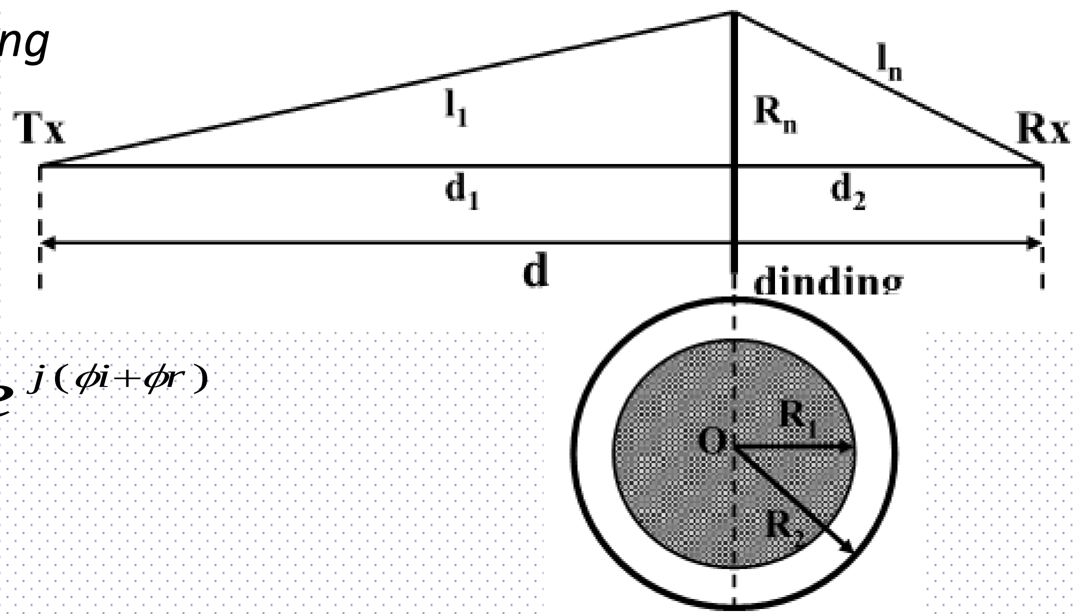
Fresnel zone

Daerah Fresnel

- Difraksi Fresnel : mula-mula menjelaskan difraksi cahaya melalui suatu celah kemudian berkembang untuk EM dan suara.
- Prinsip Huygens : setiap titik yang dilalui gelombang dapat dianggap sebagai sumber titik yang memancarkan gelombang.

Daerah Fresnel

Menentukan jari jari fresnel
Berdasar beda fasa antara
Gelombang langsung dan gelombang
Pantul.



$$E_t = E_i + E_r$$

$$E_t = E_0 e^{j\phi i} + \left|\Gamma\right| E_0 e^{j(\phi i + \phi r)}$$

ϕr : beda fasa

Ketika jarak Tx ke Rx >> dari tinggi antena
Maka komplemen sudut datang menedekati Nol.

Daerah Fresnel

- Karakteriktik propagasi gelombang tergantung kepada impedansi intrinsik medium
- Refleksi tergantung kepada **sifat bahan** yang dirambati gelombang dan **polarisasi** gelombang
- **Koefisien refleksi** dinyatakan sbb :

$$\boxed{\overline{R}_{EH} = \frac{\sin\varphi - \sqrt{\overline{n}^2 - \cos^2\varphi}}{\sin\varphi + \sqrt{\overline{n}^2 - \cos^2\varphi}}}$$

(Polarisasi horisontal)

$$\boxed{\overline{R}_{EV} = \frac{\overline{n}^2\sin\varphi - \sqrt{\overline{n}^2 - \cos^2\varphi}}{\overline{n}^2\sin\varphi + \sqrt{\overline{n}^2 - \cos^2\varphi}}}$$

(Polarisasi vertikal)

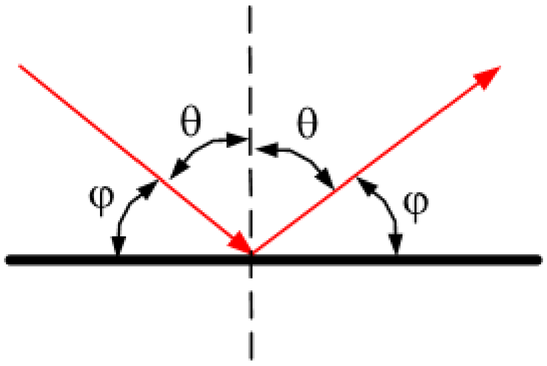
Dimana,

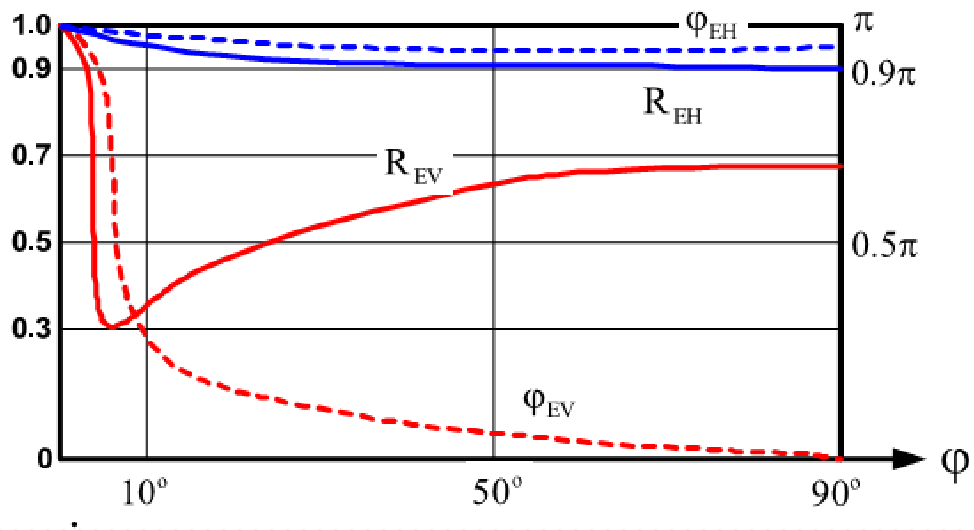
$\varphi = 90^o - \theta$ = sudut vertikal

θ = sudut datang = sudut pantul

$$\overline{n}^2 = \frac{\varepsilon_{r2} - j\dfrac{\sigma_2}{\omega\varepsilon_0}}{\varepsilon_{r1}} = \text{indeks bias relatif}$$

Daerah Fresnel



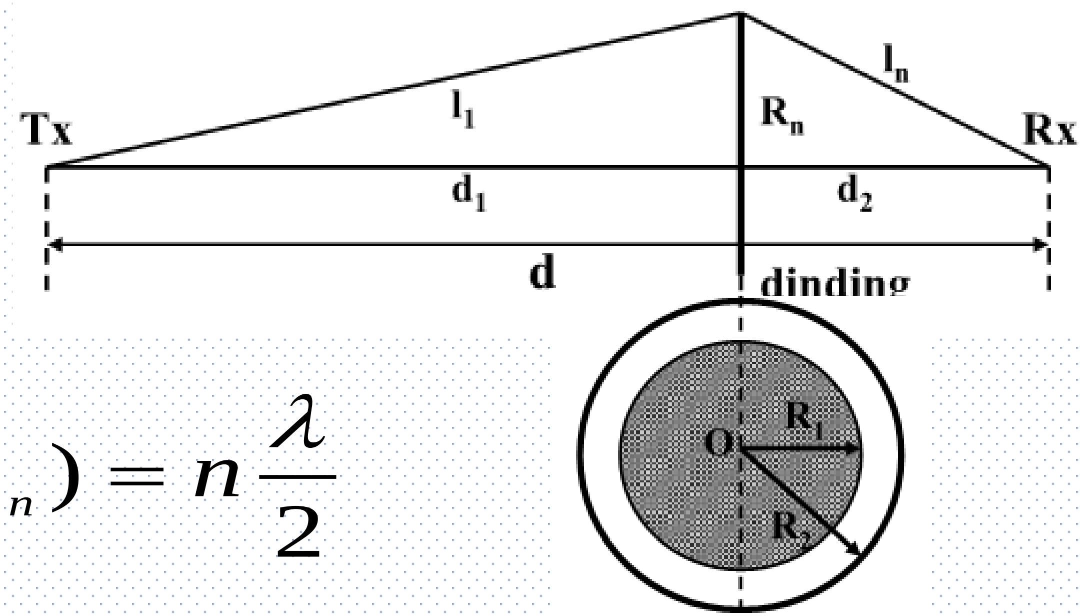


Daerah Fresnel

Ketika komplemen sudut datang $\varphi \approx 0$

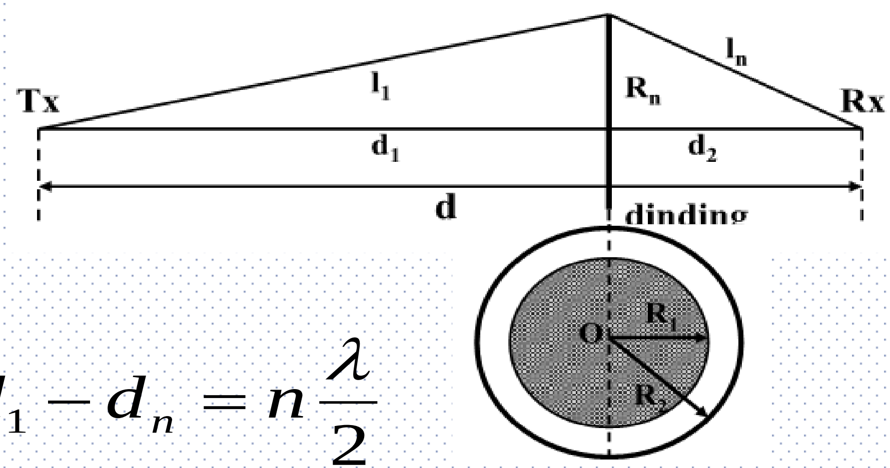
Maka $\Gamma \approx 1$

$$\phi\mathrm{r} = \pi$$



$$(l_1 + l_n) - (d_1 + d_n) = n\frac{\lambda}{2}$$

Daerah Fresnel



$$(l_1 + l_n) - (d_1 + d_n) = n\frac{\lambda}{2}$$

$$(\sqrt{d_1^{\,2} + R_n^{\,2}} + \sqrt{d_n^{\,2} + R_n^{\,2}}) - d_1 - d_n = n\frac{\lambda}{2}$$

$$d_1\sqrt{1 + \left(\frac{R_n}{d_1}\right)^2} + d_n\sqrt{1 + \left(\frac{R_n}{d_n}\right)^2} - d_1 - d_n = n\frac{\lambda}{2} \quad \textbf{(a)}$$

$$d_1\sqrt{1 + \left(\frac{R_n}{d_1}\right)^2} \approx d_1(1 + \frac{1}{2}\left(\frac{R_n}{d_1}\right)^2)$$

Daerah Fresnel

$$d_1\sqrt{1+\left(\frac{R_n}{d_1}\right)^2} \approx d_1(1+\frac{1}{2}\left(\frac{R_n}{d_1}\right)^2)$$

$$\left(1+\frac{1}{2}\left(\frac{R_n}{d_1}\right)^2\right)^{\mathbf{2}} = 1+\left(\frac{R_n}{d_1}\right)^2+\frac{1}{4}\left(\frac{R_n}{d_1}\right)^2 \approx 1+\left(\frac{R_n}{d_1}\right)^2 \quad R_n < d_1$$

(a) menjadi

$$d_1(1+\frac{1}{2}\left(\frac{R_n}{d_1}\right)^2)+d_n(1+\frac{1}{2}\left(\frac{R_n}{d_n}\right)^2)-d_1-d_n = n\frac{\lambda}{2}$$

$$\frac{d_1}{2}\left(\frac{R_n}{d_1}\right)^2+\frac{d_n}{2}\left(\frac{R_n}{d_n}\right)^2 = n\frac{\lambda}{2}$$

$$R_n^{\ 2}\left(\frac{1}{2d_1}+\frac{1}{2d_n}\right) = n\frac{\lambda}{2} \rightarrow R_n = \sqrt{\frac{n\lambda d_1 d_n}{d_1+d_n}}$$

$$R_n = \sqrt{\frac{n\lambda d_1 d_n}{d}}$$

Arti fisis daerah Fresnel

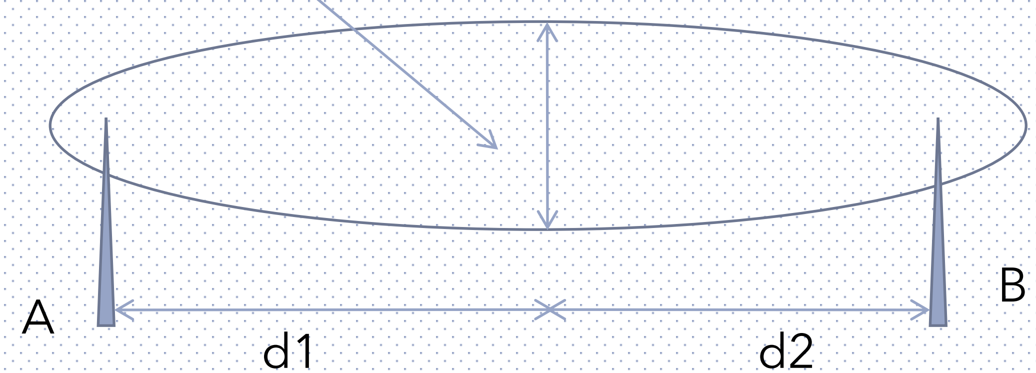
- Medan pada F1,F3,F5,..(ganjil) sefasa. Sefasa dengan F1, menghasilkan interferensi konstruktif
- Medan pada F2,F4,F6,..(genap) sefasa. Berlawanan fasa dengan F1, menghasilkan interferensi destruktif.

Daerah Fresnel 1

$$R_I = 17.3\sqrt{\frac{d_1 d_2}{d.f_{GHz}}}$$

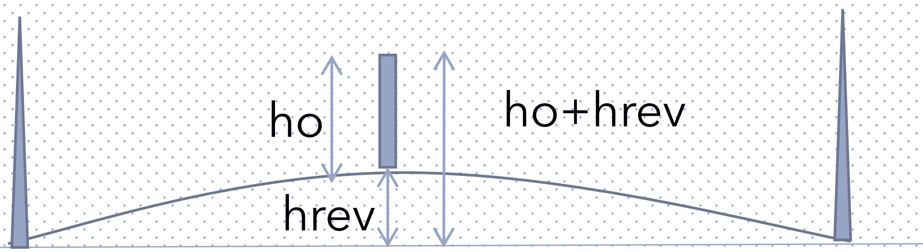
R_1 jari-jari fresnell (dalam meter)
d_1 , d_2, dan d jarak (dalam kilometer)
f frekuensi (dalam GHz)

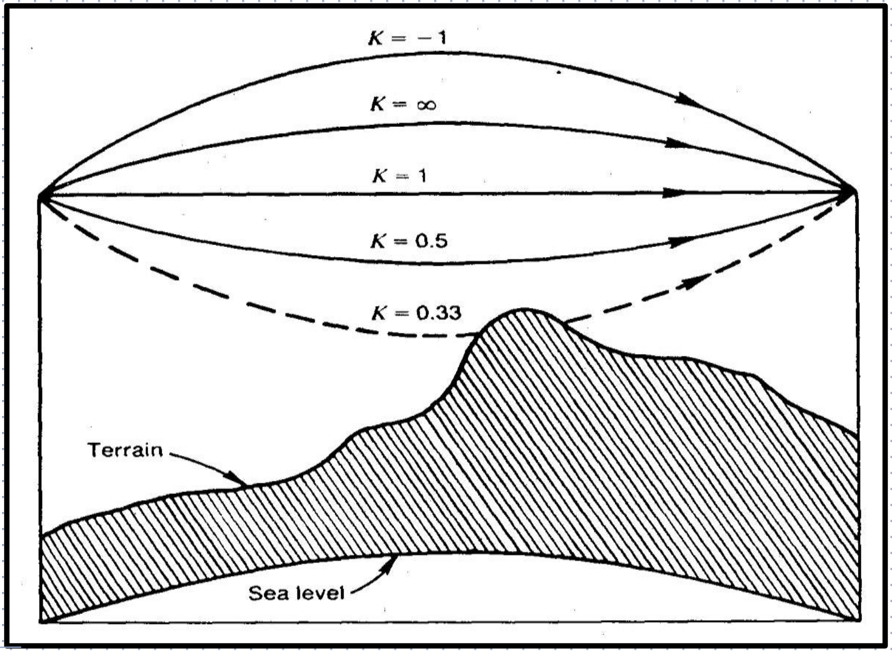
Hubungan Line of Sight
Daerah fresnel 1 bebas rintangan



Koreksi ketinggian

$$h_{rev}(m) = \frac{0.079 d_{1(km)} d_{2(km)}}{k}$$





Koreksi ketinggian

Pada lubang dengan **jari-jari = 0,6 jari-jari fresnell I**, maka kuat medan penerimaan **sama** dengan kuat medan penerimaan jika tanpa layar

Didefinisikan ***Clearance Factor***

$$C_{RI} = \frac{\text{clearance}}{\text{first fresnell radius}} = \frac{C}{R_I}$$

Redaman lintasan (pathloss) dianggap seolah adalah redaman ruang bebas (free space loss) , jika clearance factor = 0,6

$$L_{fs}(dB) = 32{,}5 + 20\log f_{(MHz)} + 20\log d_{(km)}$$

$$L_{fs}(dB) = 92{,}45 + 20\log f_{(GHz)} + 20\log d_{(km)}$$

Path loss akan berubah dari harga free space pathloss jika clearance factor ≠ 0,6

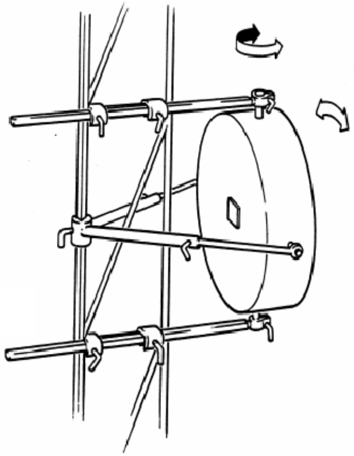
Clearance Factor = 0,6 sangat disukai dalam desain , karena $L_p = L_{fs}$ untuk jenis medium pemantul apapun

Link budget

Gelombang ruang bebas

- Gelombang ruang bebas disebut juga gelombang langsung.
- Digunakan untuk komunikasi satelit, hubungan LOS
- Tipe kanalnya memiliki fading yang sangat kecil. Fading margin tidak diperlukan.

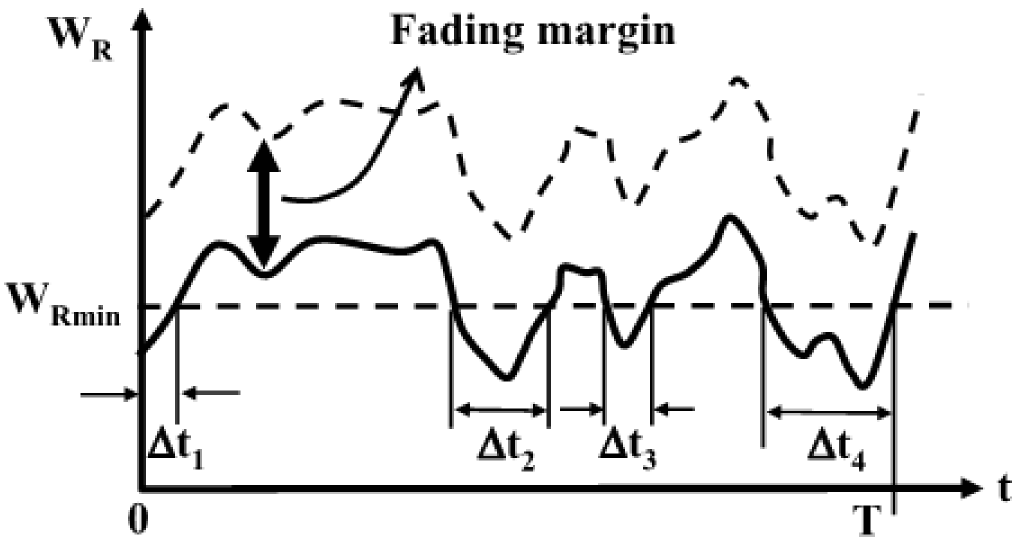
Gelombang ruang bebas



Fading

- Fading : Fluktuasi daya penerimaan.
- Teknik mengatasi Fading
  - Menambahkan fading margin
  - Menambahkan Automatic Gain Control
  - Diversity

Fading margin



Fading margin meningkatkan reliability

Fading margin	reliability
10 dB	90%
20 dB	99%
30 dB	99.9%
40 dB	99.99%

$$\boxed{P_{outage} = 1 - \text{Reliability}}$$

Reliability (keandalan)

$$\boxed{\text{Reliability} = \frac{\text{Jumlah waktu dimana } W_R > W_{R\,min}}{\text{Waktu total pengamatan}}}$$

Sebelum diberikan fading,

$$\text{Re liability} = \frac{T - (\Delta t_1 + \Delta t_2 + \Delta t_3 + \Delta t_4)}{T} \times 100\%$$

Fading margin

<u>Rumus Barnett-Vignant</u> untuk menghitung fading margin microwave link stasioner (LOS terrestrial) ...

$$F_m = 30\log_{10}(D) + 10\log_{10}(6ABf) - 10\log_{10}(1-R) - 70 \quad [\text{dB}]$$

D = distance (km)

f = frequency (GHz)

R = reliability expressed as a decimal (i.e. 99.9% = 0.999)

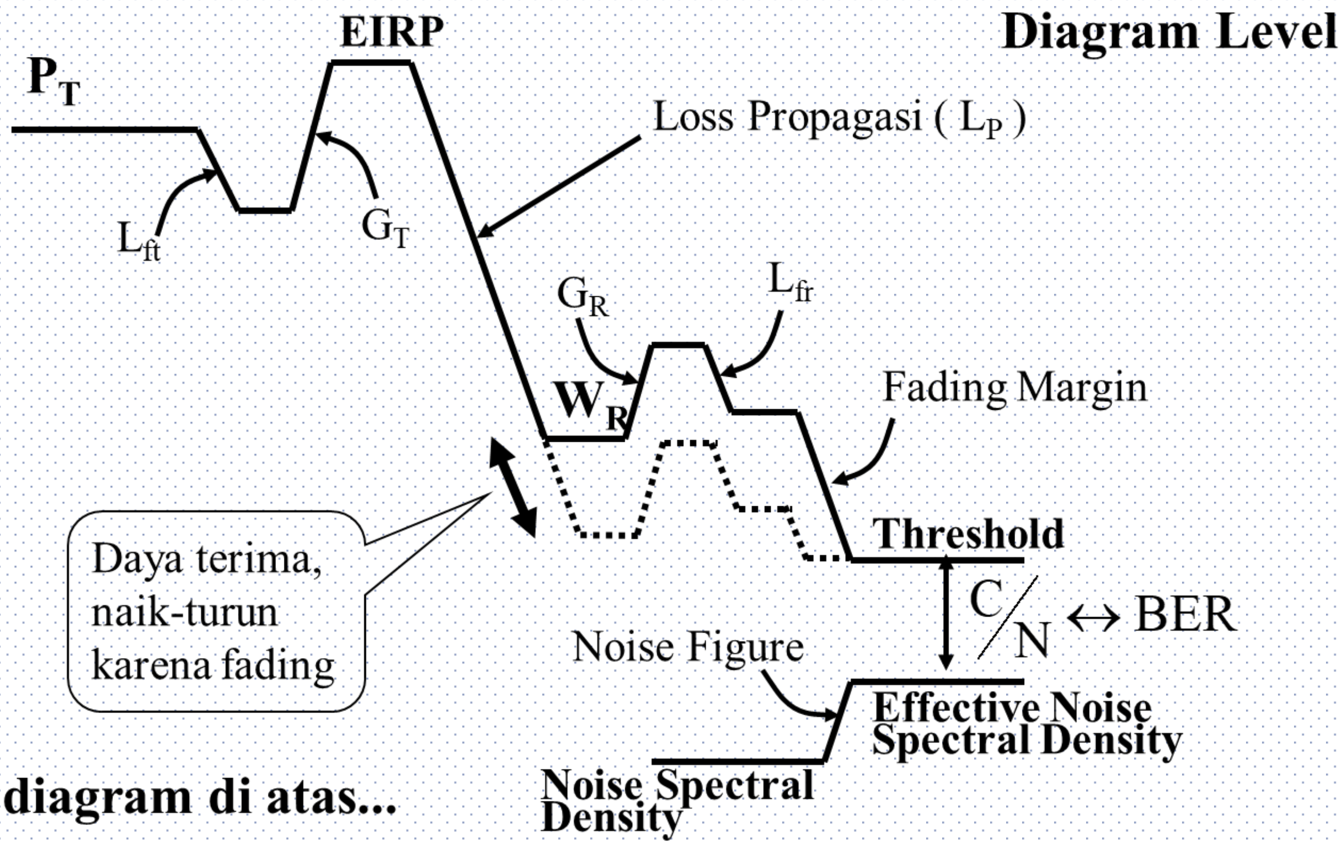
A = roughness factor (4 = smooth, 1 = avg, 0.25 = very rough)

B = v weather conversion factor (1 = worst - month case,
0.5 = hot humid areas, 0.25 = for average inland areas,
0.125 = very dry or mountainous areas)

Diversity

- Frequency diversity
- Time slot diversity
- Space diversity
- Polarization diversity

Link budget



Lihat diagram di atas...

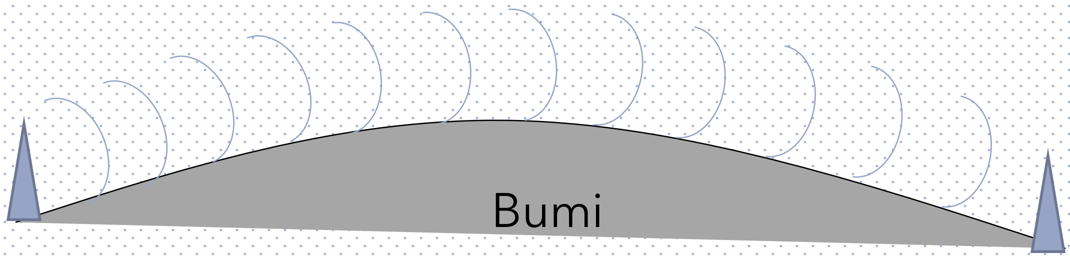
$$P_T = \text{Threshold} + FM + L_{fR} - G_R + L_P - G_T + L_{fT}$$

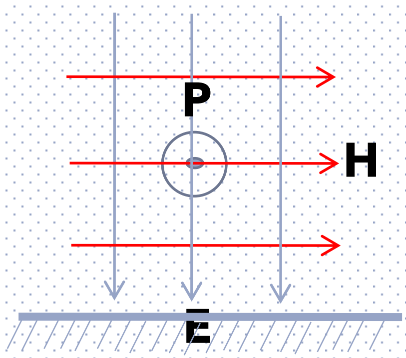
Penentuan kofigurasi sistem radio teresterial

Komunikasi ground wave

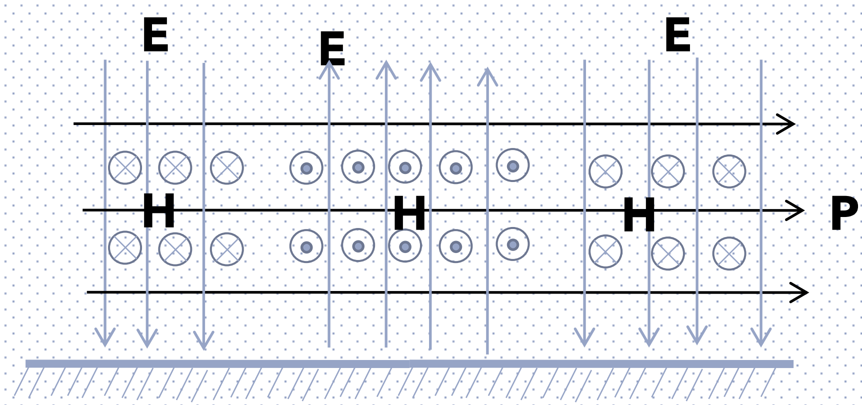
- Komunikasi radio ground wave disebut juga surface wave.
- Range frekuensi : 3 kHz sd 300 kHz (VLF-LF)
- Merambat mengikuti permukaan bumi.
- Aplikasi : Navigasi, siaran AM, Deteksi ledakan nuklir.

Propagasi ground wave





Tampak depan



Tampak samping

Polarisasi Vertikal lebih efektif dirambatkan dan polarisasi horisontal seolah di-hubung singkat oleh bumi. (ingat tentang Rv dan Rh)

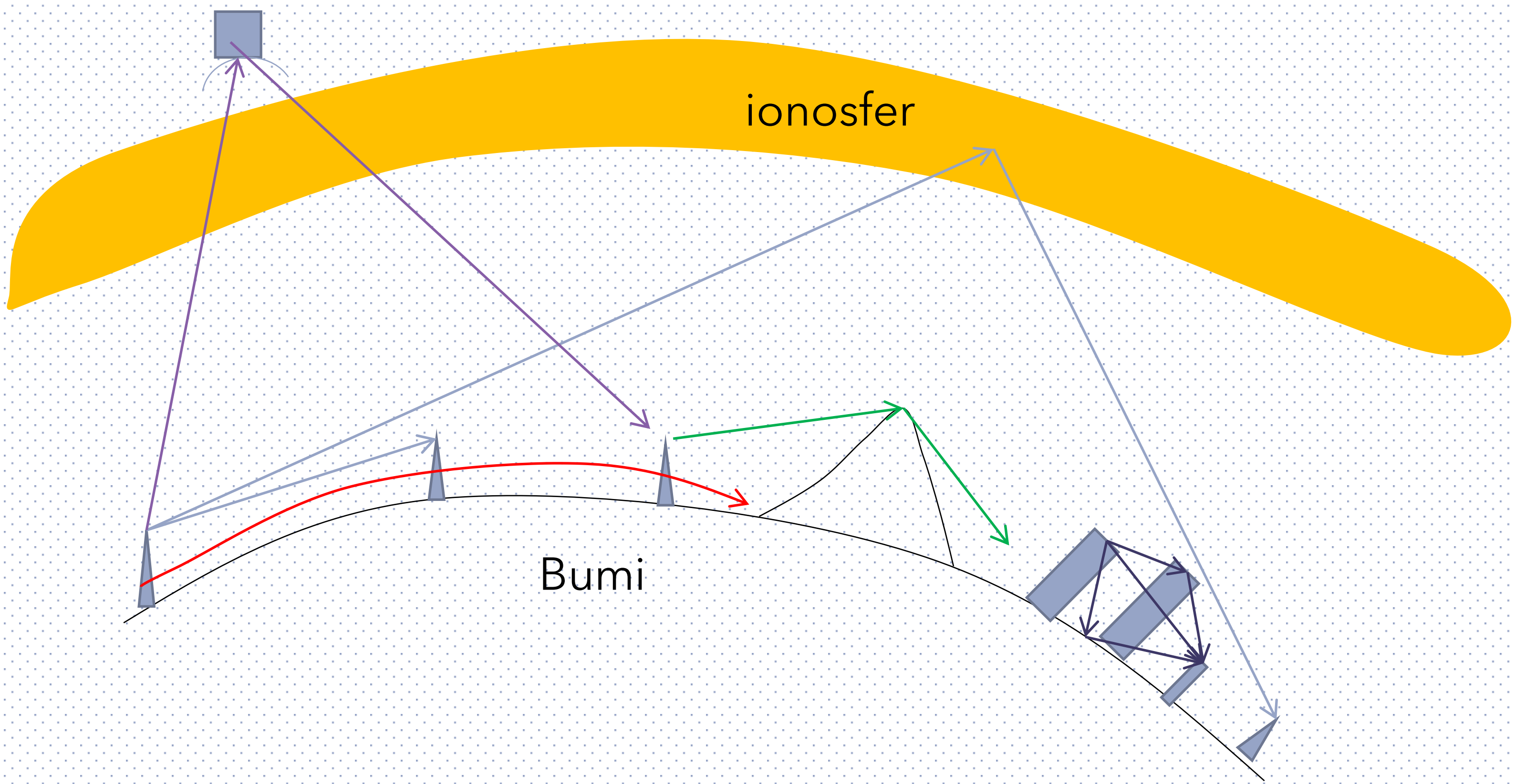
Pertimbangan frekuensi

- Frekuensi yang digunakan frekuensi rendah. Semakin tinggi frekuensi atenuasi yang diberikan oleh tanah makin besar (skin depth).
- Permukaan bumi tidak uniform (kondisi tanah bermacam-macam, rawa, laut, pegunungan, pemukiman dll). Skin depth tidak uniform.

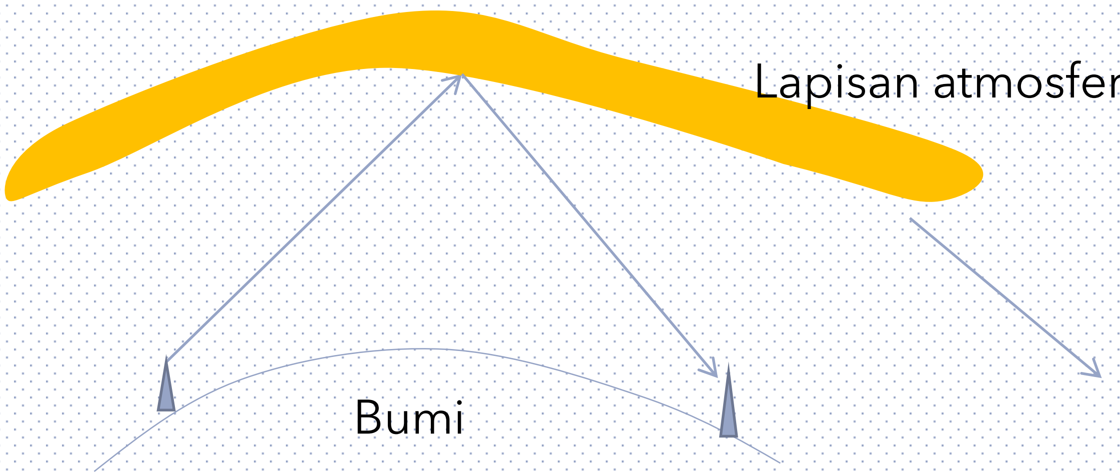
Pertimbangan antena

- Karena Ground wave lebih efektif untuk polarisasi Vertikal maka antena yang digunakan biasanya adalah antena dengan polarisasi vertikal.

Propagasi gelombang langit



Conducting layer



1902
(Oliver Heaviside, Inggris)
(Arthur Kennelly, Amerika)

Conducting layer

1920an
Ionosonde : radar untuk mengamati
Lapisan ionosfer (range frekuensi 1-40MHz).
Pengaruh terhadap gelombang radio dapat
diamati.

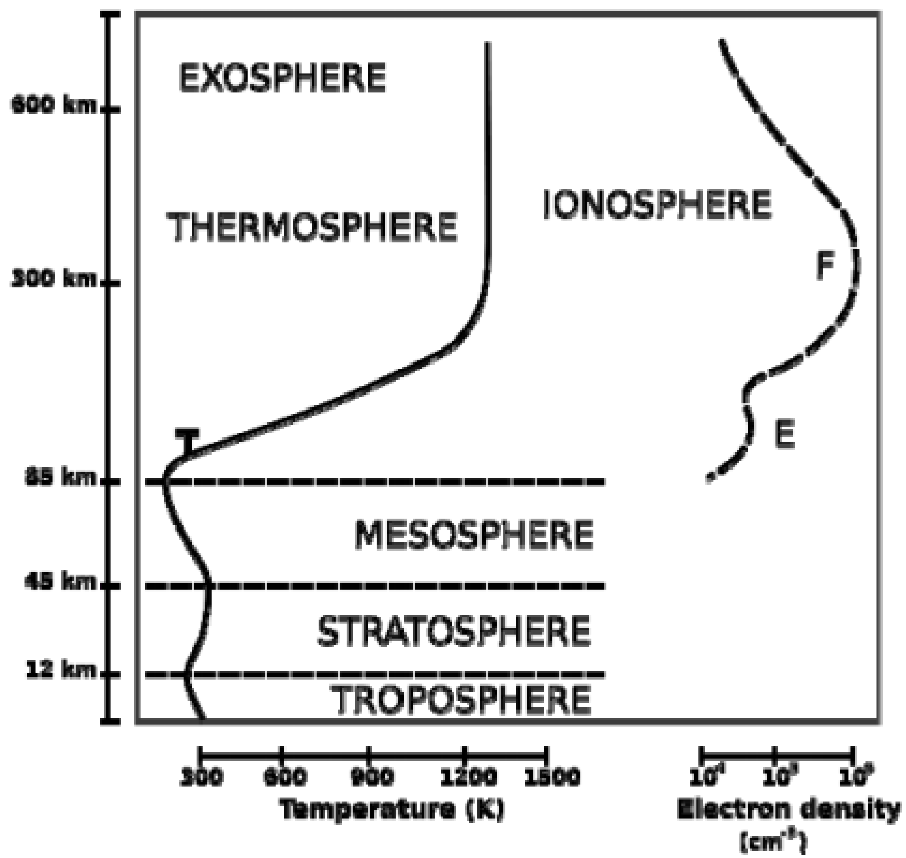
Lapisan ionosfer

- **Lapisan D (50-90 km)**
  - Konsentrasi elektron dan ion serta ketinggian tergantung elevasi matahari
  - Hanya ada pada siang hari
  - Menyerap frekuensi MF (0.3 – 3 MHz) dan parsial untuk HF
- **Lapisan E (90-140 km)**
  - Konsentrasi elektron dan ion serta ketinggian tergantung elevasi matahari
  - Untuk komunikasi HF jangkauan < 1500 km untuk siang dan >1500 km untuk malam.
- **Lapisan Es (90-140 km)**
  - Kadang-kadang terjadi kemungknan 50%.

Lapisan ionosfer

- **Lapisan F1 (140-210 km)**
  - Konsentrasi elektron dan ion serta ketinggian tergantung elevasi matahari
  - Hanya ada pada siang hari. Sering dipakai pada siang hari saja.
- **Lapisan F2 (>210 km)**
  - Konsentrasi elektron dan ion serta ketinggian tidak tergantung elevasi matahari.
  - Berubah menurut musim dan bintik matahari.

Lapisan ionosfer



Indeks bias ionosfer

$$n_i = \sqrt{\varepsilon_r^*} = \sqrt{1 + \frac{Nq^2}{j\omega\varepsilon_0 m(\upsilon + j\omega)}}$$

Dimana,

N = kepadatan ion (ion/m^3)

m = massa partikel (ion)

q = muatan partikel

υ = jumlah benturan per detik

ε_r^* = konstanta kompleks permitivitas ionosfer

Indeks bias

$$n_i = \sqrt{1 - \left[\frac{f_c}{f}\right]^2}$$ **dimana** $$f_c = \frac{1}{2\pi}\sqrt{\frac{N_{max} q^2}{m \varepsilon_0}}$$

f_c = frekuensi kritis

Ionosfer dapat dilihat sebagai lapisan dielektrik
Jika frekuensi makin tinggi maka indek bias makin mendekati 1 sampai suatu saat gelombang diteruskan.
Indeks bias < 1 maka gelombang dibiaskan menjahui normal (f> fc).
Indek bias ≈ 1 maka gelombang diteruskan (f>>fc)
Indek bias bernilai imajiner maka gelombang dipantulkan ke bumi.

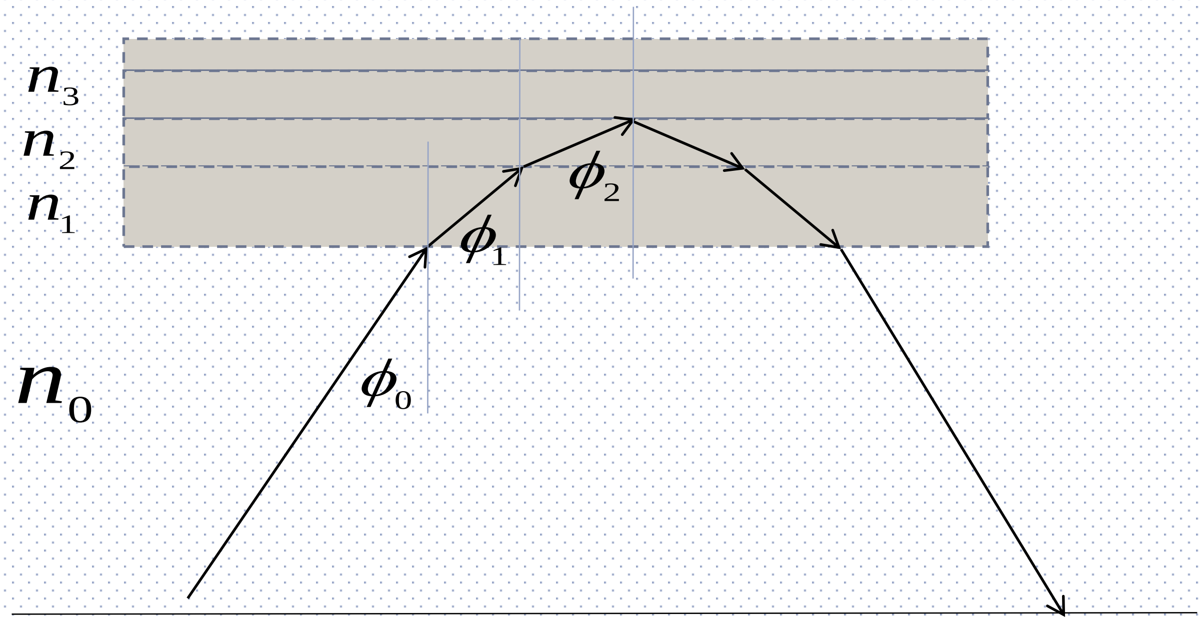
Indeks bias

$$
\left.\begin{array}{l}
m_e = 9{,}11.10^{-31}\,\text{kg} \\
q_e = 1{,}6.10^{-19}\,\text{coulomb} \\
\varepsilon_0 = \dfrac{1}{36\pi}10^{-8}\ \text{F}/\text{m} \\
N_{max}\ \left(\text{elektron}/\text{m}^3\right)
\end{array}\right\}
\begin{array}{l}
\boxed{f_c \approx 9\sqrt{N_{max}}} \\
\text{atau,} \\
\boxed{f_c \approx \sqrt{81 N_{max}}}
\end{array}
$$

$$n_0 \sin\phi_0 = n_1 \sin\phi_1$$

$$\text{ketika } n_0 = 1 \text{ dan } \phi_1 = 90^0$$

$$\text{maka} \quad \sin\phi_0 = n_1$$



Pemantulan ionosfer

$$n_1 = \sqrt{1 - \left(\frac{fc}{f}\right)^2}$$

$$\text{maka} \quad \sin\phi_0 = n_1 = \sqrt{1 - \left(\frac{fc}{f}\right)^2}$$

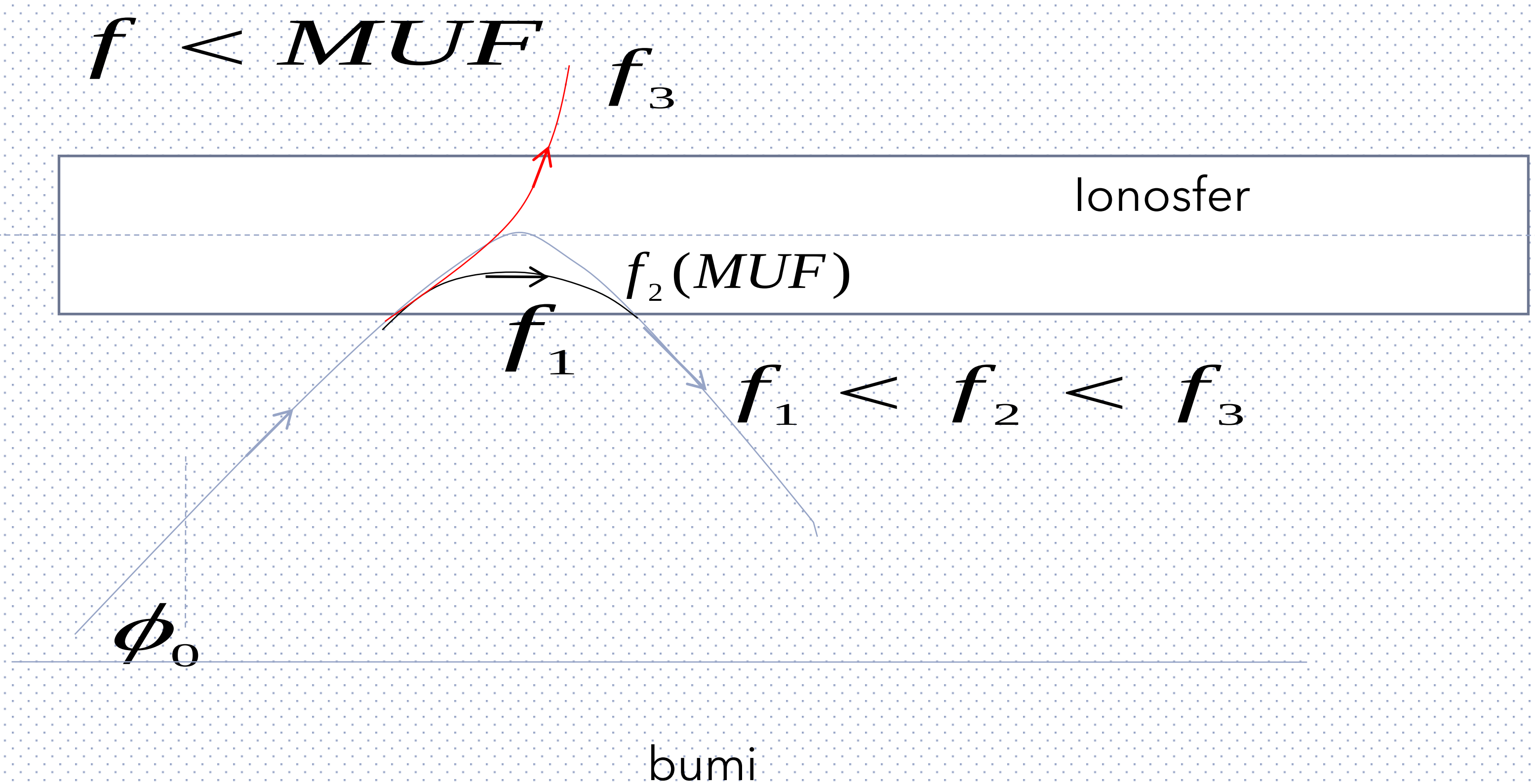
$$\sin^2\phi_0 = 1 - \left(\frac{f_c}{f}\right)^2$$

$$\left(\frac{f_c}{f}\right)^2 = 1 - \sin^2\phi_0 = \cos^2\phi_0$$

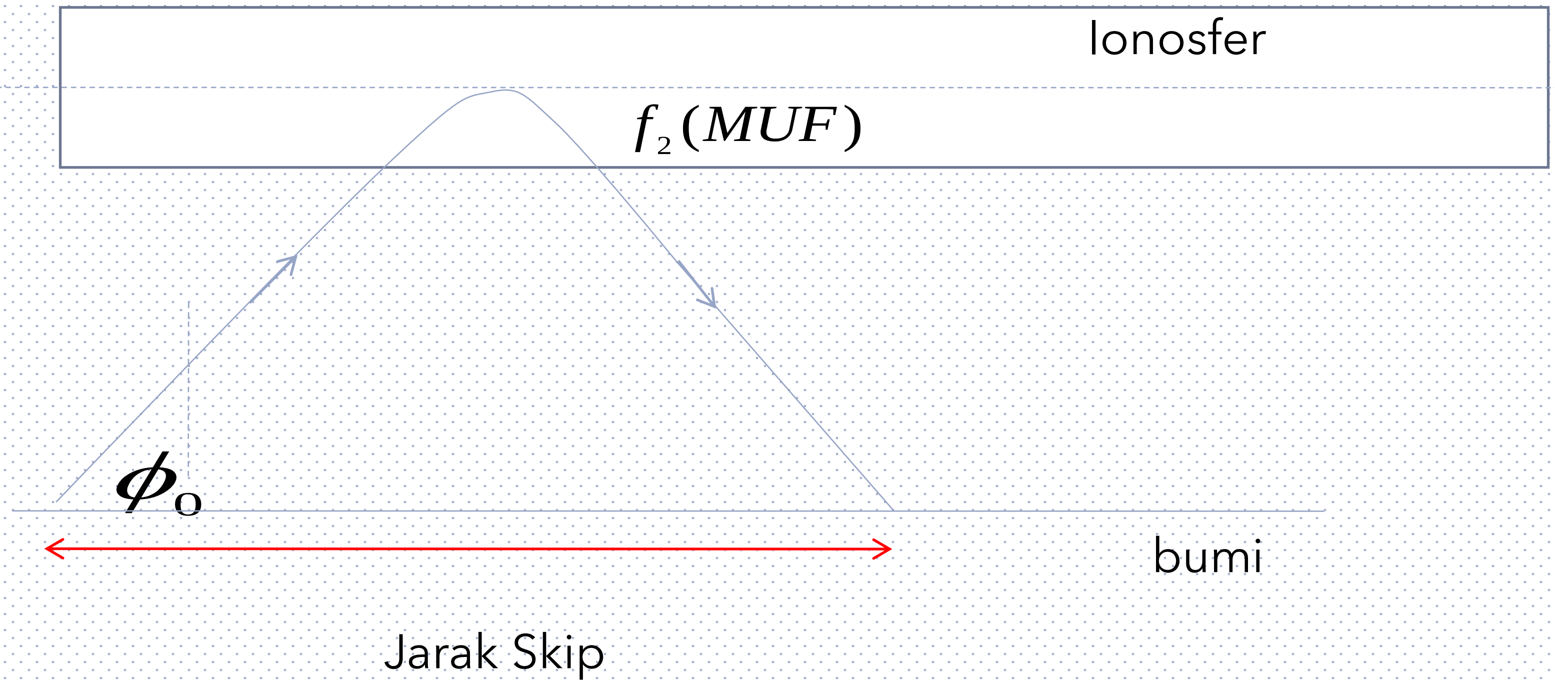
$$f = \frac{f_c}{\cos\phi_0} = f_c \sec\phi_0 \text{ dimana } f_c = \sqrt{81 N_{\max}}$$

Maximum Usable Frequency (MUF)

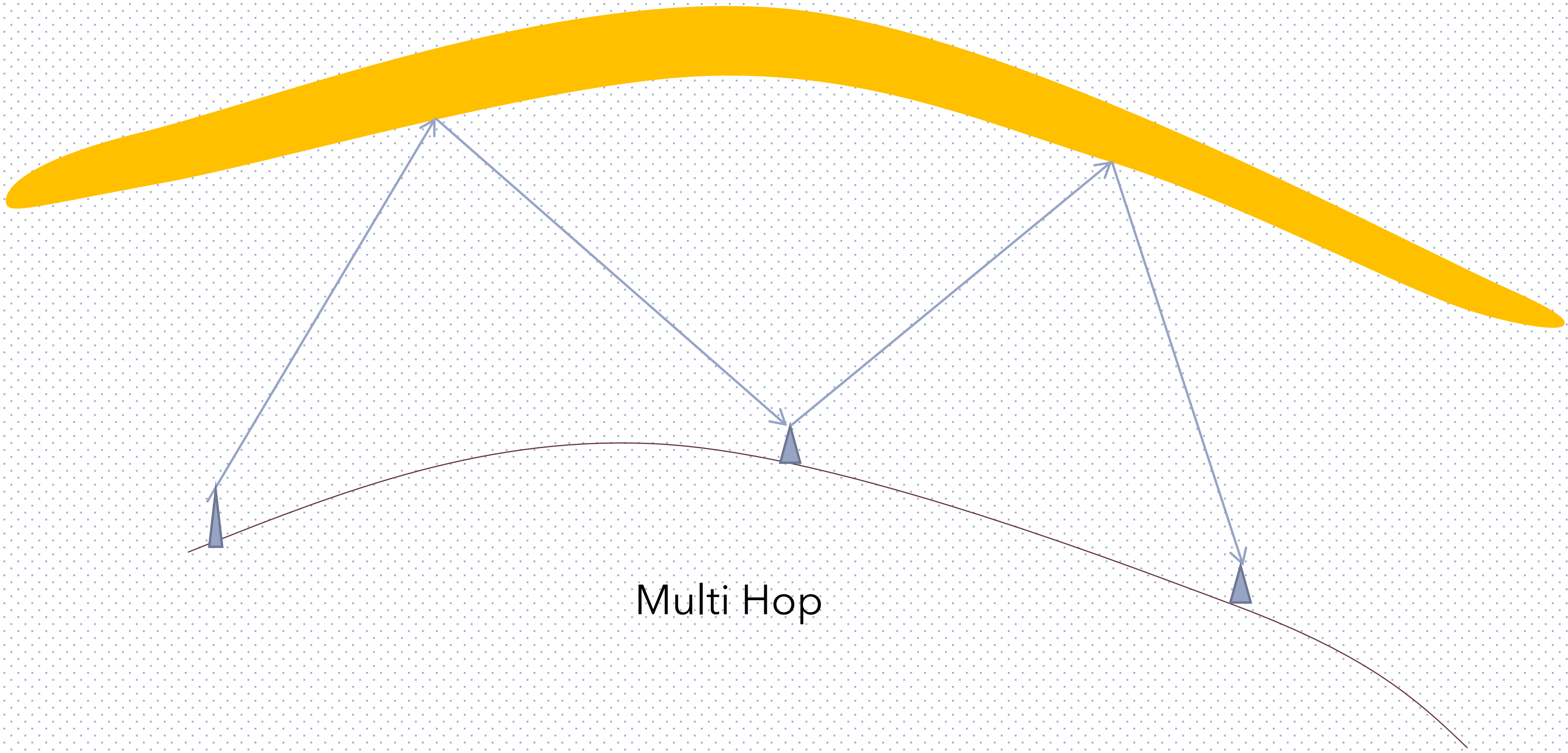
Pemantulan ionosfer



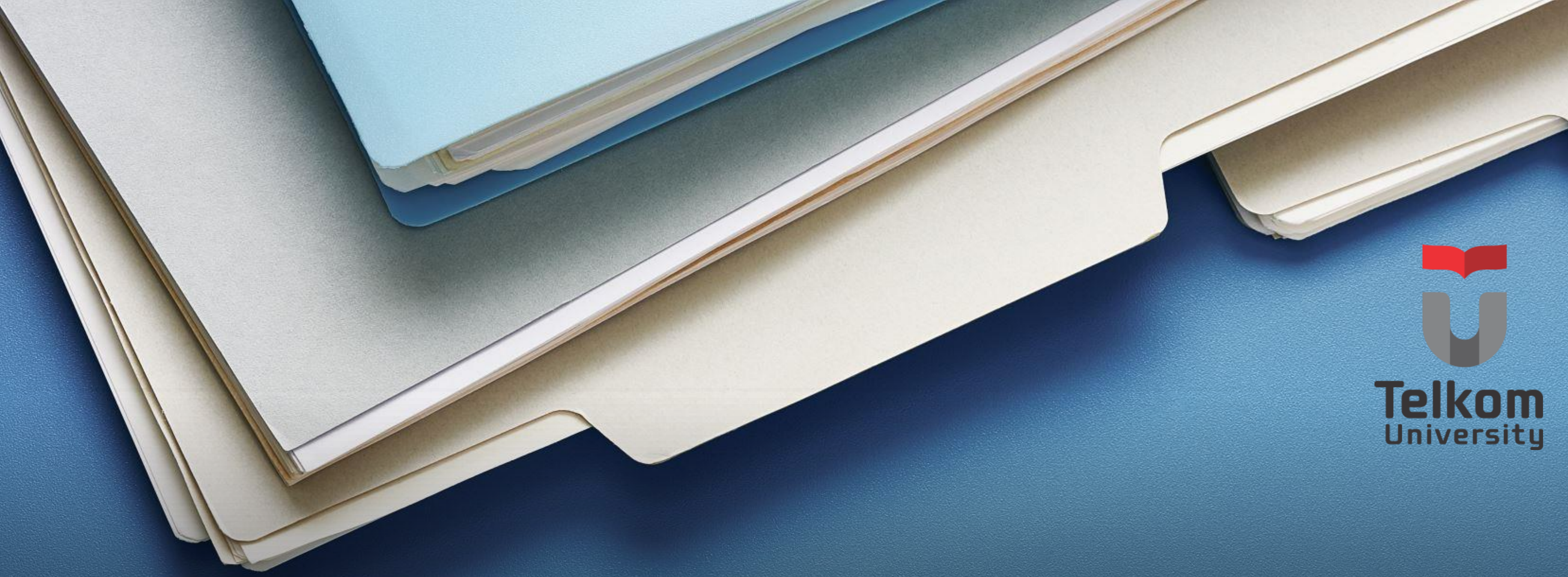
Jarak skip



Link gelombang langit



Multi Hop



Terima kasih