Satellittkommunikasjon

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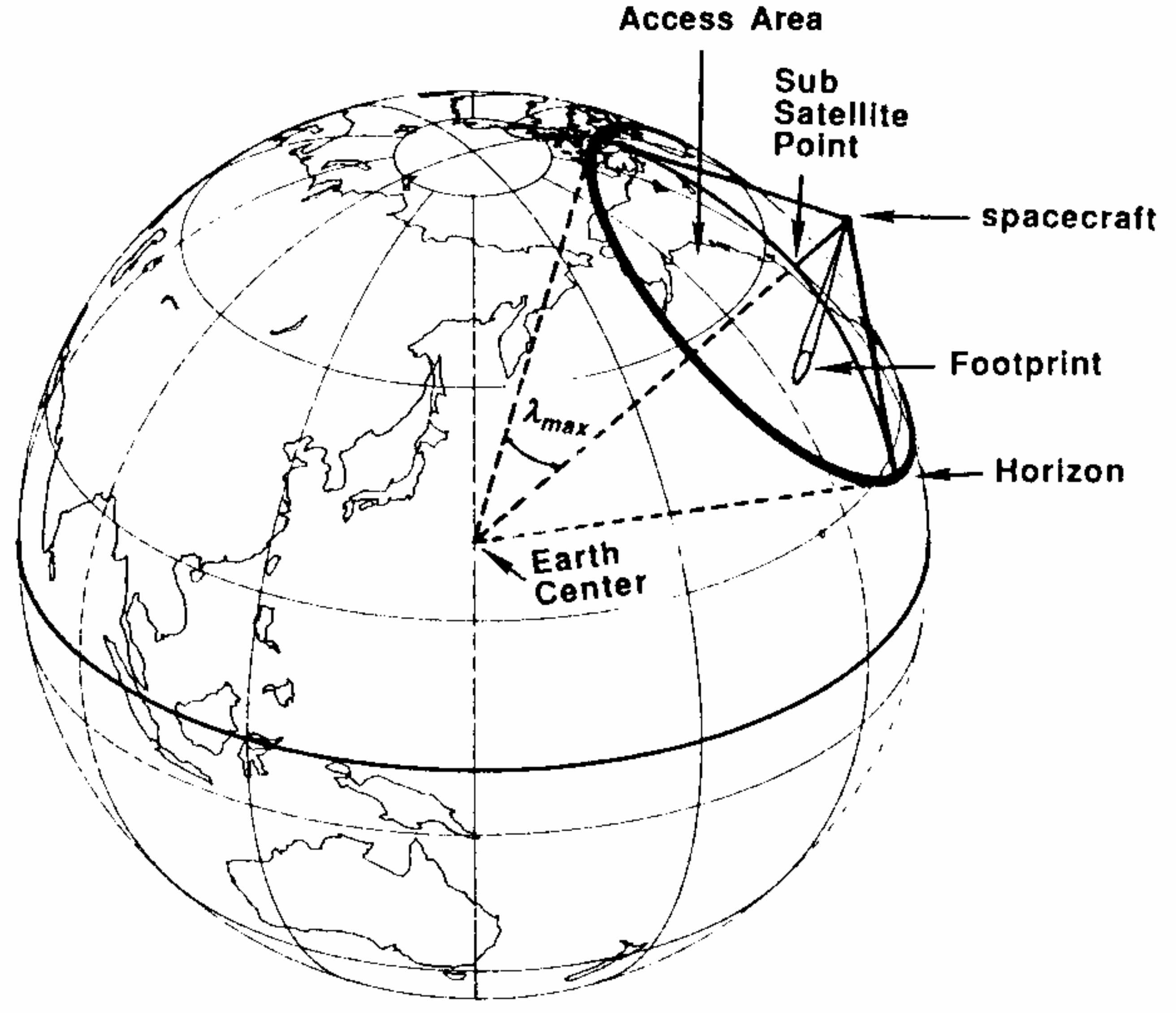
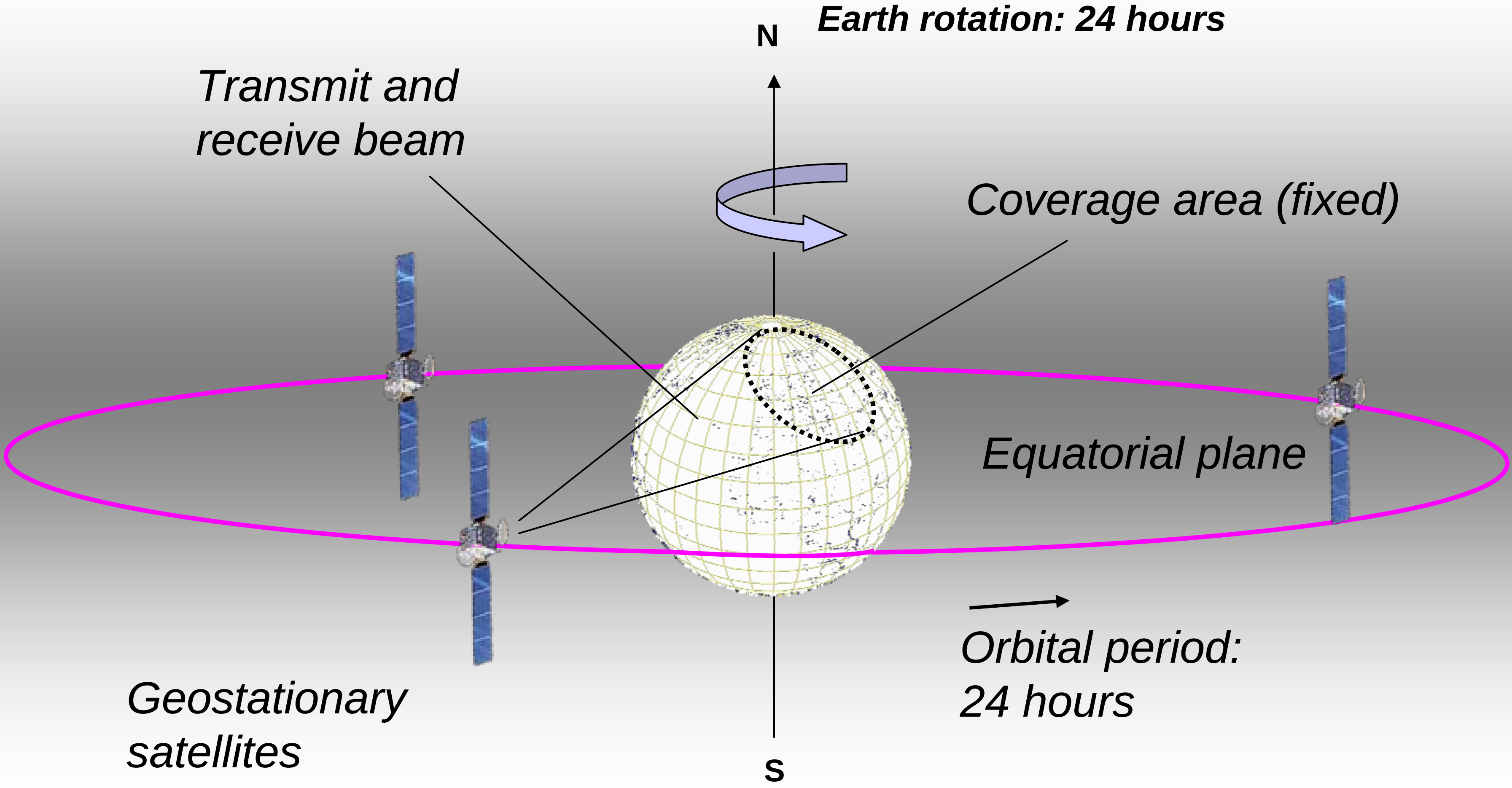
- Fundamentale prinsipper
- Satellitt/Nyttelast
- Støy/Linkbudsjett
- Atmosfærens innvirkning på radiosignalene
- Modulasjon/Koding
- Aksessmetoder
- Jordstasjoner
- Nye systemer

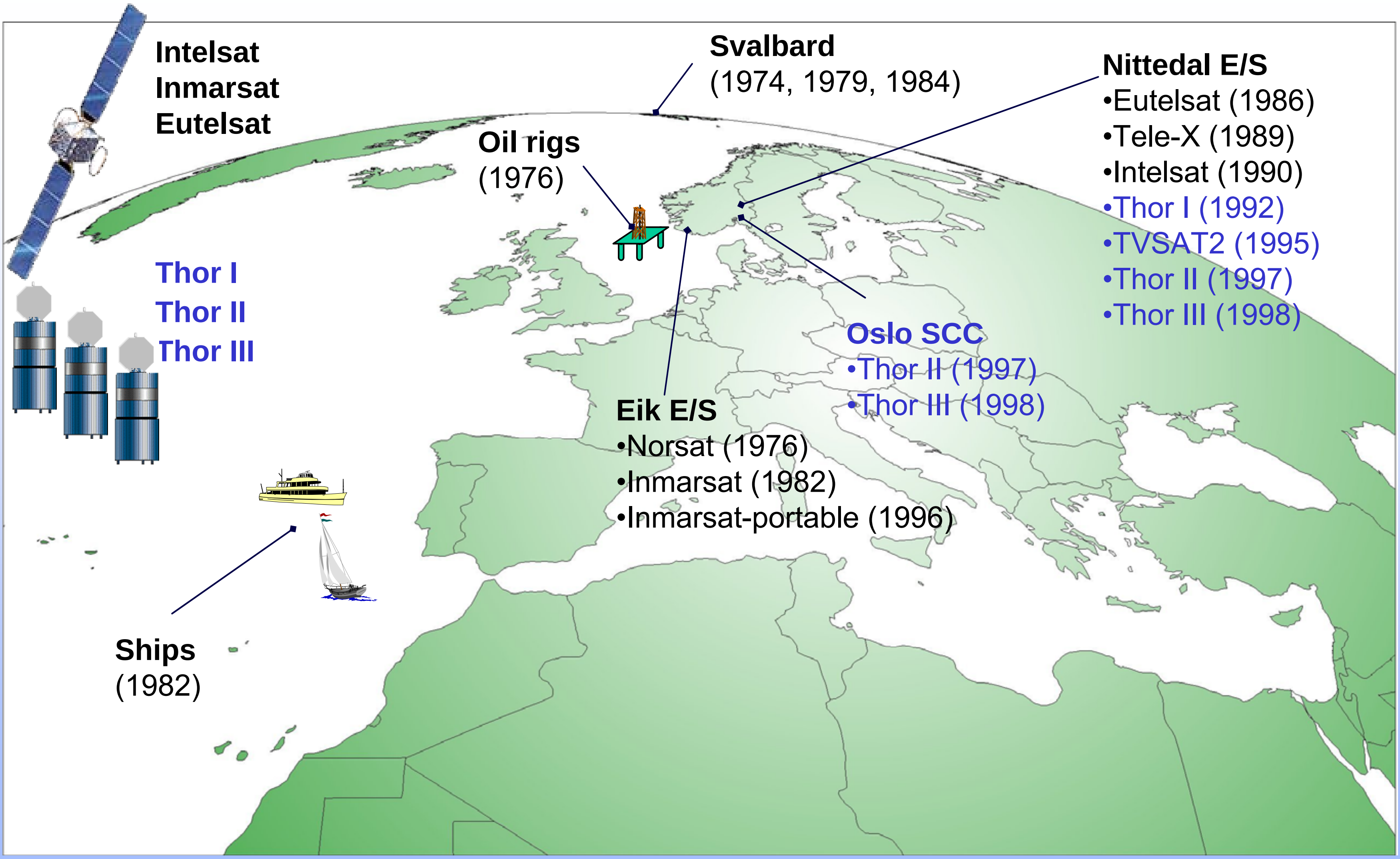
SATELLITTGEOMETRI



Fundamentals of GEO satellite communications



Norwegian communication satellite history



Intelsat
Inmarsat
Eutelsat

Thor I
Thor II
Thor III

Svalbard
(1974, 1979, 1984)

Oil rigs
(1976)

Nittedal E/S
- Eutelsat (1986)
- Tele-X (1989)
- Intelsat (1990)
- Thor I (1992)
- TVSAT2 (1995)
- Thor II (1997)
- Thor III (1998)

Oslo SCC
- Thor II (1997)
- Thor III (1998)

Eik E/S
- Norsat (1976)
- Inmarsat (1982)
- Inmarsat-portable (1996)

Ships
(1982)

Satellittkommunikasjonens problemområder

- lav vekt
- min effektbehov
- høy pålitelighet
- nøyaktig retnings- og banekontroll

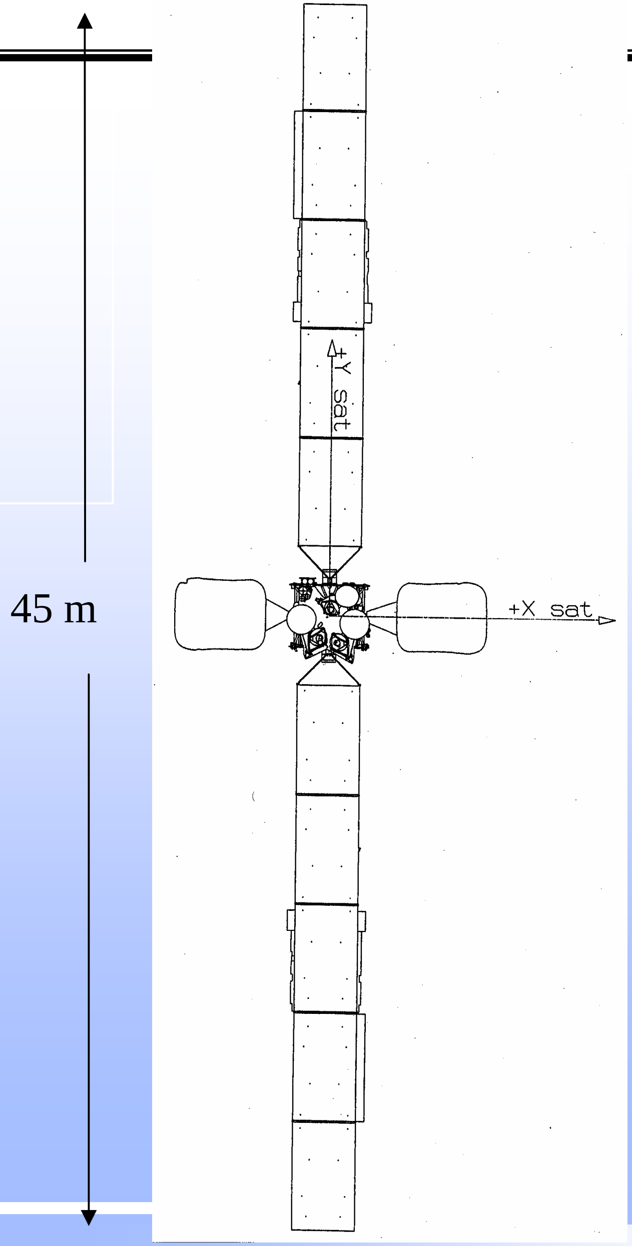
- begrenset frekvensspektrum
- bare en geostasjonær bane

- stor avstand, dvs store krav til antenne/mottaker
- innvirkning av atmosfæren
- robust modulasjon/koding pga støy

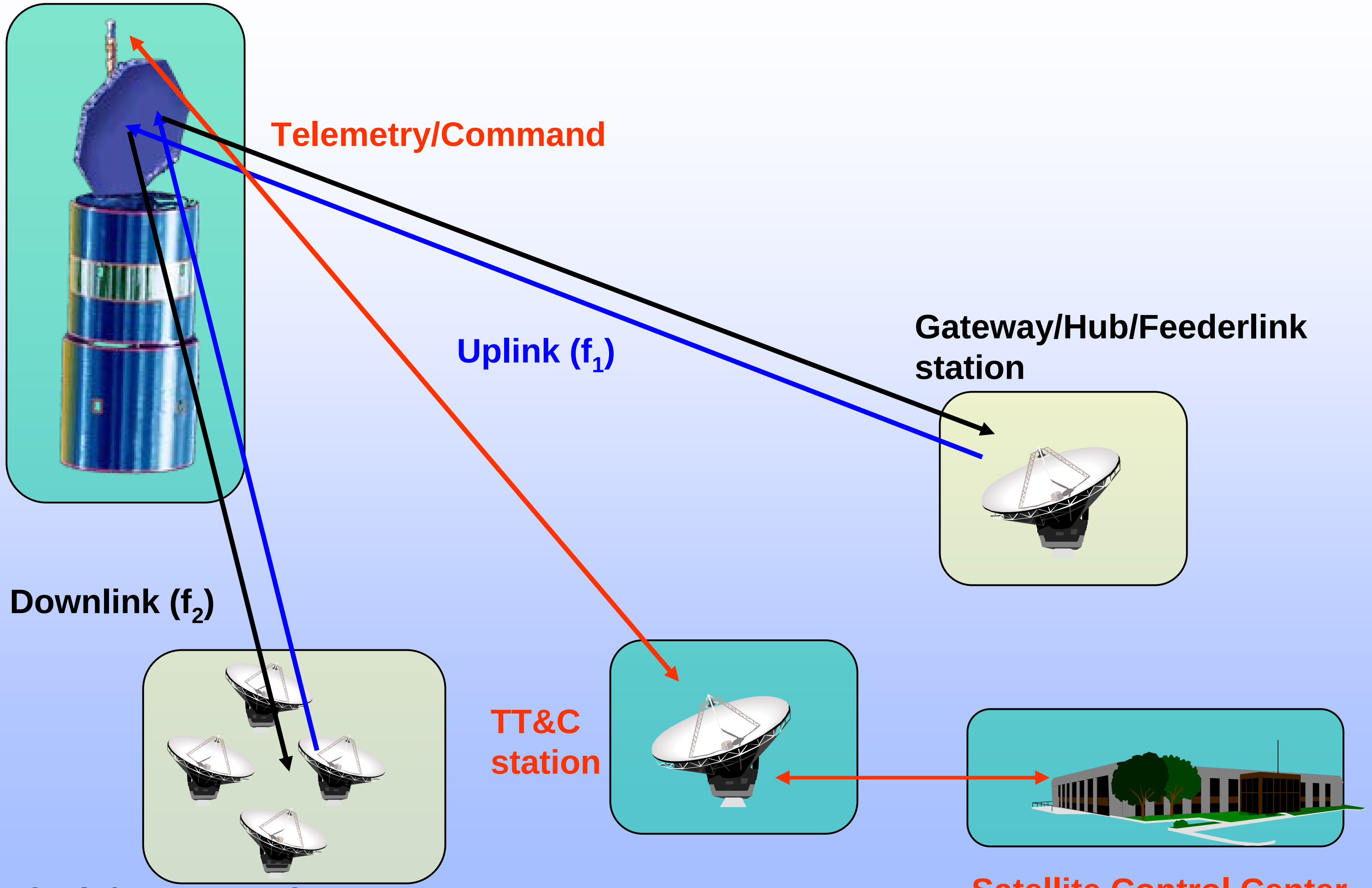
- billige jordstasjoner/terminaler
- tilfredstille reguleringsbestemmelsene (sidetråling etc)

Intelsat 10-02

- **Dry mass: approx 3000 kg**
- **Payload mass: approx 1000 kg**
- **Size: approx 7.5 m tall and 3.5 m wide**
- **Required power: 11.5 kW**
- **Lifetime: 13 years**



Components in satellite communication systems



Telemetry/Command

Uplink (f_1)

Gateway/Hub/Feederlink station

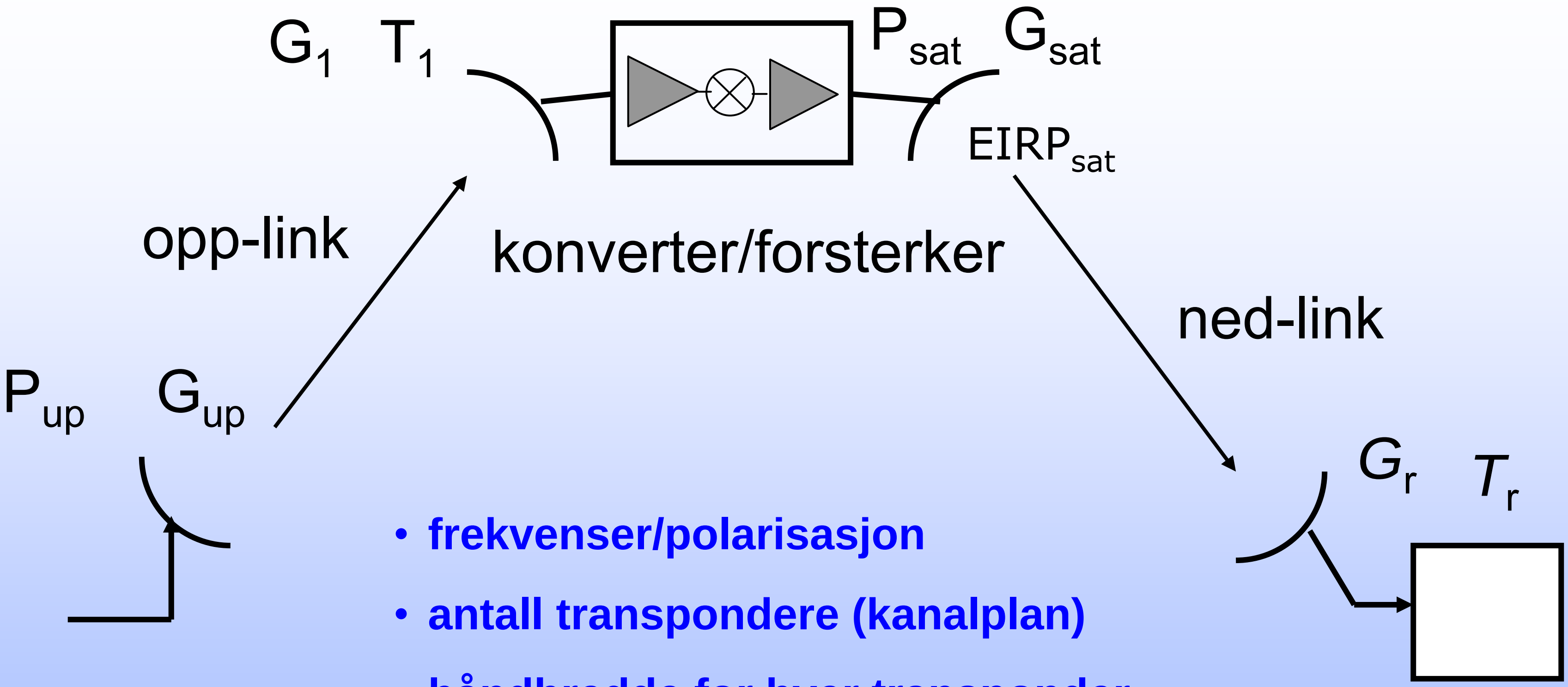
Downlink (f_2)

TT&C station

User terminals/Home receivers

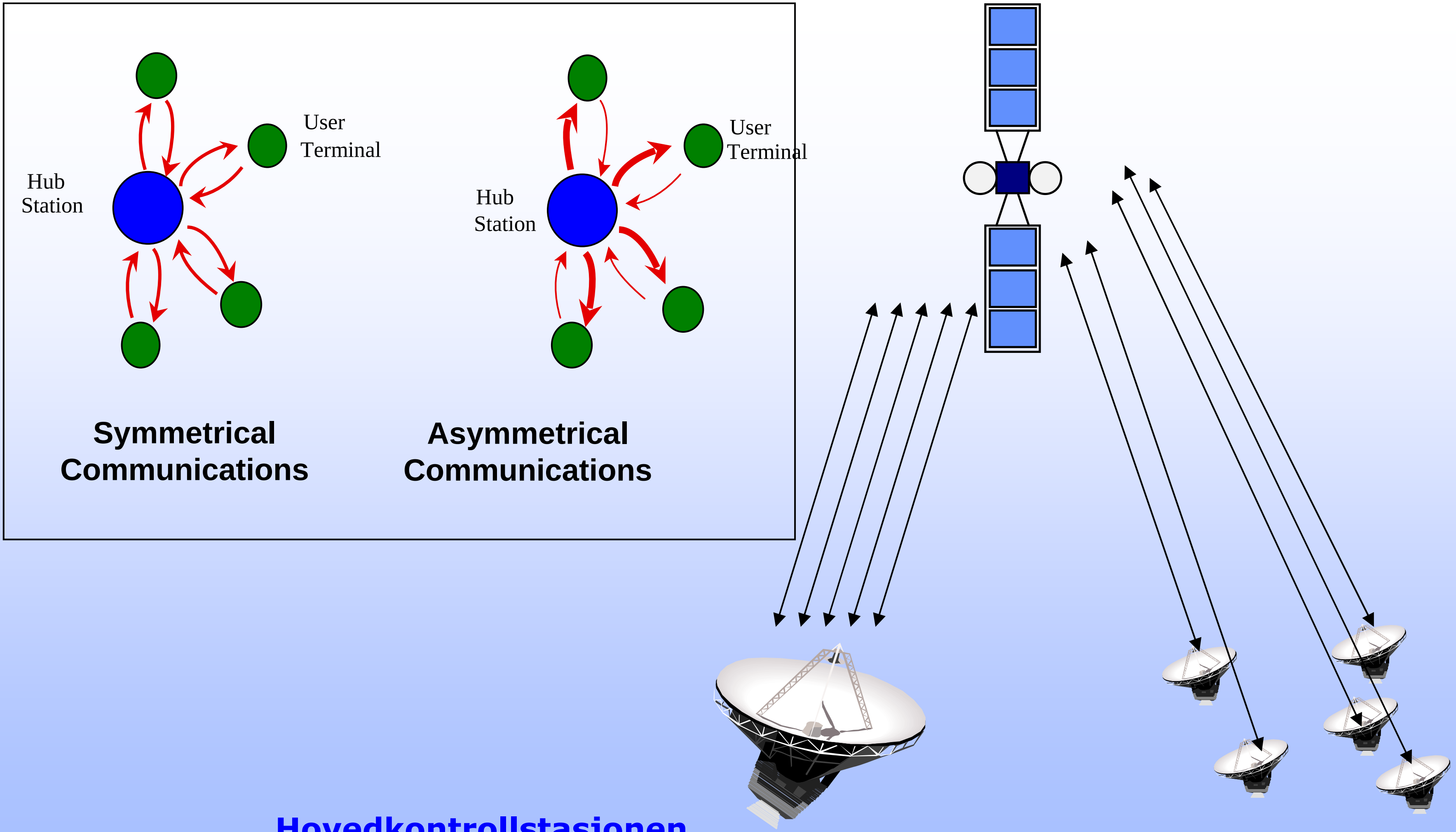
Satellite Control Center

Satellitt-link, ”bent pipe” transponder



- **frekvenser/polarisasjon**
- **antall transpondere (kanalplan)**
- **båndbredde for hver transponder**
- **dekningsområder (opp/ned)**
- **utstrålt effekt (EIRP=P·G)**

VSAT stjernenett



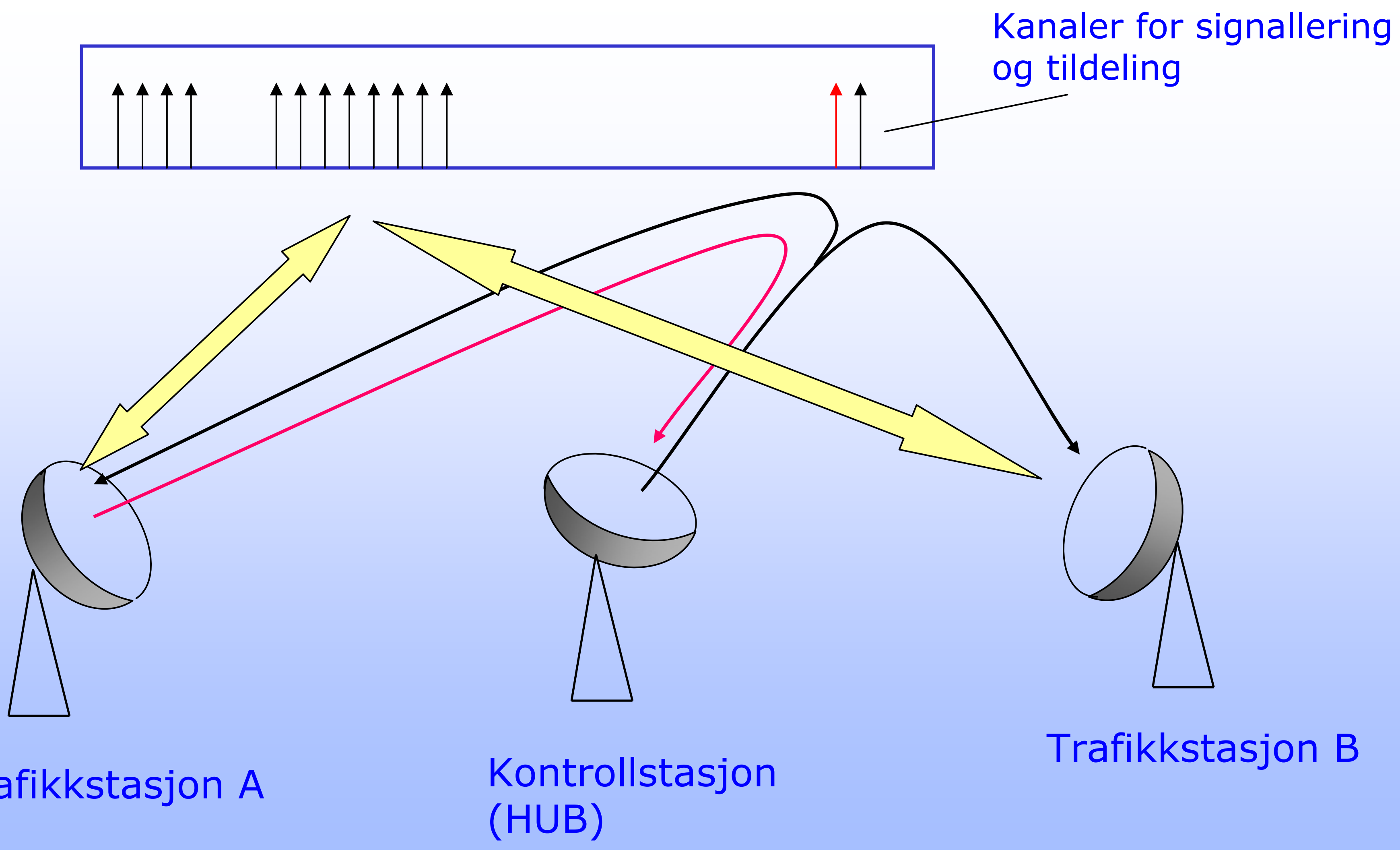
Symmetrical Communications

Asymmetrical Communications

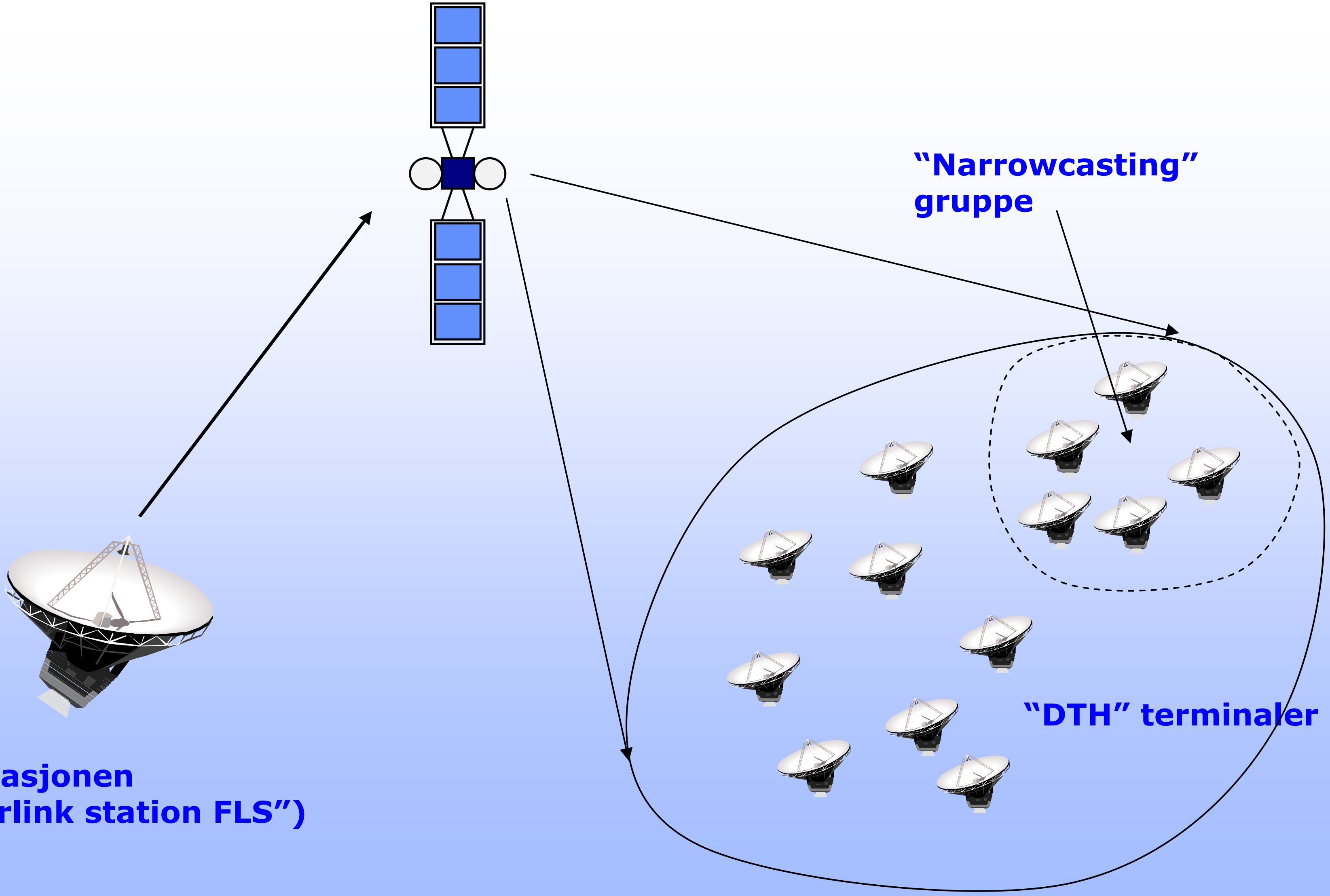
Hovedkontrollstasjonen ("the HUB")

Terminaler

Kanaltildeling



Kringkastingsnett



"Narrowcasting" gruppe

"DTH" terminaler

Hovedstasjonen (“Feederlink station FLS”)

Antenna

Relationship between antenna aperture are and gain:

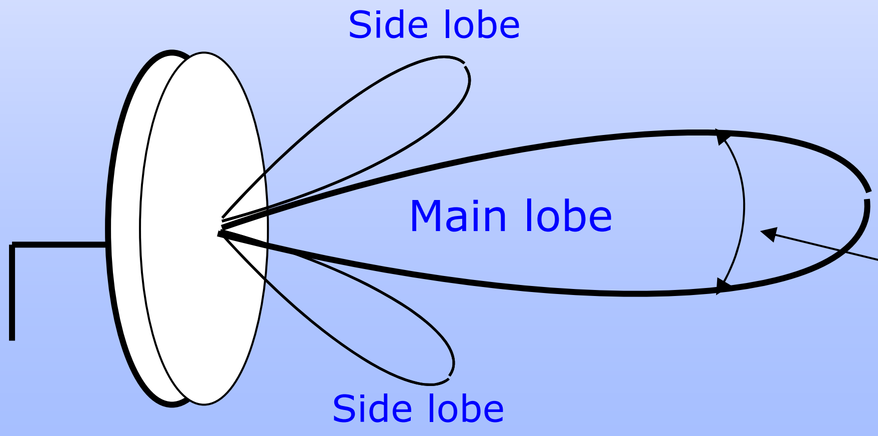
$$G = \eta \times 4\pi \frac{A}{\lambda^2}$$

Aperture-area

Antenna gain

Aperture efficiency

Wavelength



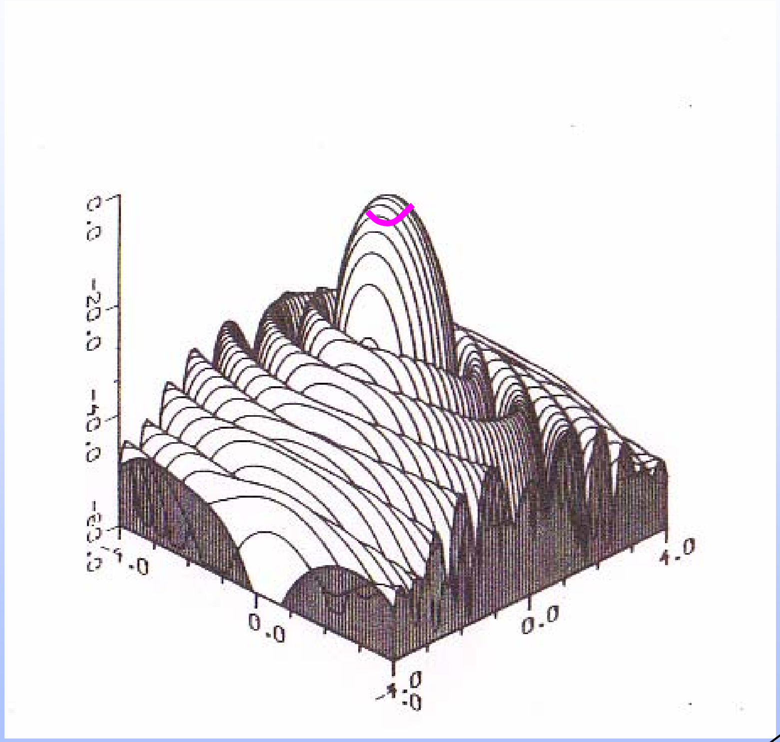
$$\theta_{3dB} = \frac{65 \cdot \lambda}{D} \quad \text{deg}$$

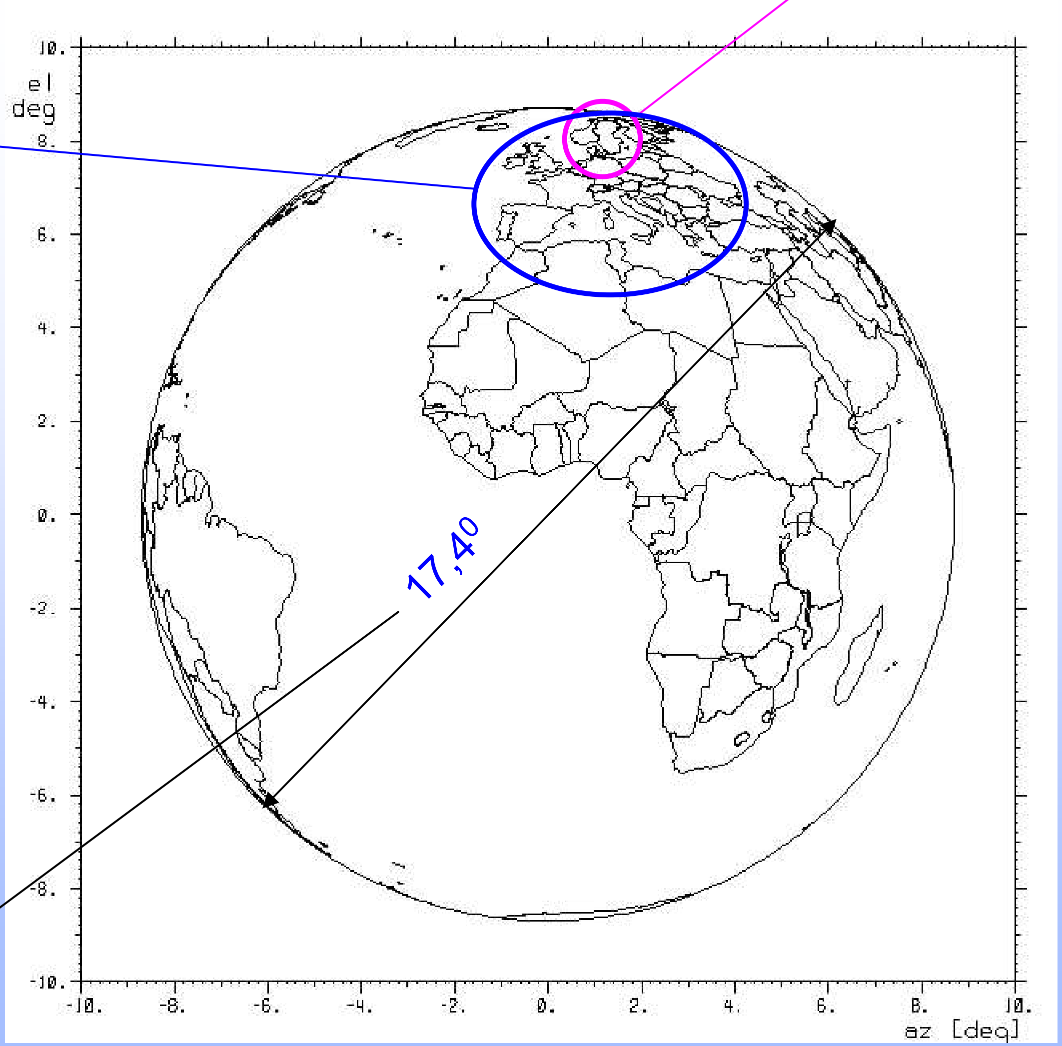
Måling av satellittantenne (Thor III)

Earth seen from 1° West GEO orbit

Coverage area 1.5^0

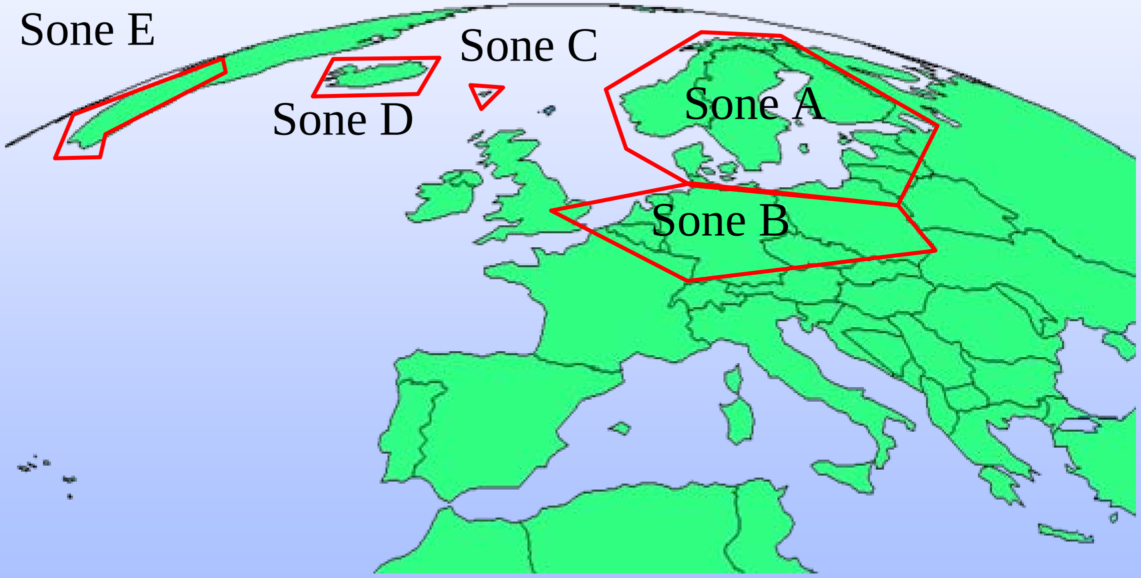
Coverage area 4x6^0





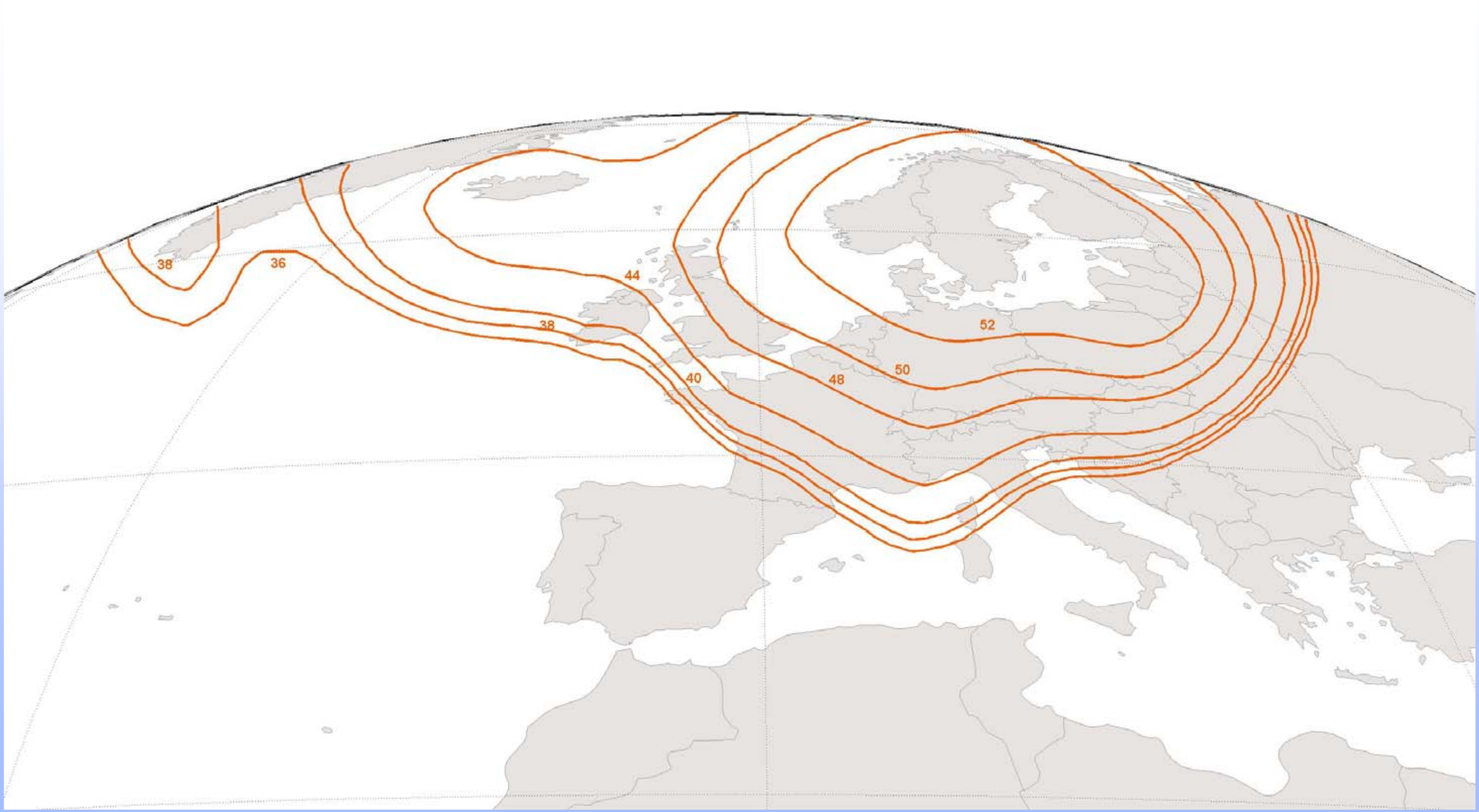
Global coverage 17.4^0

Spesifikasjon av dekningsområde



Sone	EIRP (dBW)
A	52,0
B	48,0
C	44,0
D	44,0
E	32,5

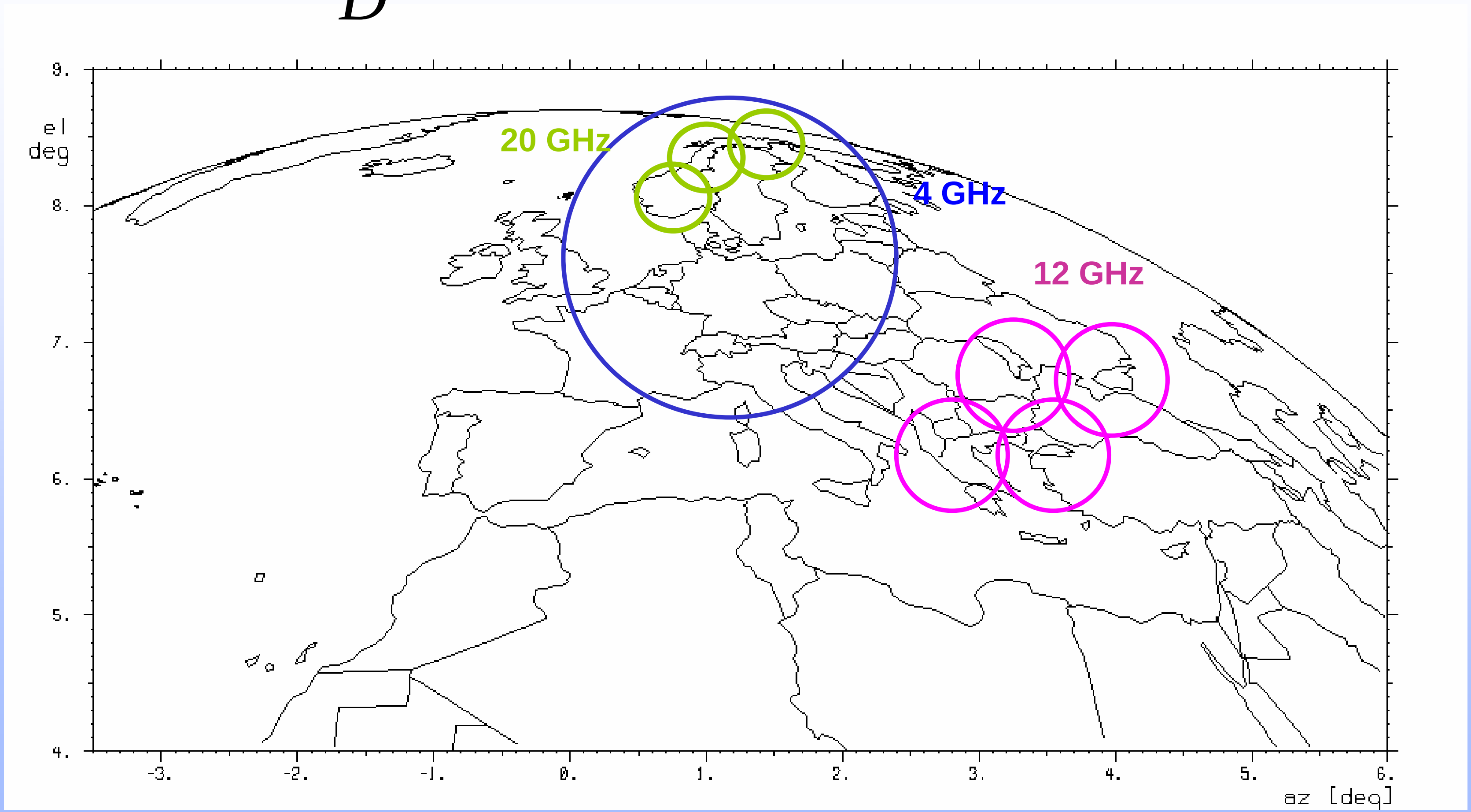
Thor II dekningsdiagram, EIRP-konturer (dBW)



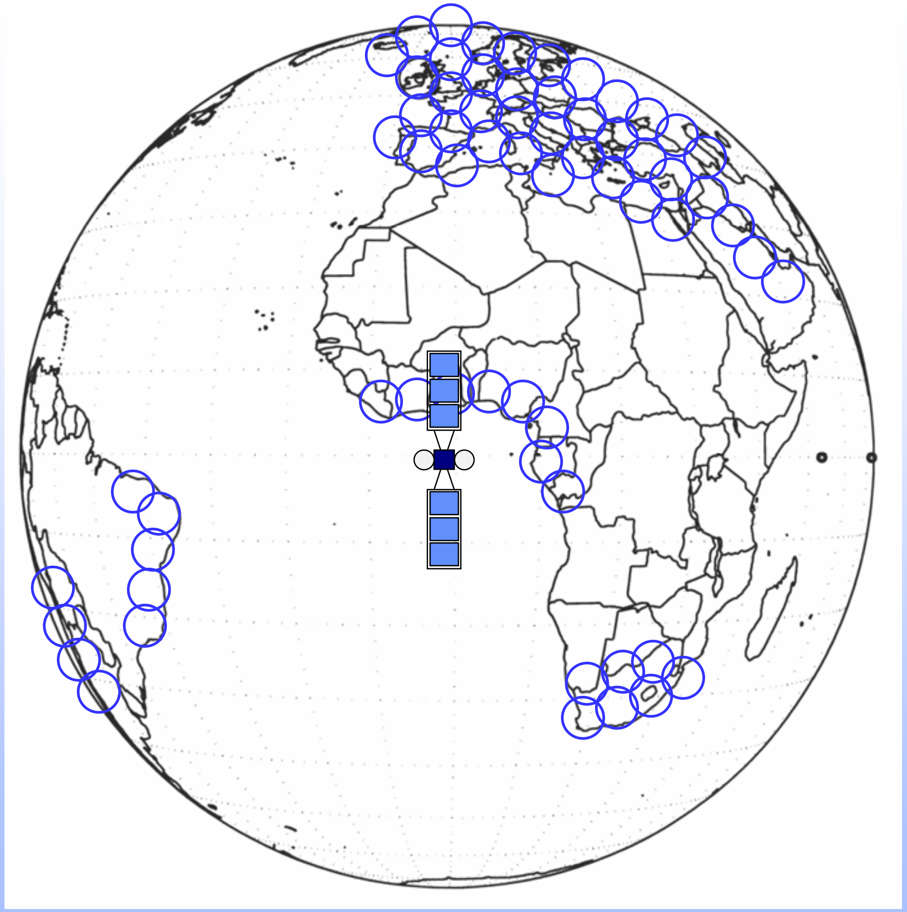
Eksempler på dekningsdiagrammer vs frekvens

$$\theta = 65\frac{\lambda}{D}$$

Satellittantennens diameter
D = 2 meter

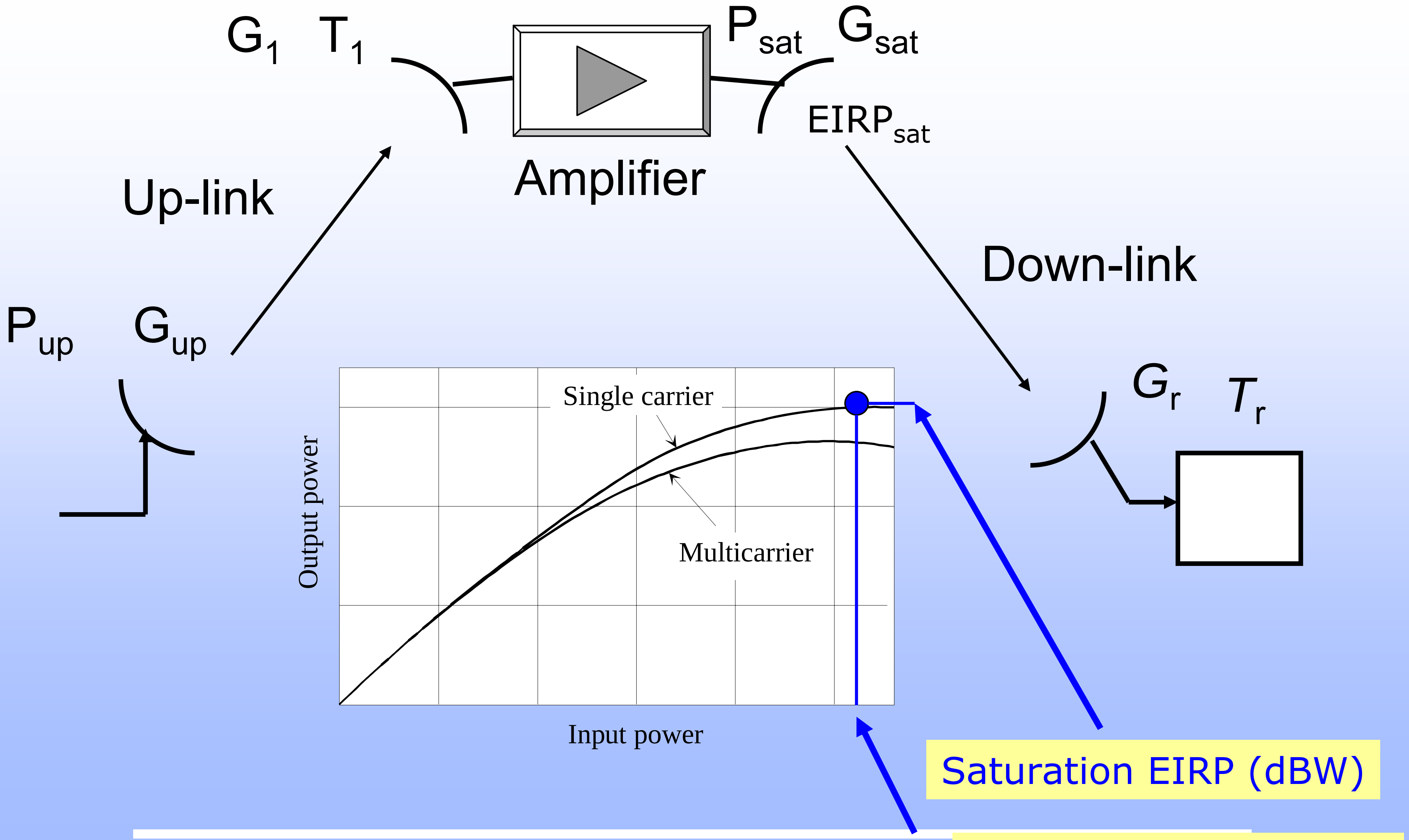


Spot-Beam Coverages (frequency reuse)



1º W

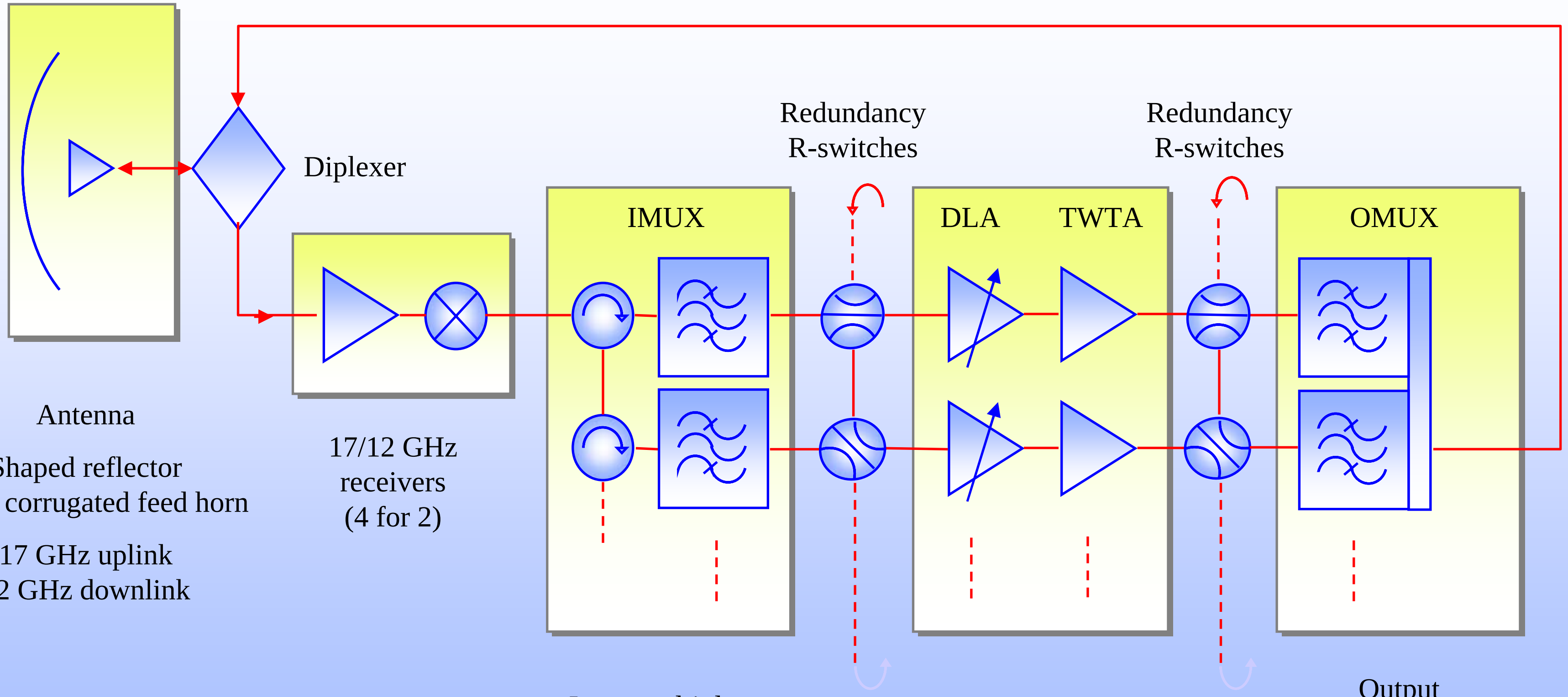
Satellite link, ”bent pipe” transponder



Saturation EIRP (dBW)

Saturation flux density (dBW/m²)

Payload Block Diagram (“Bent Pipe” /Thor III)



Antenna

Shaped reflector
Single corrugated feed horn

17 GHz uplink
12 GHz downlink

17/12 GHz
receivers
(4 for 2)

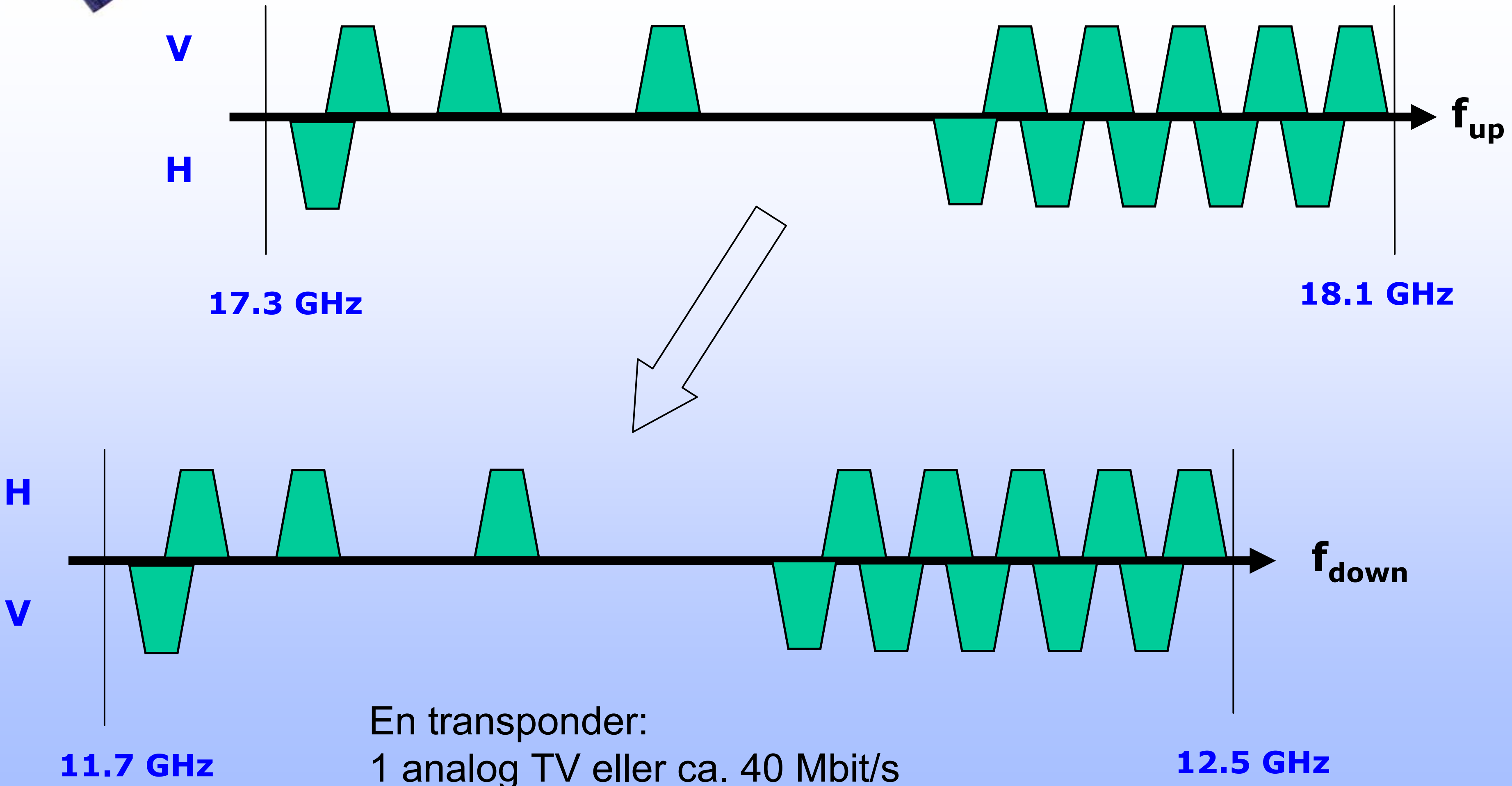
Input multiplexer

Driver/Limiter Amplifier
and Traveling Wave
Tube Amplifiers
(17 for 14)

Output
multiplexer

Eksempel på frekvensplan

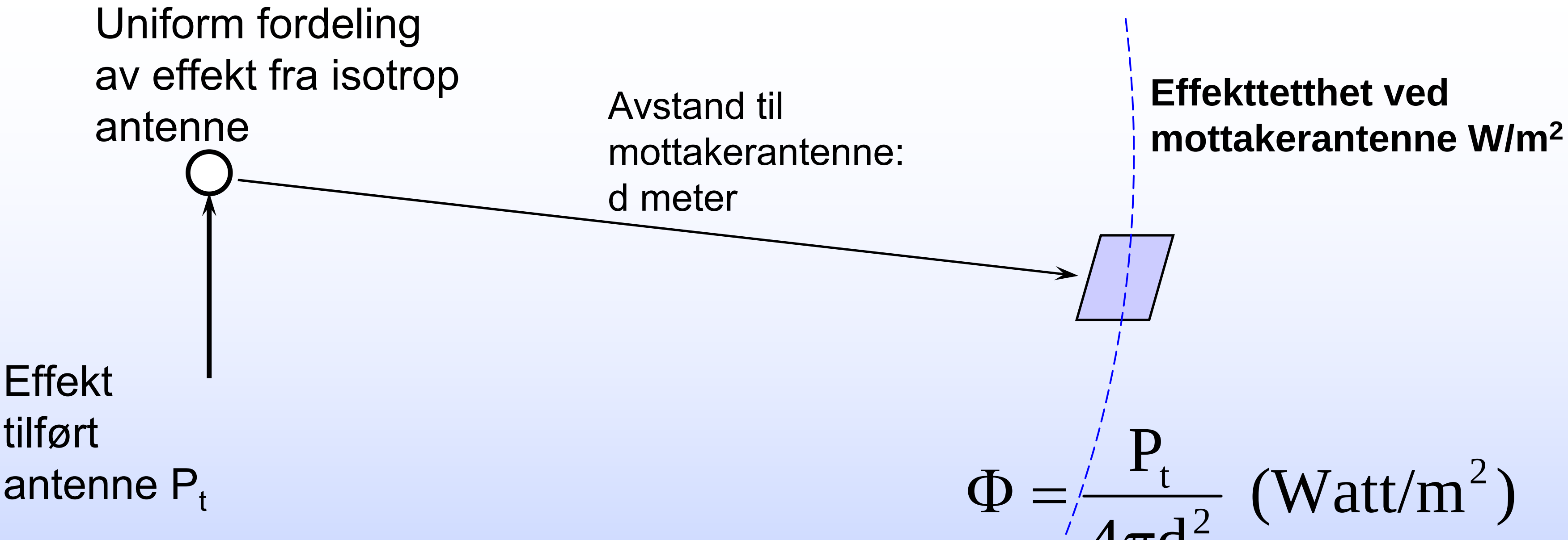
14 transpondere



En transponder:
1 analog TV eller ca. 40 Mbit/s

En transponder er en separat kanal i en satellitt, med bestemt frekvens.

Radiotransmisjon i fritt rom



Uniform fordeling av effekt fra isotrop antenne

Avstand til mottakerantenne: d meter

Effekttetthet ved mottakerantenne W/m²

Effekt tilført antenne P_t

$$\Phi = \frac{P_t}{4\pi d^2} \quad (\mathrm{Watt/m^2})$$

Mottakerantennen kan karakteriseres ved sitt effektive arealet A_{eff}

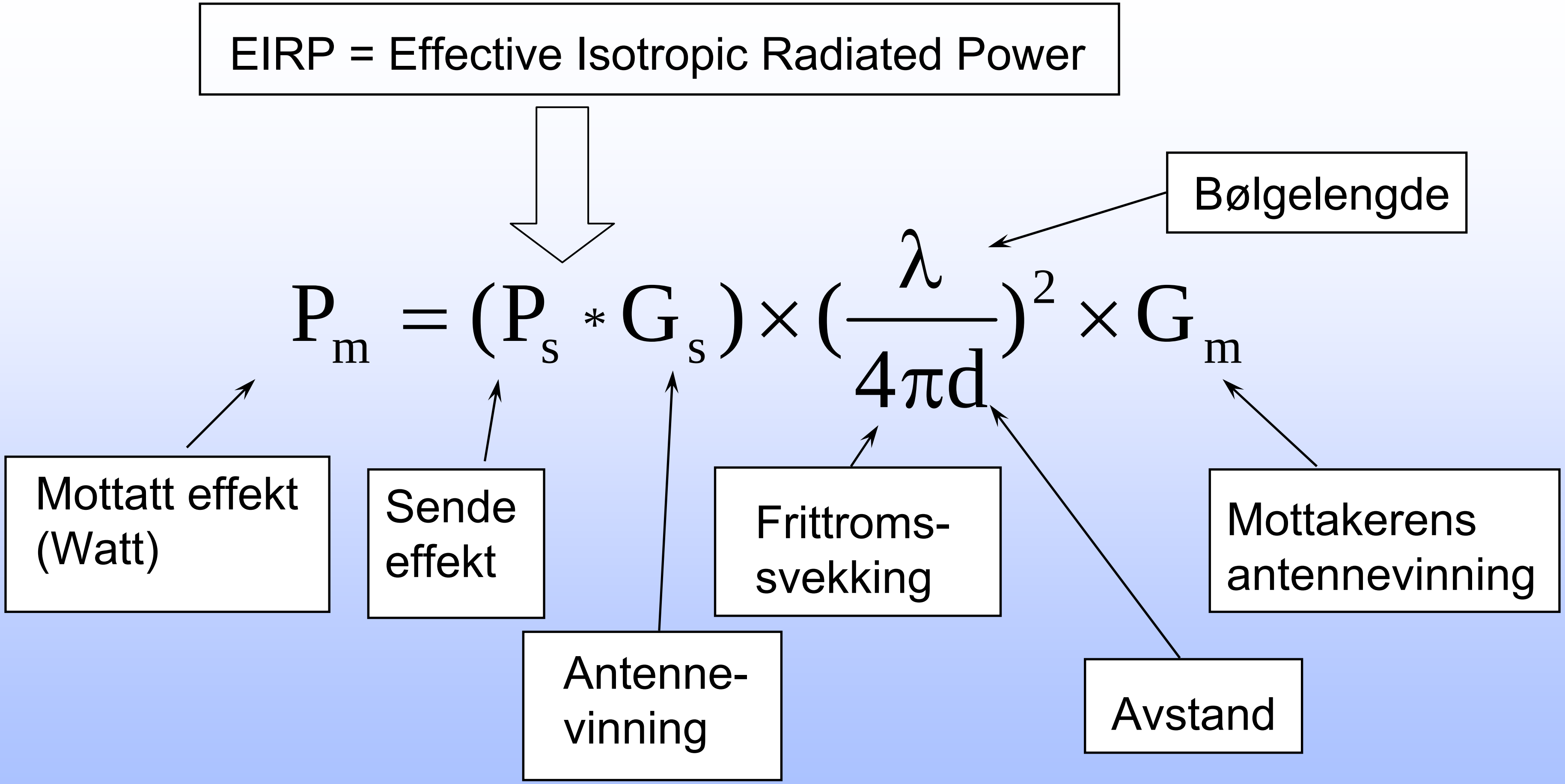
Mottatt effekt P_r er gitt av

$$P_r = \Phi \cdot A_{eff} = P_t \cdot \frac{1}{4\pi d^2} \cdot A_{eff}$$

Mottatt effekt P_r hvis senderen har en antennevinning G_t:

$$P_r = P_t G_t \cdot \frac{1}{4\pi d^2} \cdot A_{eff} = EIRP \cdot \frac{1}{4\pi d^2} \cdot A_{eff}$$

Frittromssvekking



EIRP = Effective Isotropic Radiated Power

$$P_m = (P_s * G_s) \times \left(\frac{\lambda}{4\pi d}\right)^2 \times G_m$$

Bølgelengde

Mottatt effekt (Watt)

Sende effekt

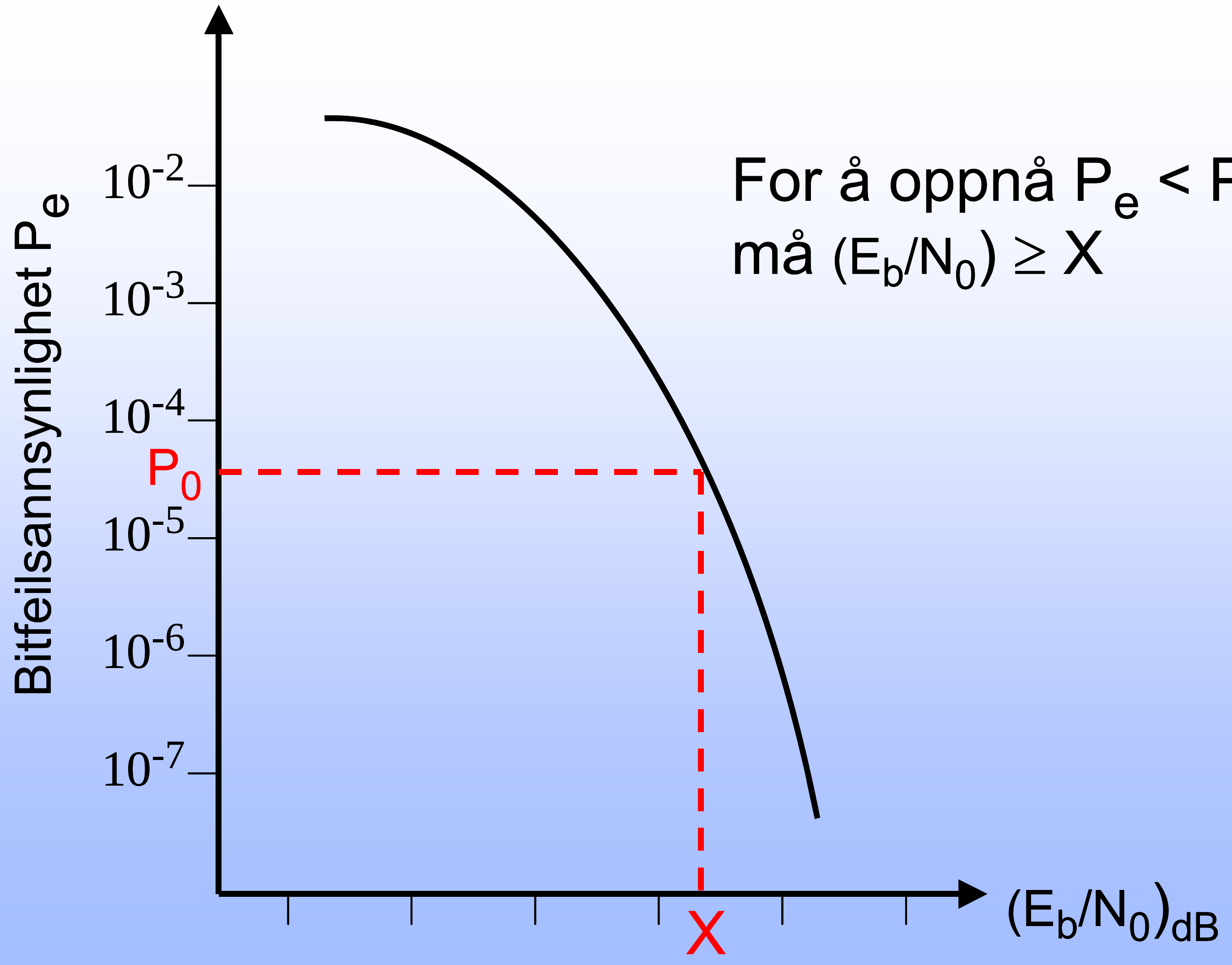
Antenne-vinning

Frittroms-svekking

Avstand

Mottakerens antennevinning

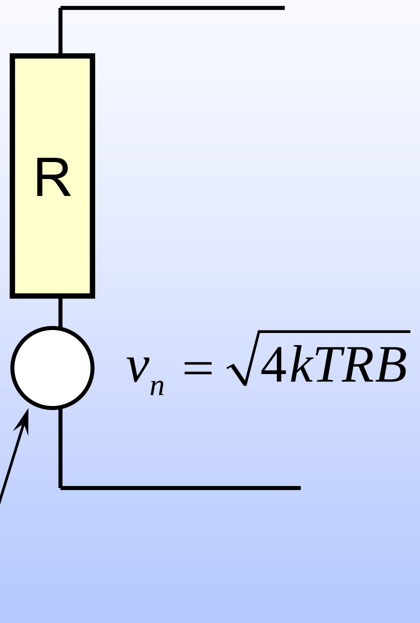
Typisk sammenheng E_b/N_0 og P_e



For å oppnå $P_e < P_0$
må $(E_b/N_0) \geq X$

Tilgjengelig støyeffekt

Ekvivalentkretser for generering av elektrisk støy (AWGN):



$v_n = \sqrt{4kTRB}$

Ekvivalent spenningskilde

v_n har gaussisk fordeling

$\bar{v}_n = 0$

$v_{n_{rms}} = \sigma$

Tilgjengelig støyeffekt ved impedanstilpasning:

$$\boxed{N = kTB}$$

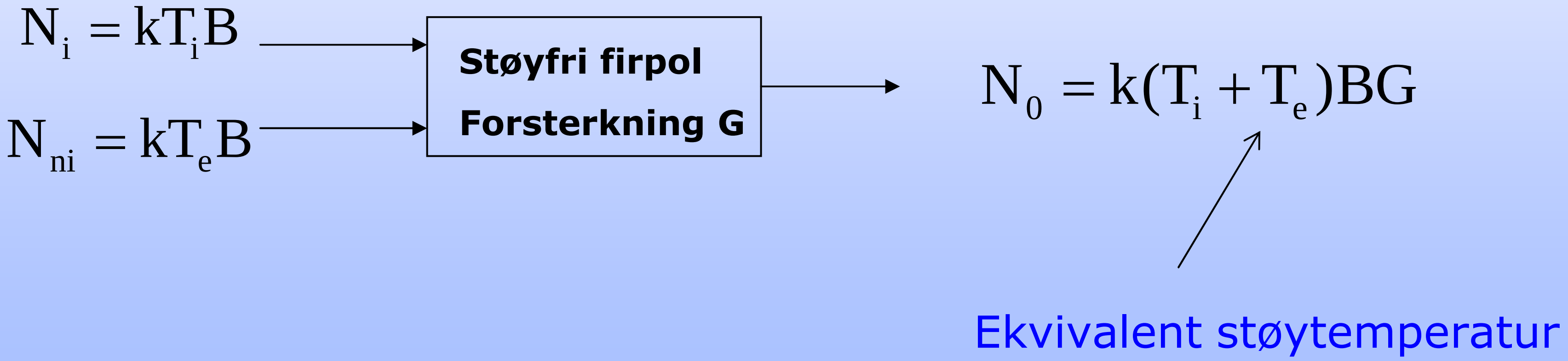
Ekvivalent støytemperatur

$N_i = kT_iB$

Støyende firpol

Forsterkning G

$N_0 = kT_iBG + kT_nB$



$N_i = kT_iB$

$N_{ni} = kT_eB$

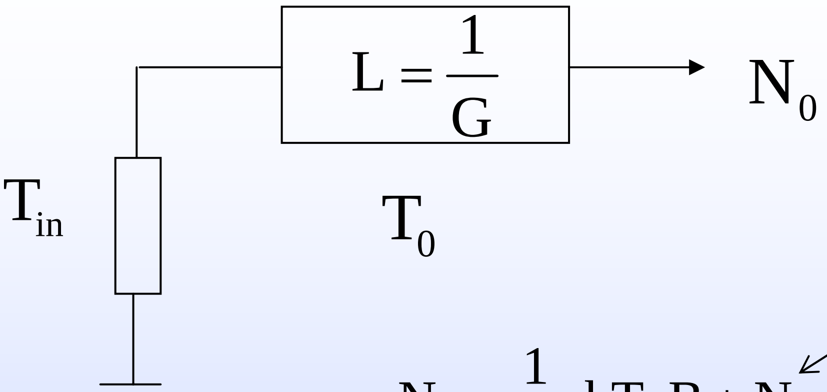
Støyfri firpol

Forsterkning G

$N_0 = k(T_i + T_e)BG$

Ekvivalent støytemperatur

Ekvivalent støytemperatur til et dempeledd



Egensstøyen til dempeleddet

$$N_0 = \frac{1}{L} \cdot kT_{in}B + N_{att} = \frac{1}{L} \cdot kB\left(T_{in} + \frac{N_{att}}{\frac{1}{L}kB}\right) = \frac{1}{L} \cdot kB(T_{in} + T_e)$$

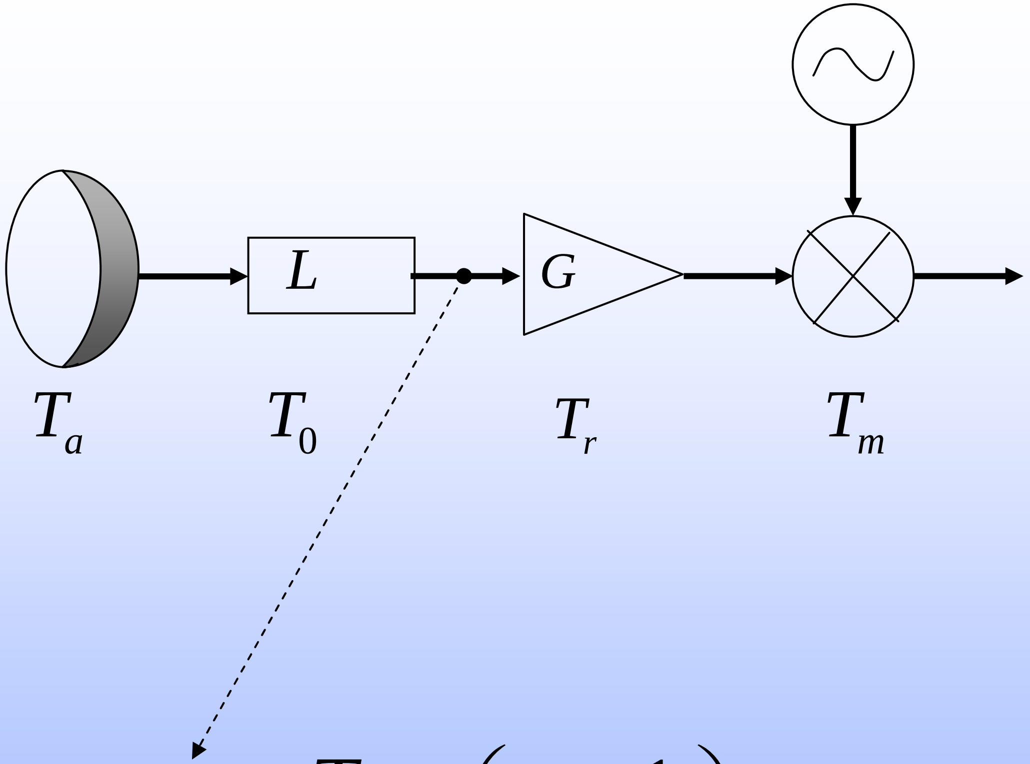
Hvis $T_{in} = T_0$ blir støyeffekten på utgangen $N_0 = kT_{in}B$

$$\Rightarrow \frac{1}{L} \cdot kB(T_{in} + T_e) = kT_{in}B$$

$$T_e = LT_{in} - T_{in} = T_{in}(L-1) = 290(L-1)$$

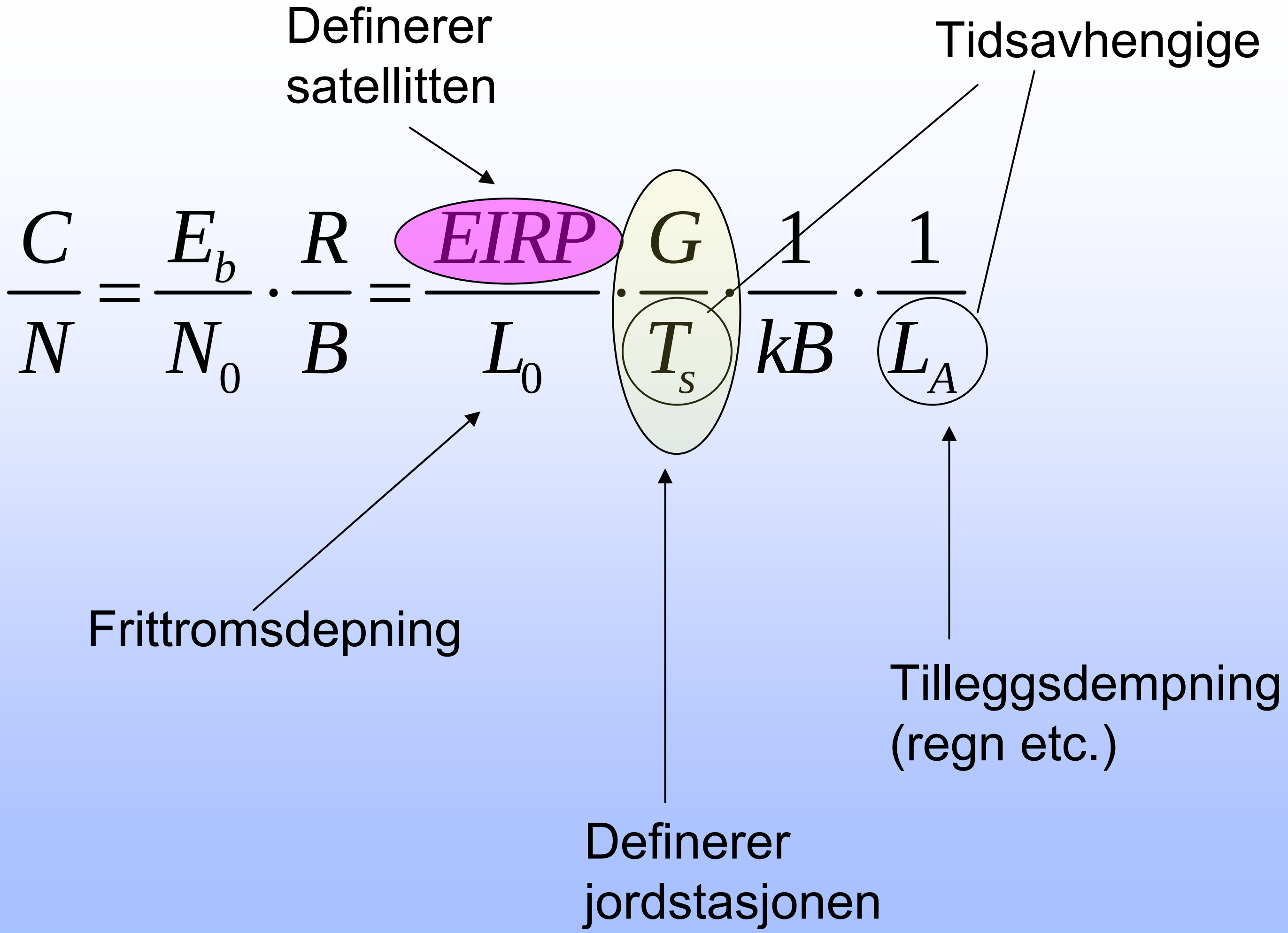
$$F = 1 + \frac{T_e}{T_0} = 1 + \frac{T_0(L-1)}{T_0} = L$$

System noise temperature



$$T_s = \frac{T_a}{L} + \left(1 - \frac{1}{L}\right) \cdot T_0 + T_r + \frac{T_m}{G}$$

Linkanalyse (nedlink)



$$\frac{C}{N}=\frac{E_b}{N_0}\cdot\frac{R}{B}=\frac{EIRP}{L_0}\cdot\frac{G}{T_s}\cdot\frac{1}{kB}\cdot\frac{1}{L_A}$$

Definerer satellitten

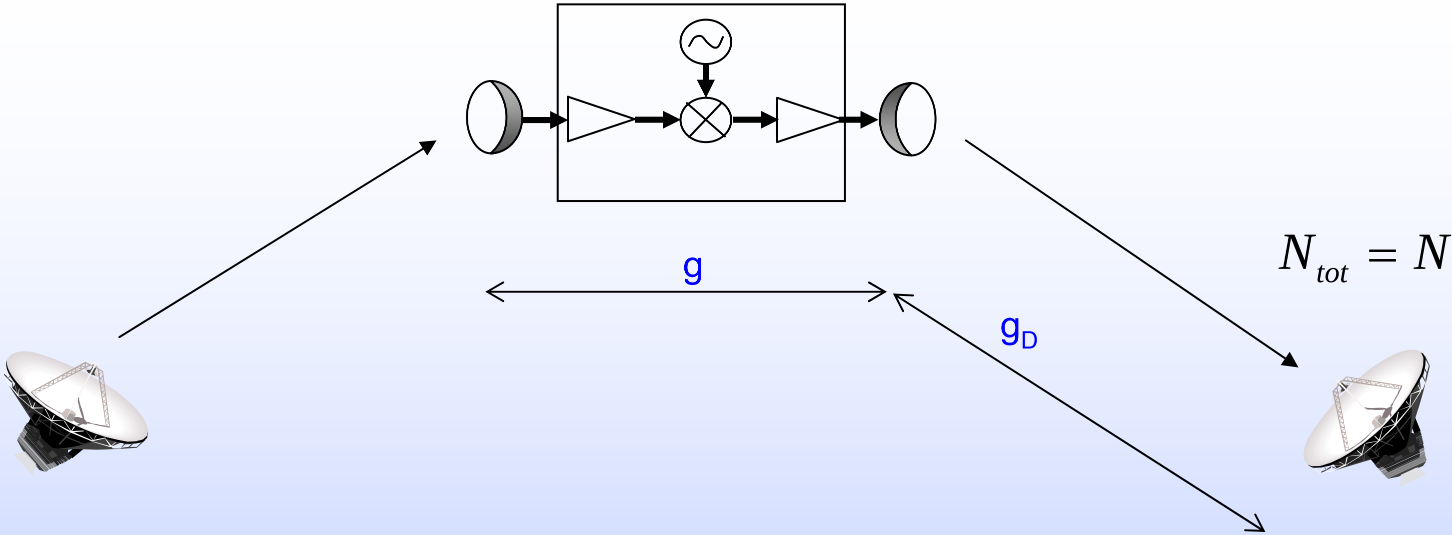
Tidsavhengige

Frittromsdepning

Definerer jordstasjonen

Tilleggsdempning (regn etc.)

Kombinasjon av støy på opp- og nedlink

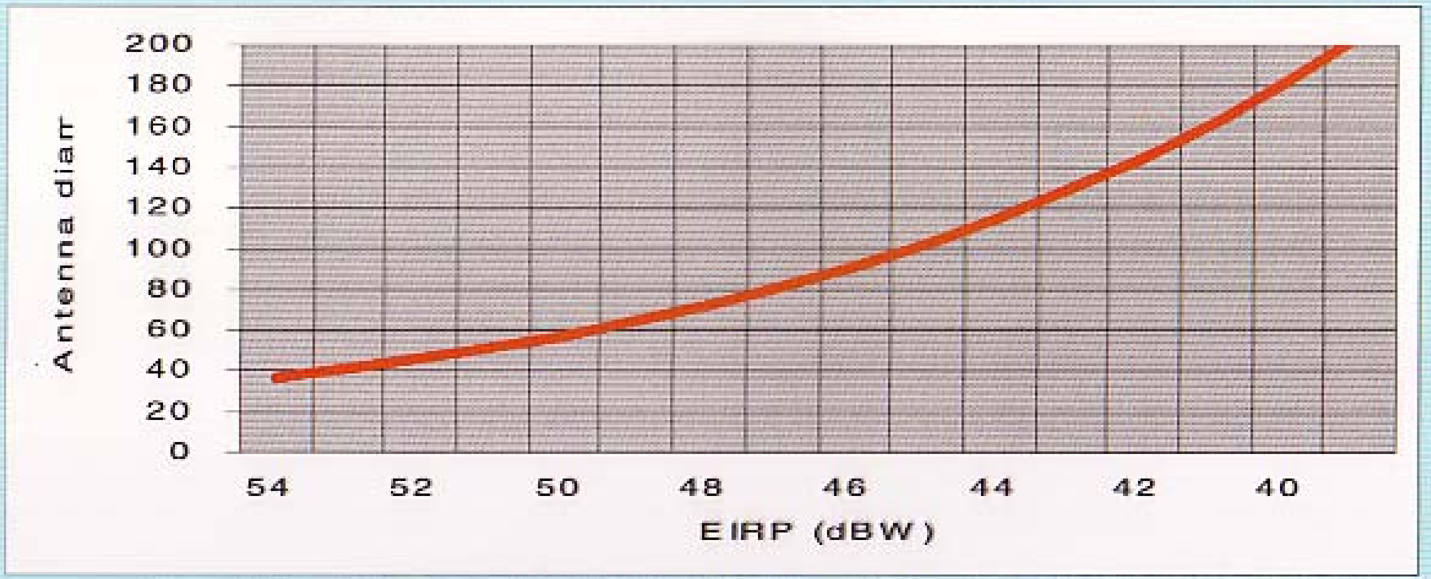


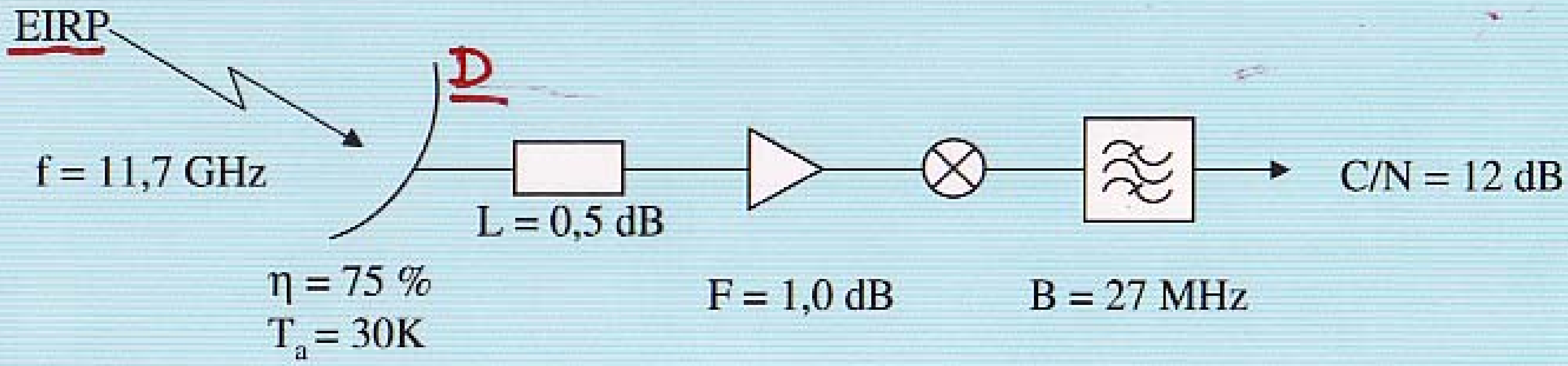
$$N_{tot} = N_{opp} \cdot g \cdot g_D + N_{ned}$$

$$\frac{N_{tot}}{C} = \frac{N_{opp} \cdot g \cdot g_D + N_{ned}}{C} = \frac{N_{opp} \cdot g \cdot g_D}{C} + \frac{N_{ned}}{C} \quad = \frac{N_{opp}}{\dfrac{C}{g \cdot g_D}} + \frac{N_{ned}}{C} = \frac{N_{opp}}{C_{opp}} + \frac{N_{ned}}{C_{ned}} = \left(\frac{N}{C}\right)_{opp} + \left(\frac{N}{C}\right)_{ned}$$

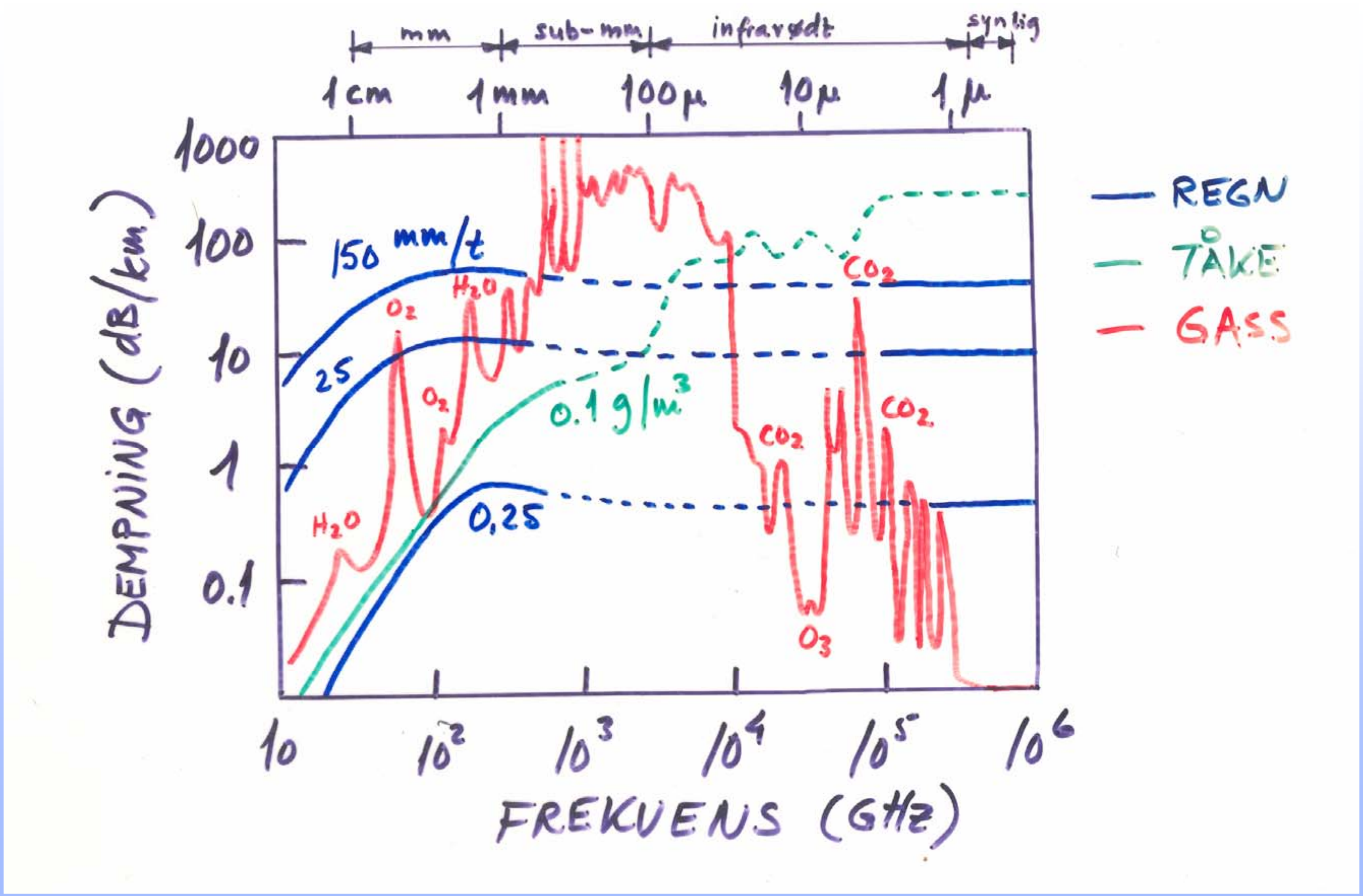
$$\boxed{\left(\frac{C}{N}\right)_{tot} = \frac{1}{\dfrac{1}{(C/N)_{opp}} + \dfrac{1}{(C/N)_{ned}} + \dfrac{1}{(C/N)_{IM}} + \ldots..}}$$

Linkbudsjett/antennediameter vs EIRP

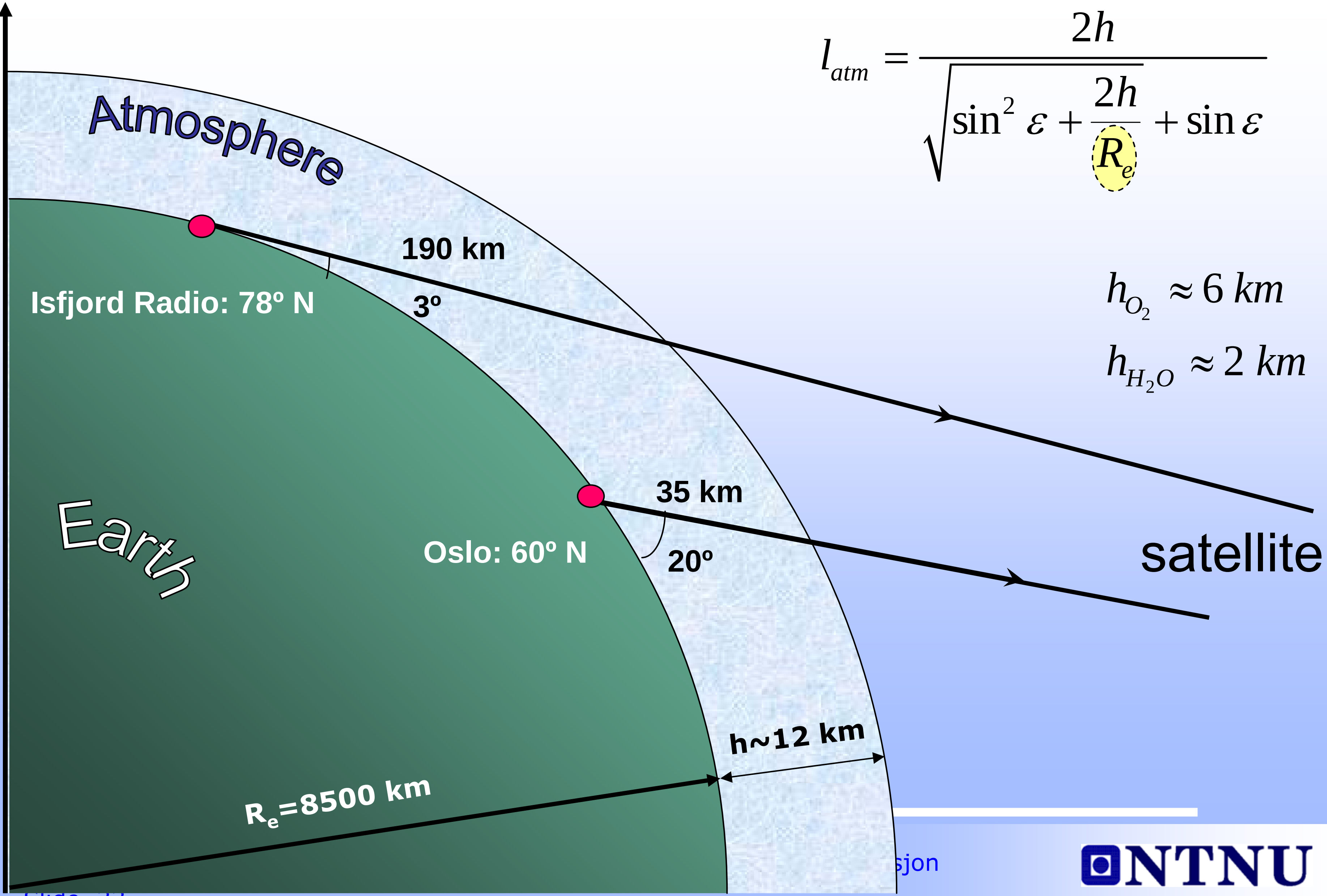




Vinduer i atmosfæren



Northern latitude vs. elevation

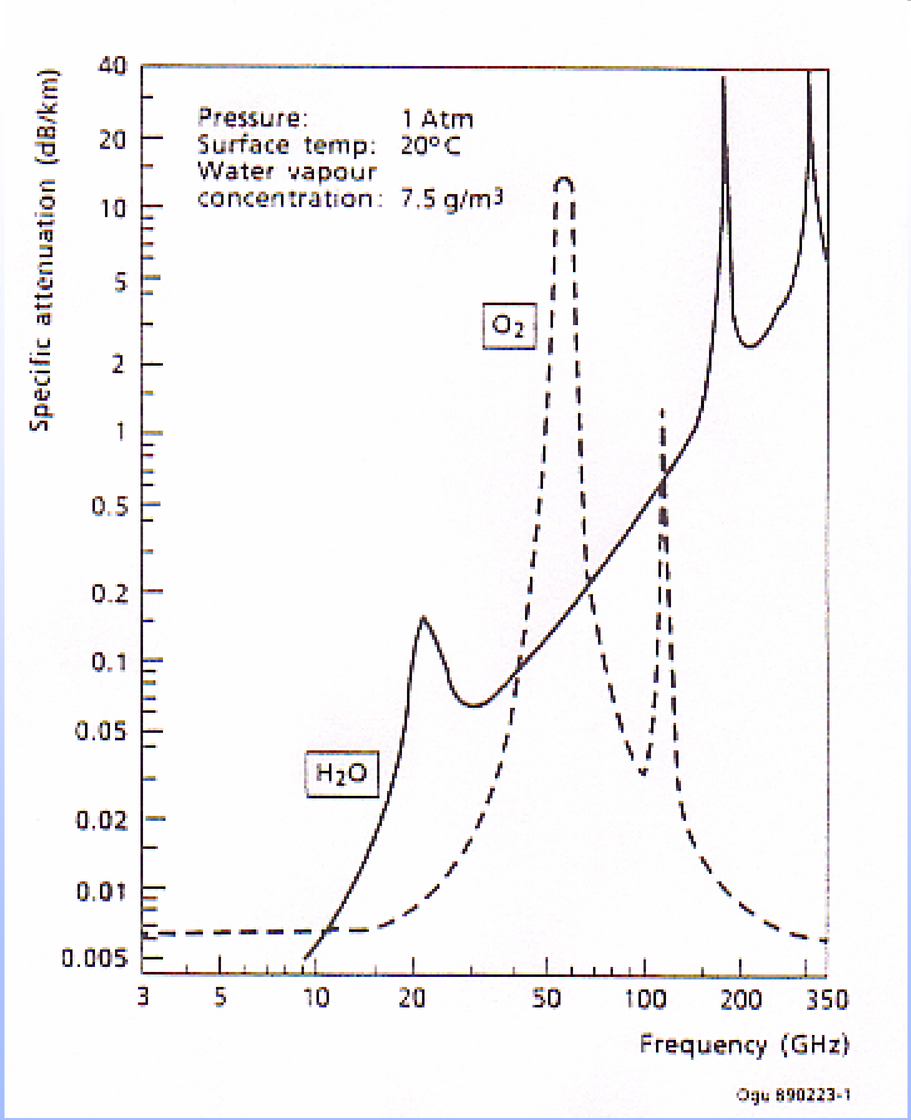


$$l_{atm} = \frac{2h}{\sqrt{\sin^2 \varepsilon + \frac{2h}{R_e}} + \sin \varepsilon}$$

$$h_{O_2} \approx 6\ km$$

$$h_{H_2O} \approx 2\ km$$

Dempning i atmosfæren

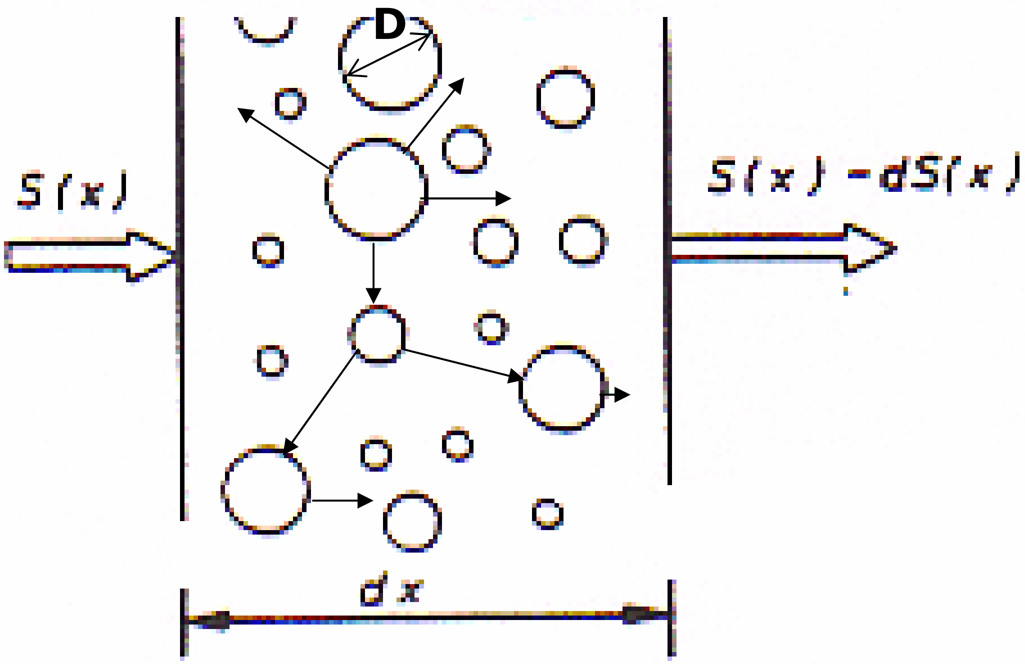


- Spesifikk attenuasjon i dB/km på grunn av vanndamp og oksygen i atmosfæren, trykk 1 atm, temperatur 20 grader, vanndamp 7.5 g/m^3.
- Ingen dempning på grunn av regn og skyer.
- Absorbsjonslinjer for vanndamp ved 22 GHz.
- Absorpsjonslinje for oxygen ved 60 og 130 GHz

$$A_{tot} = \gamma_{O_2} \cdot l_{O_2} + \gamma_{H_2O} \cdot l_{H_2O}$$

Dempning i regn (1)

$$\int_0^\infty N(D)\,dD = \text{dråper pr volumenhet}$$



$$L_{tot} = S(Q_a + Q_s) = S \cdot Q_t$$

Dempning i regn (2)

Dempningen i regn skjer fordi de enkelte vanndråpene

- sprer energi ut av strålen
- absorberer energi

$$R \propto \int_0^\infty N(D)v(D)D^3 dD$$

$$N(D) = N_0 e^{-D/D_m}$$

Dempningen er følgelig avhengig av

- volum av vann i radiostrålen
  dvs avhengig av regnintensitet (R)
  og dråpestørrelsesfordelig (N)
- dråpens totale dempningstverrsnitt (Q), som igjen er en funksjon av
  - diameter og bølgelengde (D/λ)
  - vannets brytningsindeks (n)

Spesifikk dempning blir da:

$$\gamma \propto \int_0^\infty Q_t N(D) dD$$

For praktiske formål:

$$\gamma = aR^b \quad (\mathrm{dB/km})$$

Dempning i regn/våt snø, 12 GHz, lin.pol.

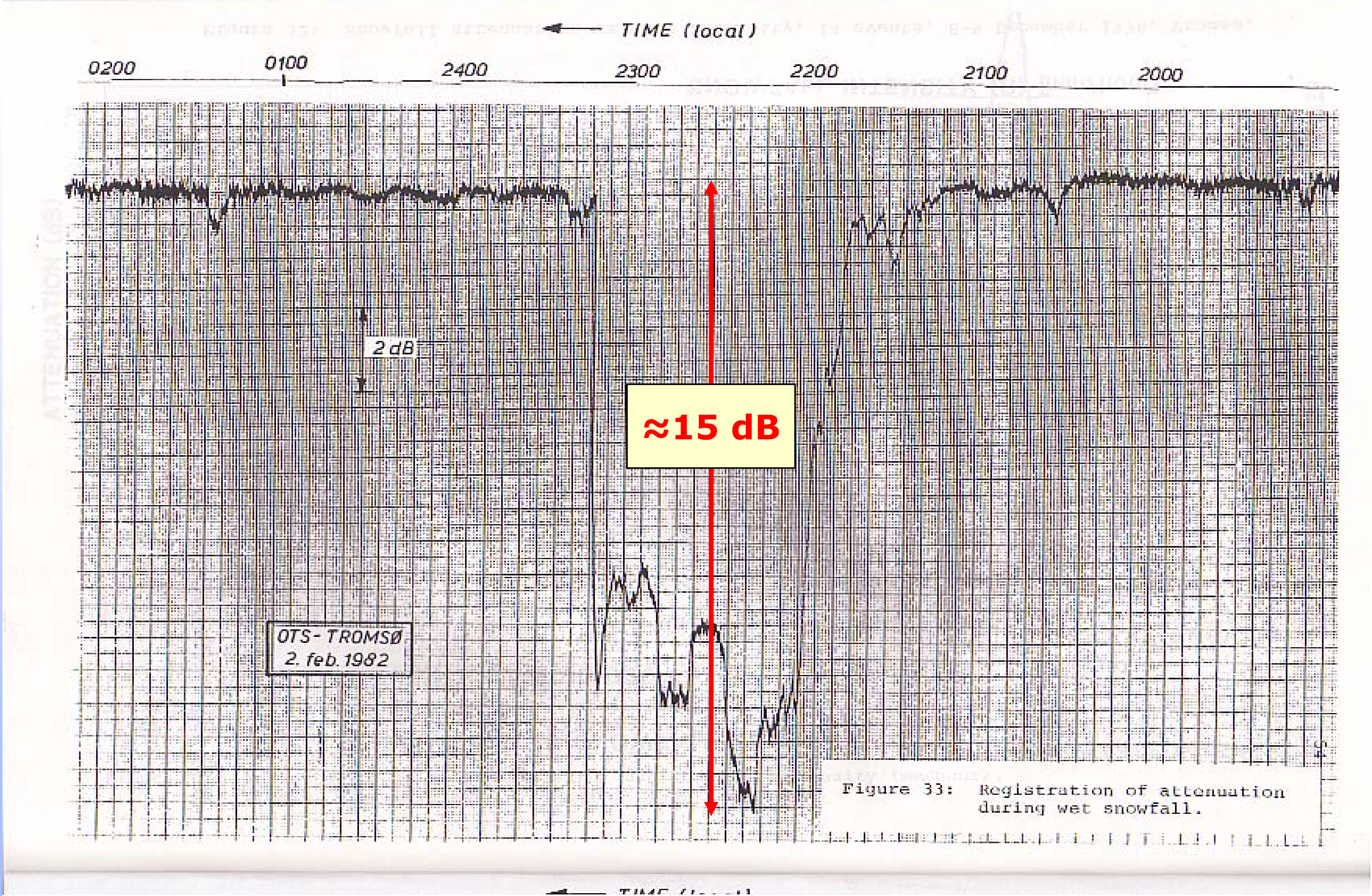


Figure 33: Registration of attenuation during wet snowfall.

Spesifikk dempning pga regn

Siden γ, er proporsjonal med R, vil for praktiske formål:

$$\gamma = a \cdot R^{b} \quad \text{dB/km}$$

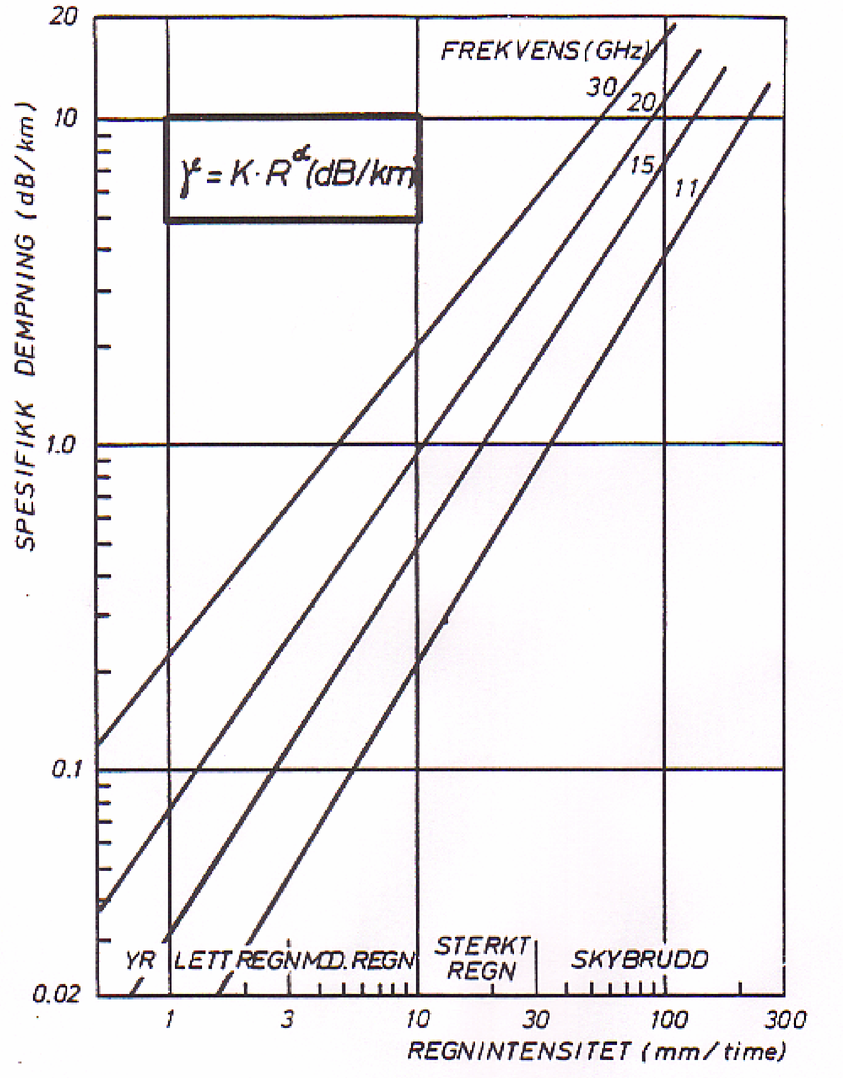
For frekvenser mellom 10 og 30 GHz vil b være nær 1, dvs

$$\gamma = a \cdot R \quad \text{dB/km}$$

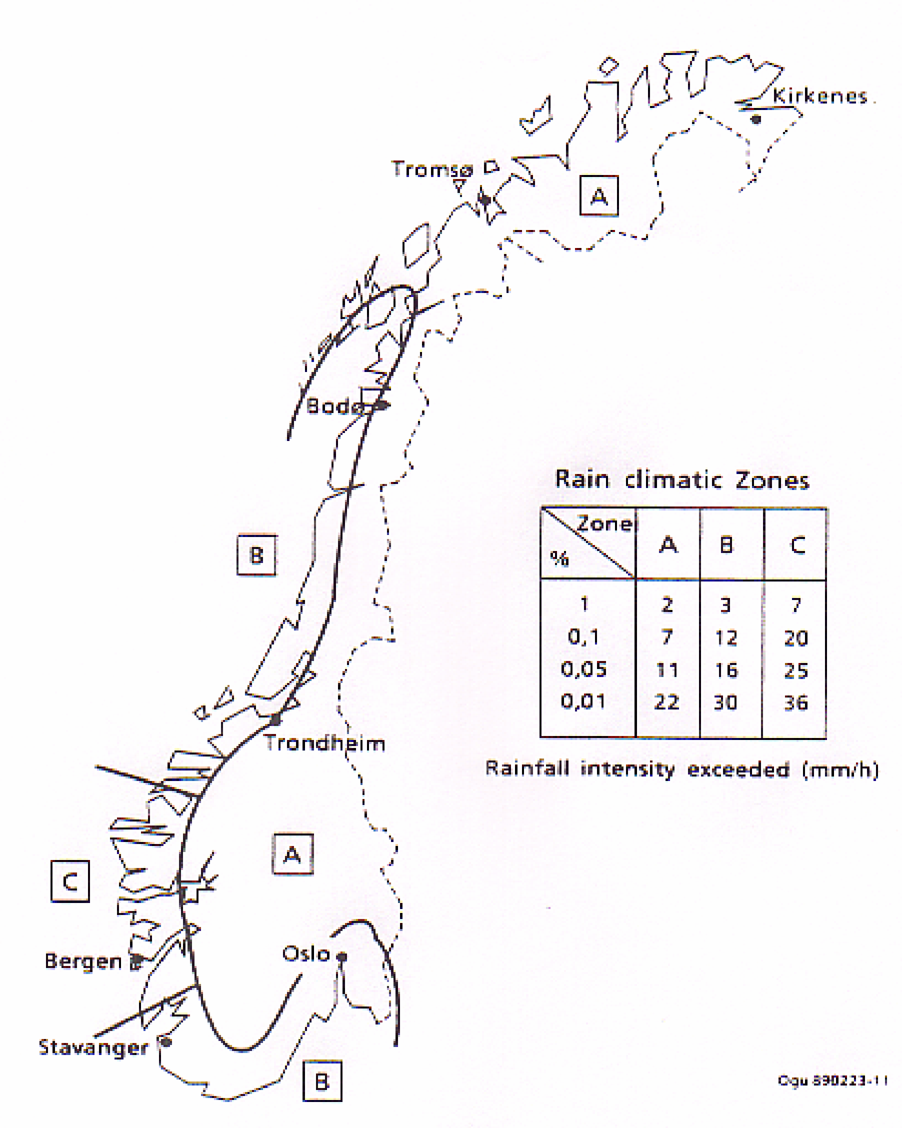
f. eks. vil

γ ≈ 0.045R ved 15 GHz

γ ≈ 0.1R ved 20 GHz



Regnintensitetssoner for Norge

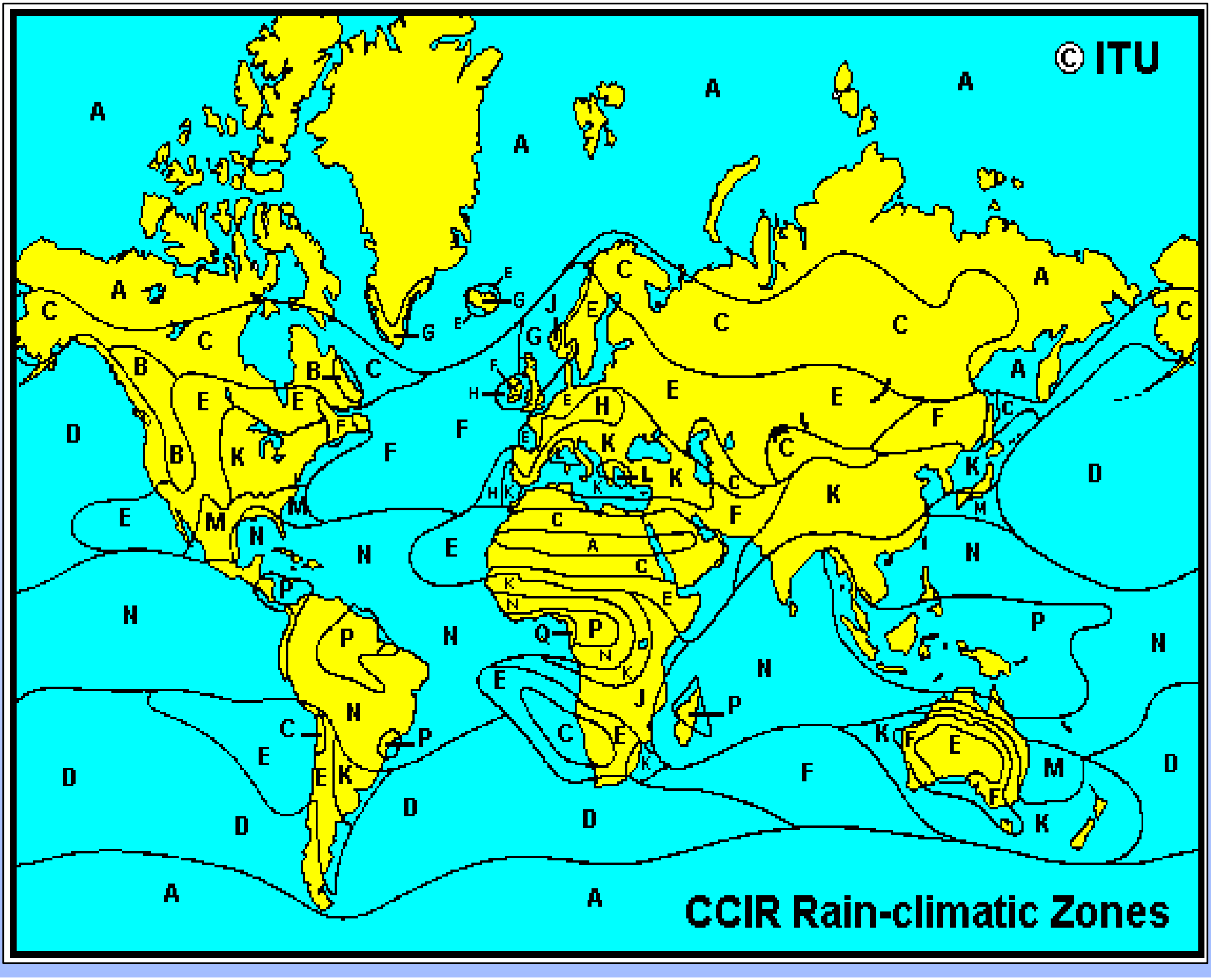


Rain climatic Zones

Zone / %	A	B	C
1	2	3	7
0,1	7	12	20
0,05	11	16	25
0,01	22	30	36

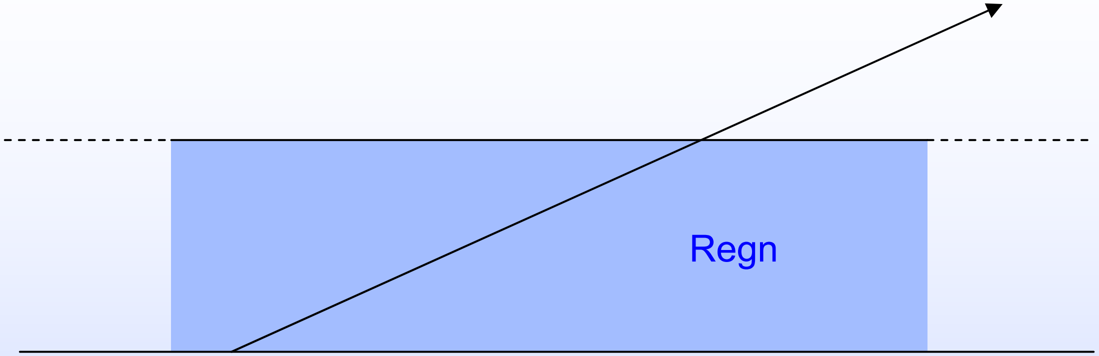
Rainfall intensity exceeded (mm/h)

Regnintensitets-soner i Europa



“Regnmodeller”

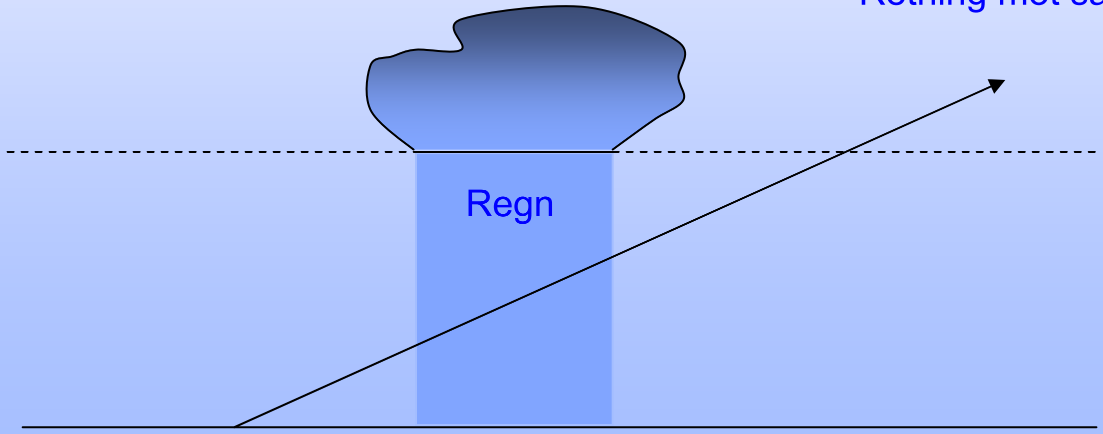
“Vestlandsmodellen”



Retning mot satellitten

0^0 C isoterm
(smeltesonen)

Regn



Retning mot satellitten

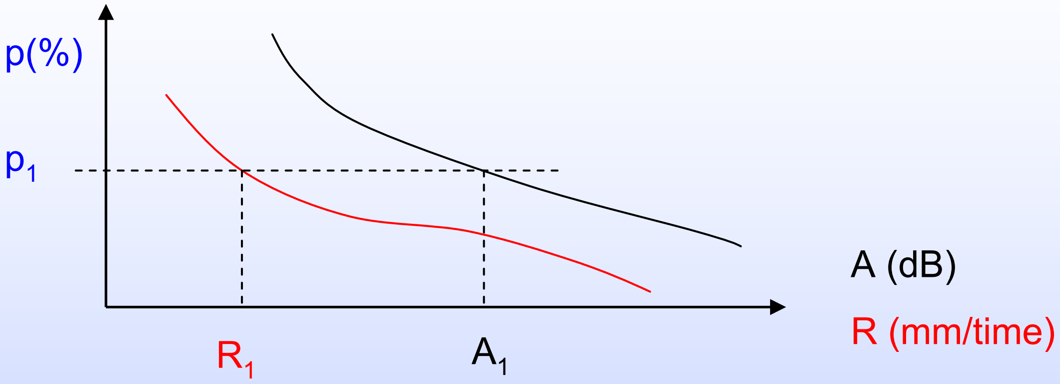
0^0 C isoterm
(smeltesonen)

Regn

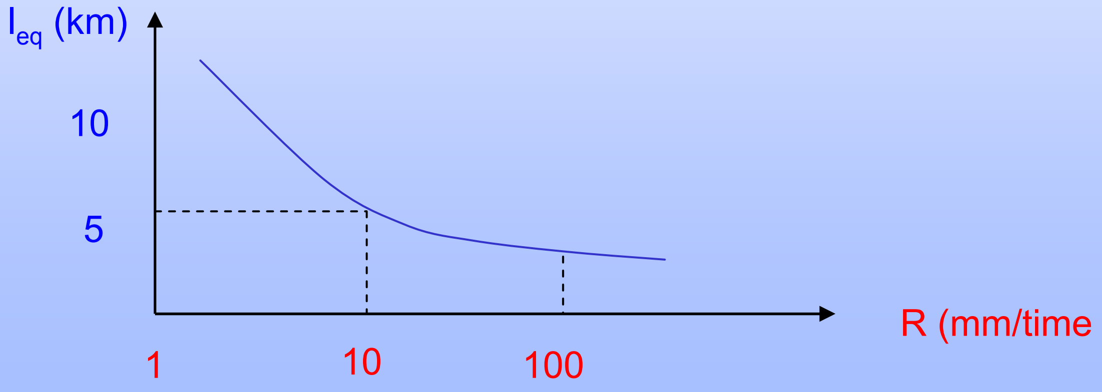
“Østlandsmodellen”

Ekvivalent lengde gjennom regnvær

Måler kumulative regnintensitets- og dempningsfordelinger på samme sted over samme tidsperiode:

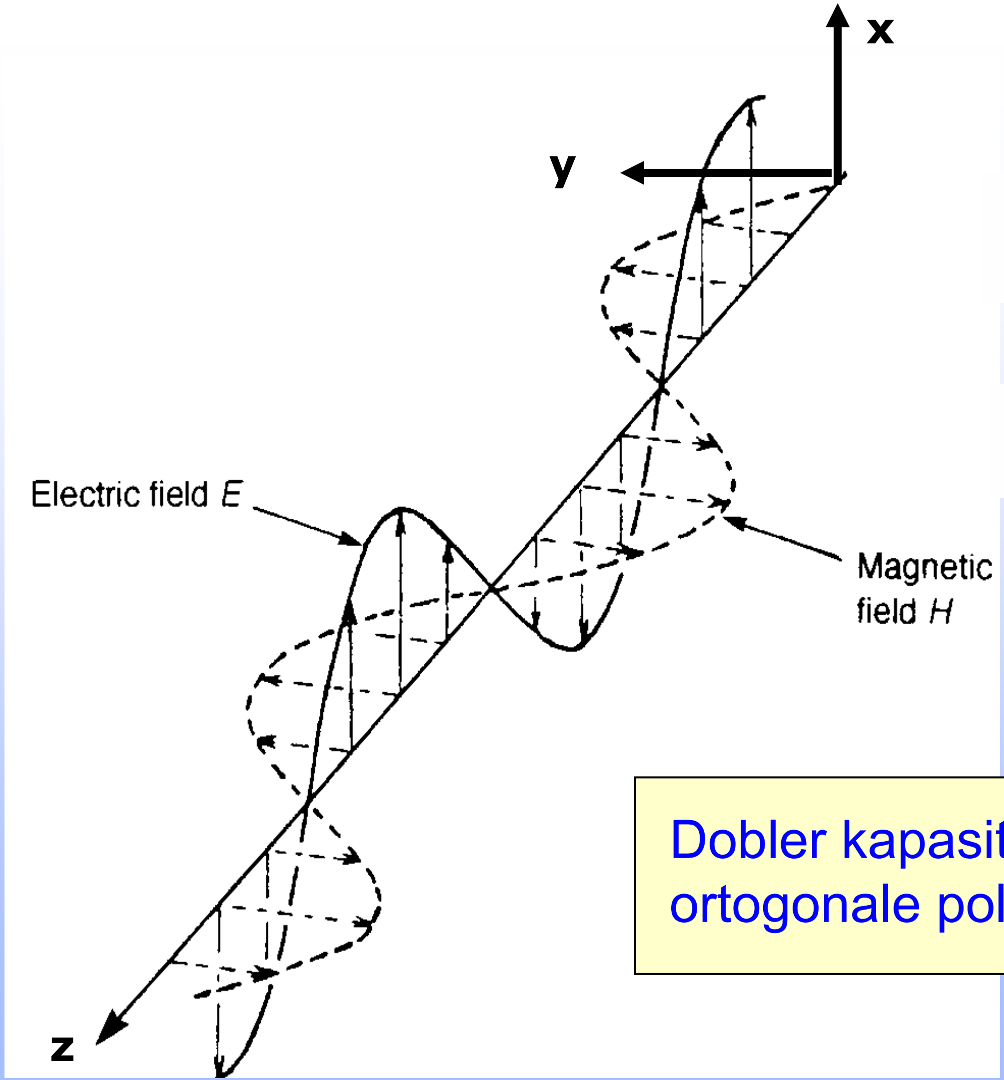


$$l_{eq}(R_1) = \frac{A_1}{\gamma(R_1)} \quad \text{(km)}$$



$$l_{eq} = \frac{A_{tot}(p)}{\gamma\left[R(p)\right]} \quad \text{(km)}$$

Plan bølge (lineær vertikal polarisasjon)

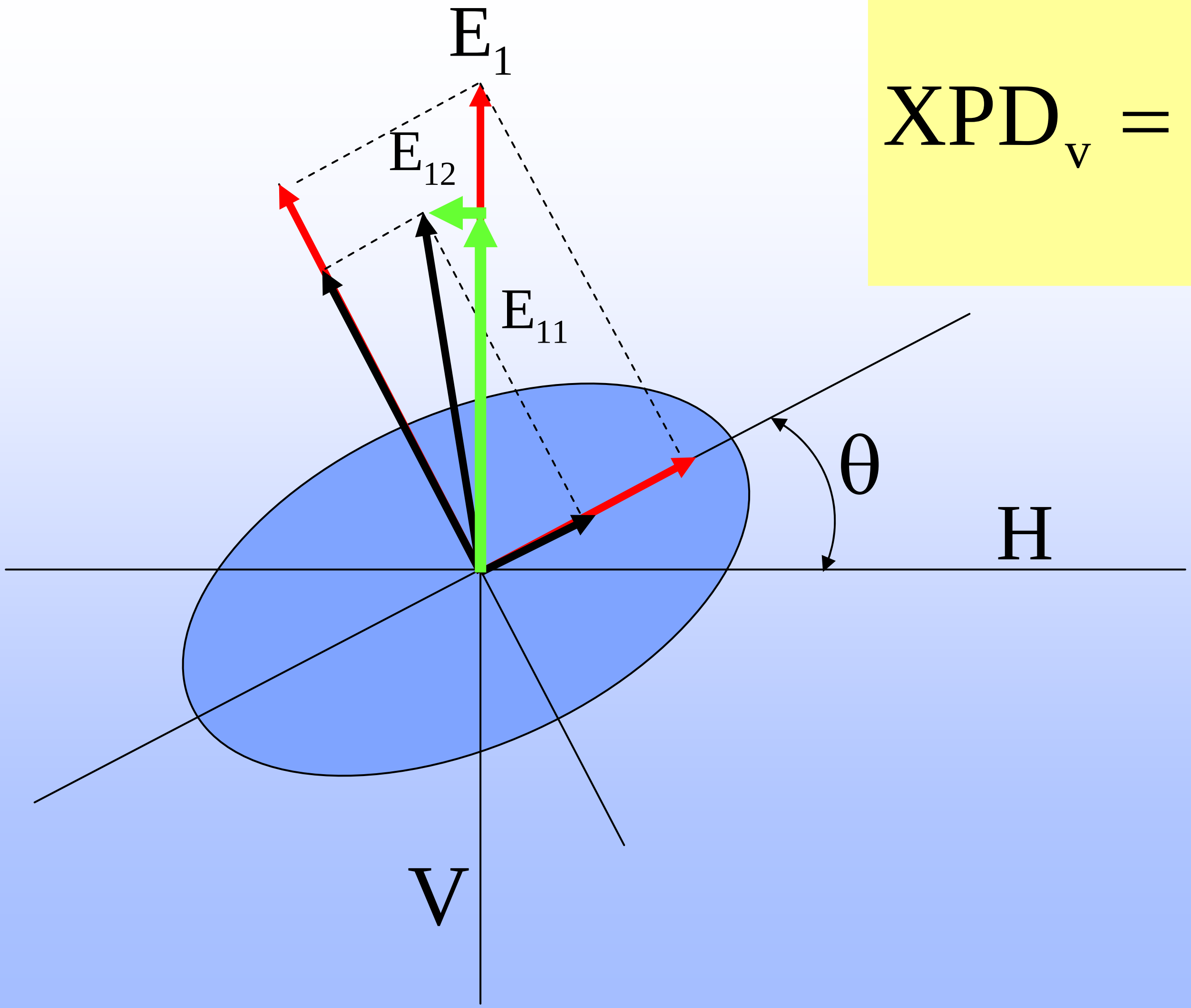


$$\mathbf{E} = E_0 \cos(\omega t - kz)\hat{\mathbf{x}}$$

$$\mathbf{H} = H_0 \cos(\omega t - kz)\hat{\mathbf{y}}$$

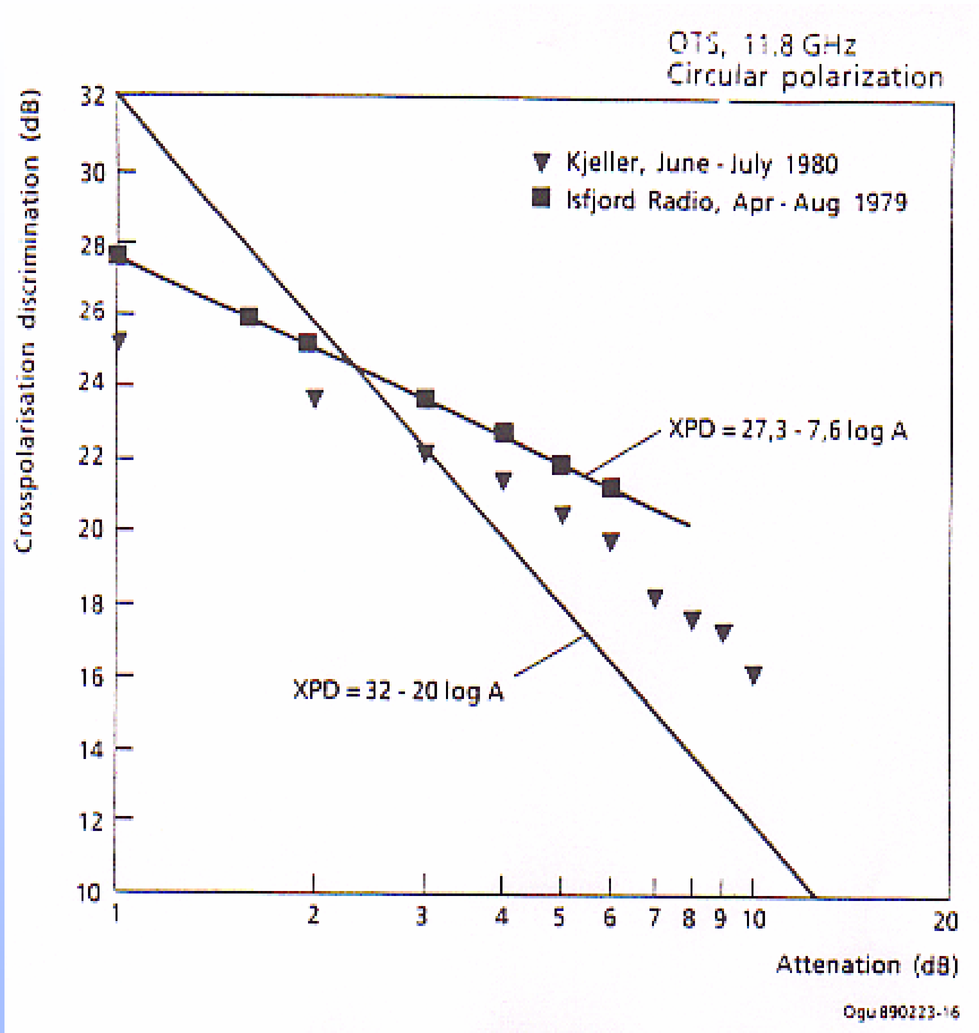
Dobler kapasiteten ved å benytte ortogonale polarisasjoner

Depolarisasjon i regn



$$XPD_v = 20\log\frac{E_{11}}{E_{12}}$$

Depolarisasjon p.g.a. regn



Regndråpene ligner mer på “pastiller” enn på hengende vanndråper.

Det fører til av horisontal og vertikalkomponentene av radiobølger ser forskjellig impedans. Dermed vil resultatanten (feltstyrkekomponenten) dreie.

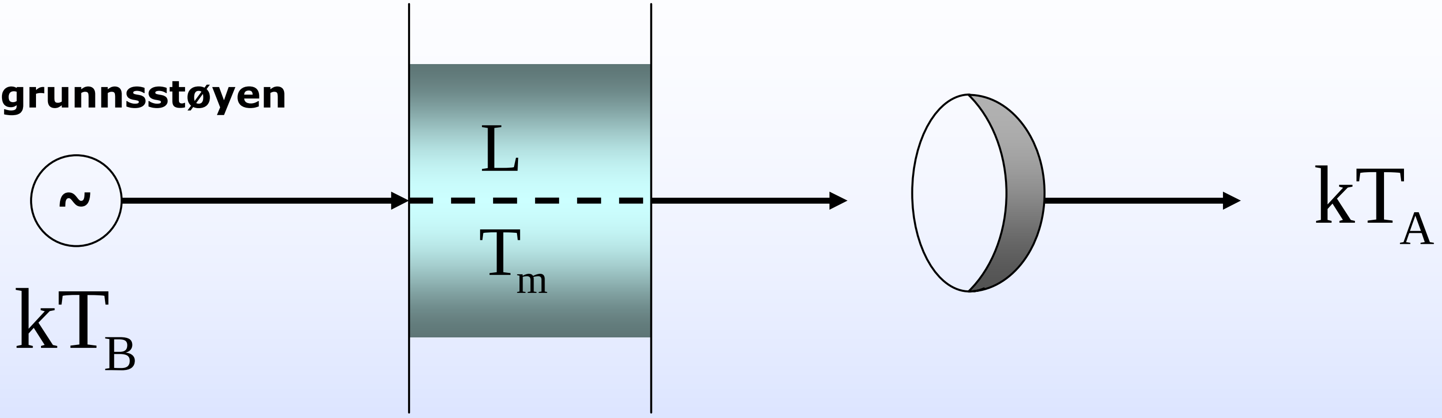
Det er en statistisk sammenheng mellom regnintensitet og polarisasjonsdreining,
og dermed en sammen-
heng mellom attenuasjon
og depolarisasjon. En modell er

XPD = a – b log(ATT)
hvor XPD og ATT er gitt i dB
For 12 GHz er a=32 og b=20

Støy pga absorpsjon i atmosfæren/regn

Atmosfæren (regnet) kan betrakte som et "dempeledd"

Bakgrunnsstøyen



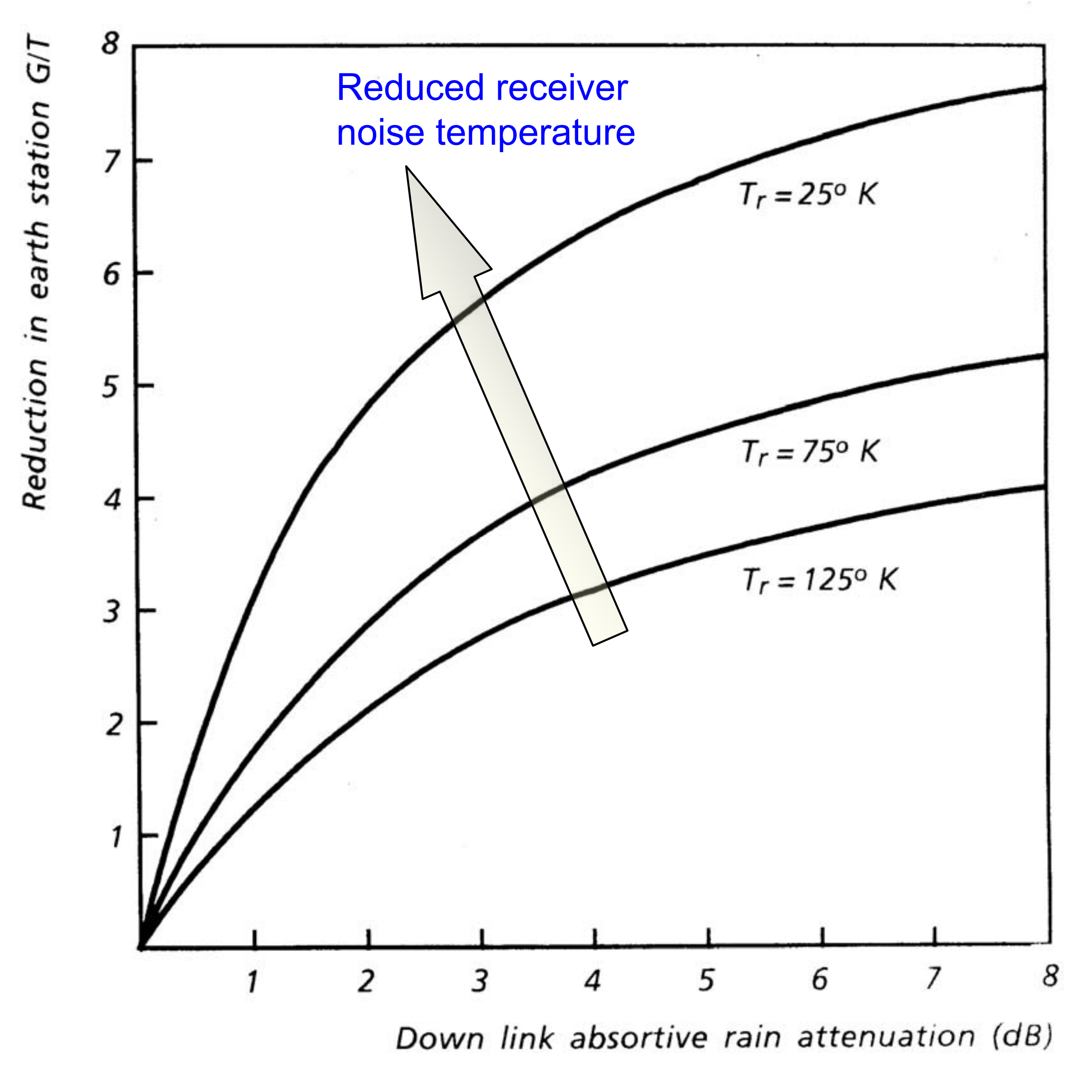
$$T_A = \frac{T_B}{L} + \frac{L-1}{L}T_m \approx \boxed{(1-\frac{1}{L})T_m}$$

Støyøkningen

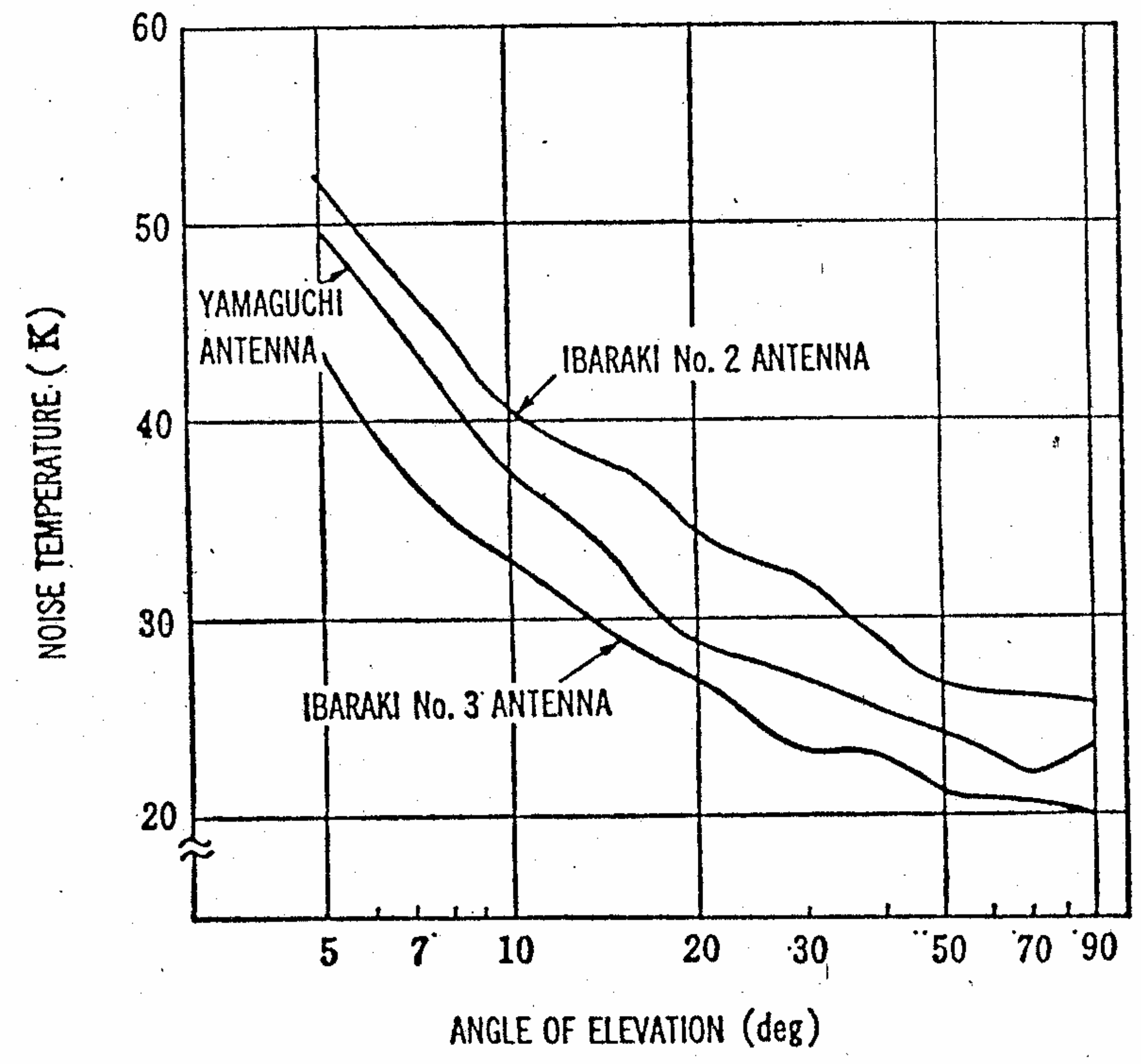
$$\boxed{L = \frac{T_m}{T_m - T_A}}$$

Radiometerlikningen (absorpsjonsbidraget)

Reduction in G/T



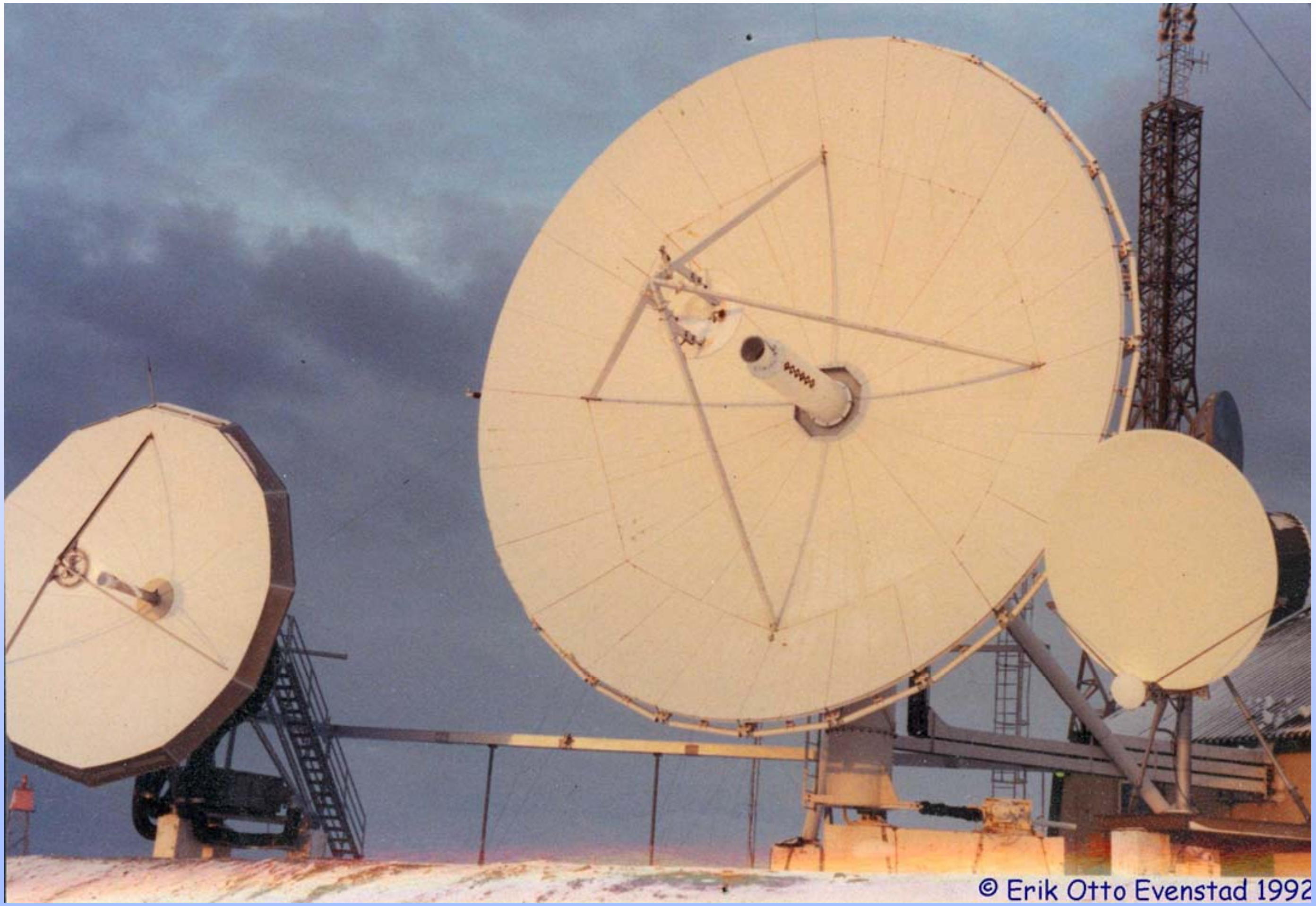
Antenna noise (clear sky)



Antenna noise temperature for C-band earth stations (antenna diameter ca 11 meter)

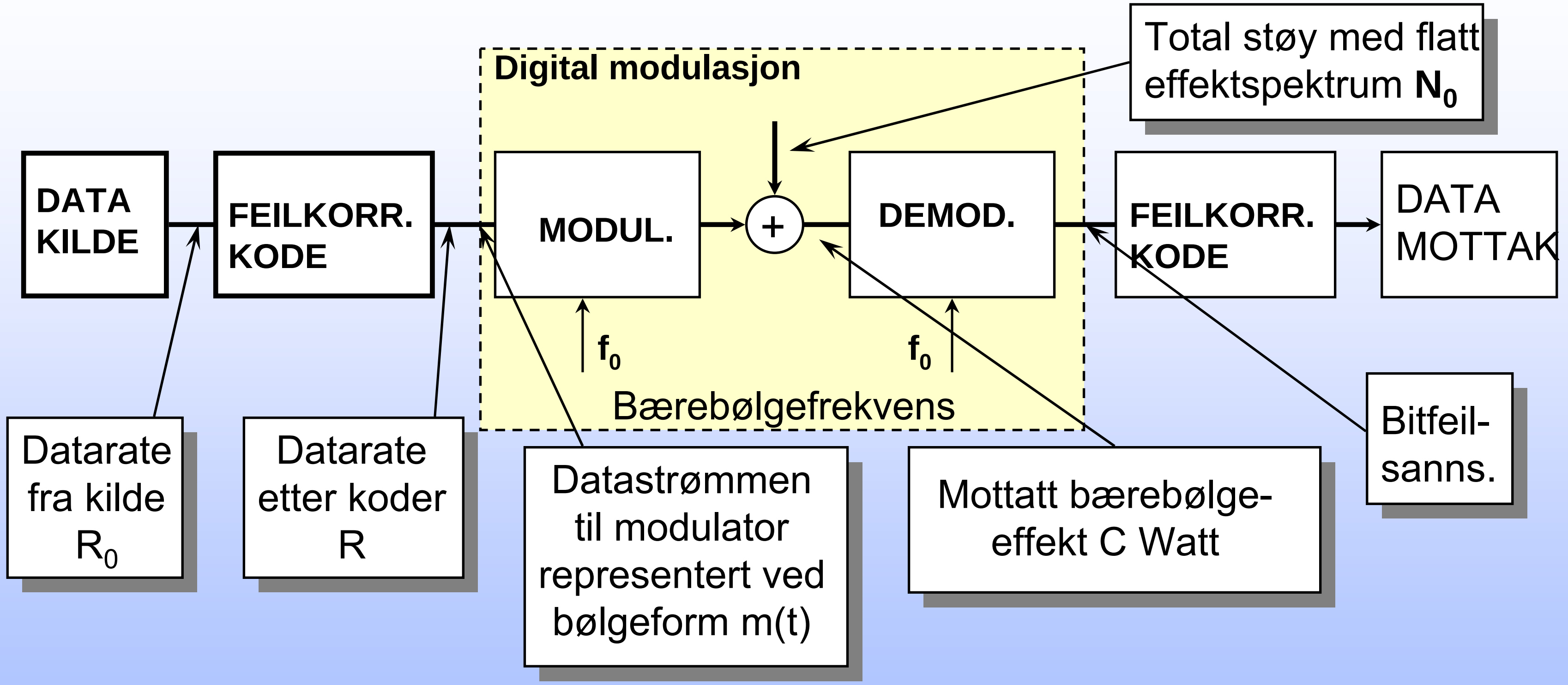
Ibaraki 1 & 2 and Yamaguchi are land earth stations in the INMARSAT system.

Maksimal solinterferens!



© Erik Otto Evenstad 1992

SYSTEMMODELL



Digital modulasjon

DATA KILDE

FEILKORR. KODE

MODUL.

+

DEMOD.

FEILKORR. KODE

DATA MOTTAK

f_0

f_0

Bærebølgefrekvens

Total støy med flatt effektspektrum $\mathbf{N_0}$

Datarate fra kilde R_0

Datarate etter koder R

Datastrømmen til modulator representert ved bølgeform m(t)

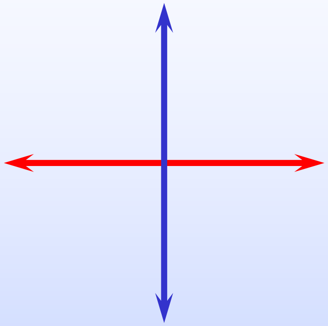
Mottatt bærebølgeeffekt C Watt

Bitfeilsanns.

MODULATION METHODS

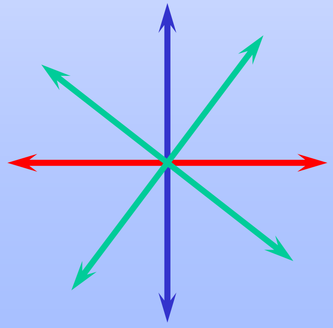
BPSK Binary Phase Shift Keying

- 1 bit per symbol
- “antipodal” modulasjon, lavest energi per bit for gitt bitfeilsannsynlighet



QPSK Quarternary Phase Shift Keying

- 2 bit per symbol, dobler bitraten per båndbreddeenhet relativt BPSK
- kan betraktes som to ortogonale BPSK signaler, samme enegi per bit for gitt bitfeilsannsynlighet



8PSK 8 Phase Shift Keying

- 3 bit per symbol, 3 ganger datahastighet per båndbreddeenhet relativt til BPSK
- økt energi per bit i forhold til BPSK and QPSK

BINÆR PSK (BPSK)

Den modulerte bærebølgen er

$$x(t) = \sqrt{2C} \cdot \cos\left(2\pi f_0 t + \phi(t)\right)$$

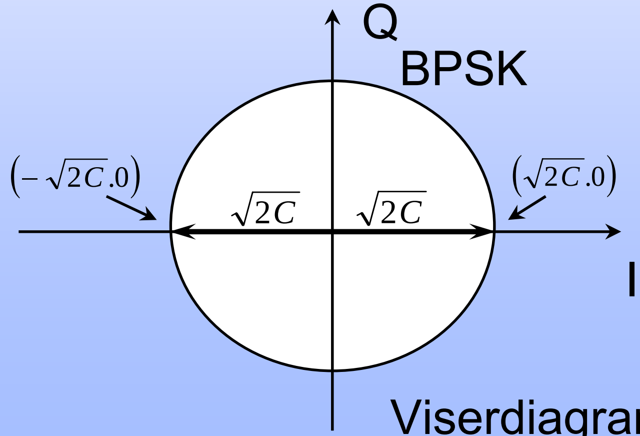
$a(t)$	$\phi(t)$
+1	0
-1	π

$a(t) = m(t)$

C = bærebølgeeffekten

Uttrykket kan omformes til:

$$x(t) = \sqrt{2C} \cdot a(t) \cdot \cos 2\pi f_0 t$$



Viserdiagram

BPSK signalet har konstant amplitude

QPSK (4-PSK)

Den modulerte bærebølgen kan skrives:

$$x(t) = \sqrt{2C} \cdot \cos\left(2\pi f_0 t - \phi(t)\right)$$

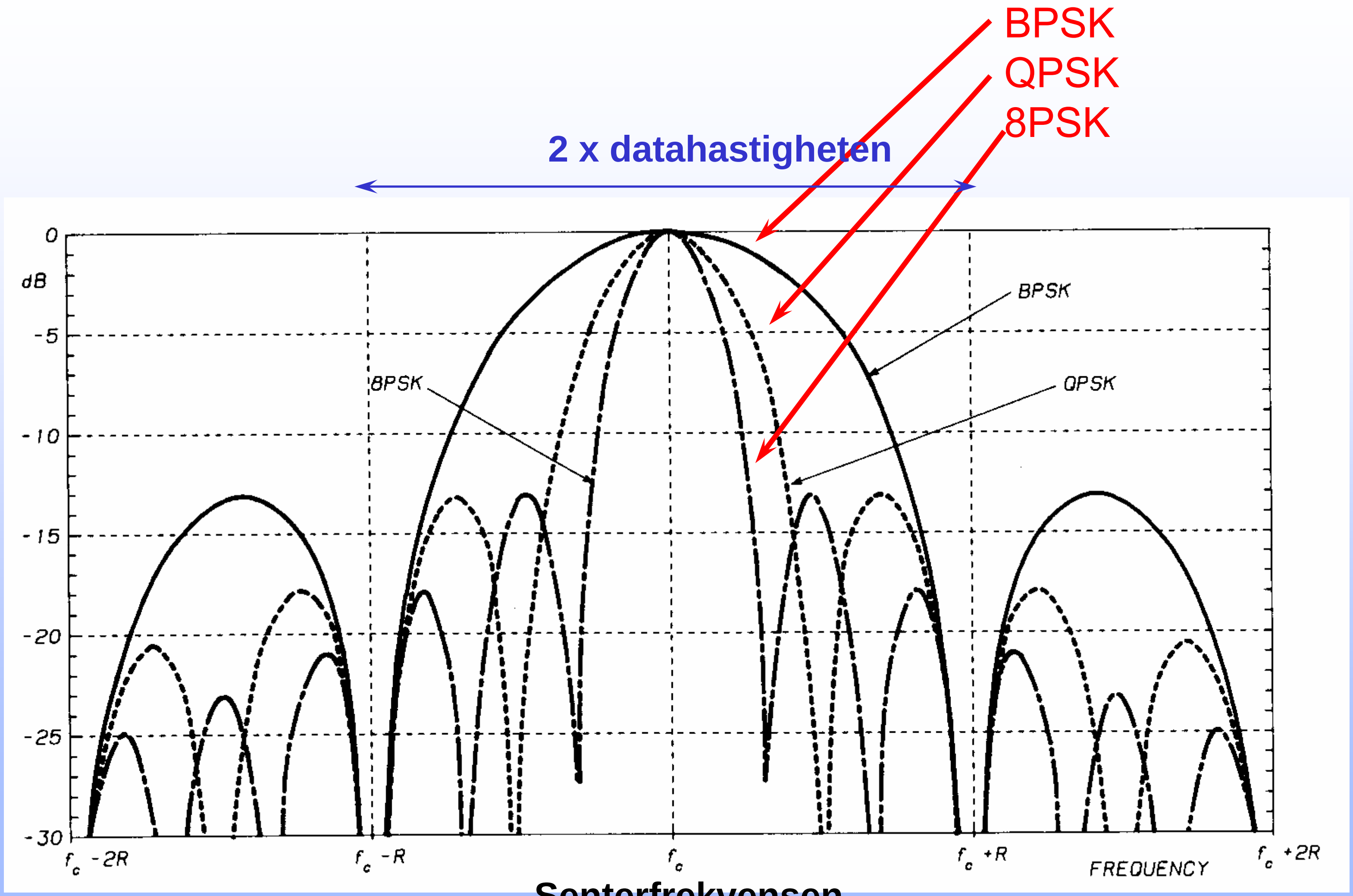
$$= \sqrt{2C} \cdot \cos\phi \cdot \cos\omega_0 t + \sin\phi \cdot \sin\omega_0 t$$

$$= \sqrt{C}\left(a \cdot \cos\omega_0 t + b \cdot \sin\omega_0 t\right)$$

$a(t)$	$b(t)$	$\phi(t)$
+1	+1	$+\pi/4$
-1	+1	$+3\pi/4$
+1	-1	$-\pi/4$
-1	-1	$-3\pi/4$

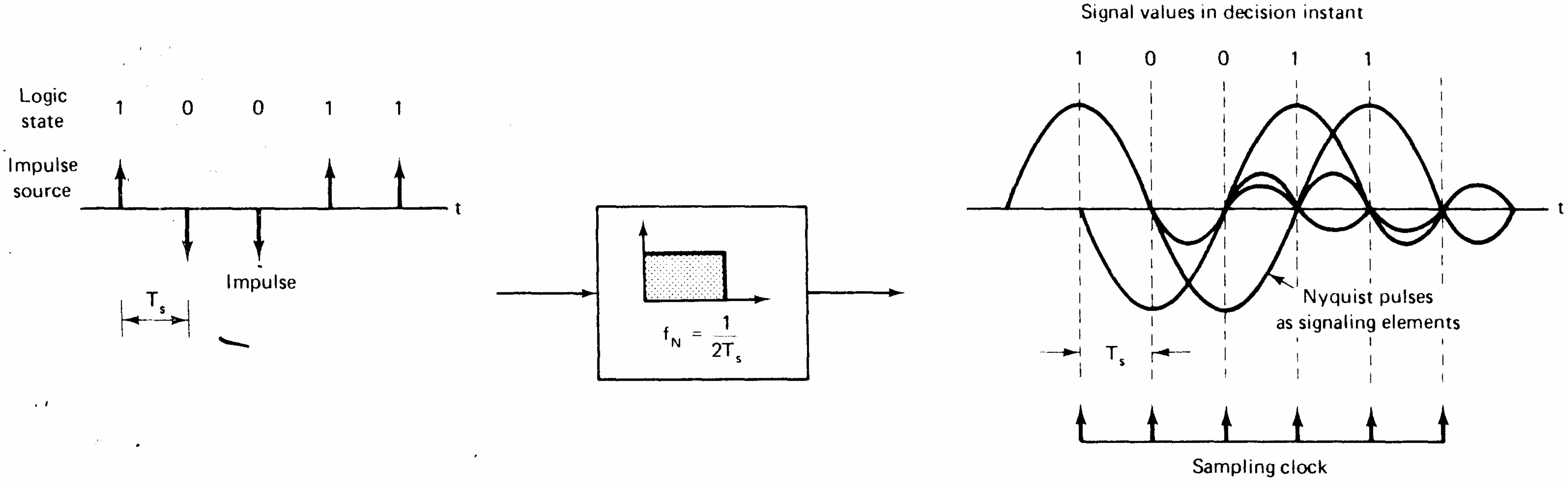
QPSK-signalet er en sum av to BPSK-signaler i kvadratur (I- og Q-kanalene)

Effektspektra med samme overføringshastighet



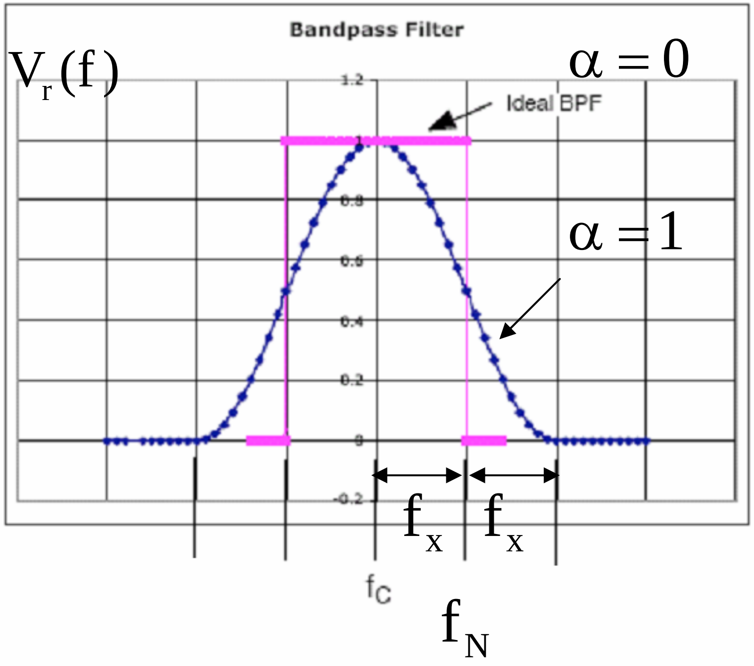
Senterfrekvensen

Transmisjon av båndbegrensede impulser



Ingen intersymbolinterferens (ISI-fri)

Nyquist-filter



Nyquist-frekvensen $f_N = \frac{R_s}{2}$

Roll-off faktoren $\alpha = \frac{f_x}{f_N}$ $0 < \alpha < 1$

Båndbredde $B_{occ} = (1+\alpha)R_s$

$$V_r(f) = \begin{cases} 1 & \text{når } |f| < \frac{R_s}{2}(1-\alpha) \\ \cos^2\left\{\frac{\pi}{2\alpha R_s}\left[|f| - \frac{R_s}{2}(1-\alpha)\right]\right\} & \text{når } \frac{R_s}{2}(1-\alpha) \le |f| \le \frac{R_s}{2}(1+\alpha) \\ 0 & \text{når } |f| > \frac{R_s}{2}(1+\alpha) \end{cases}$$

Impulsresponsen til et Nyquistfilter

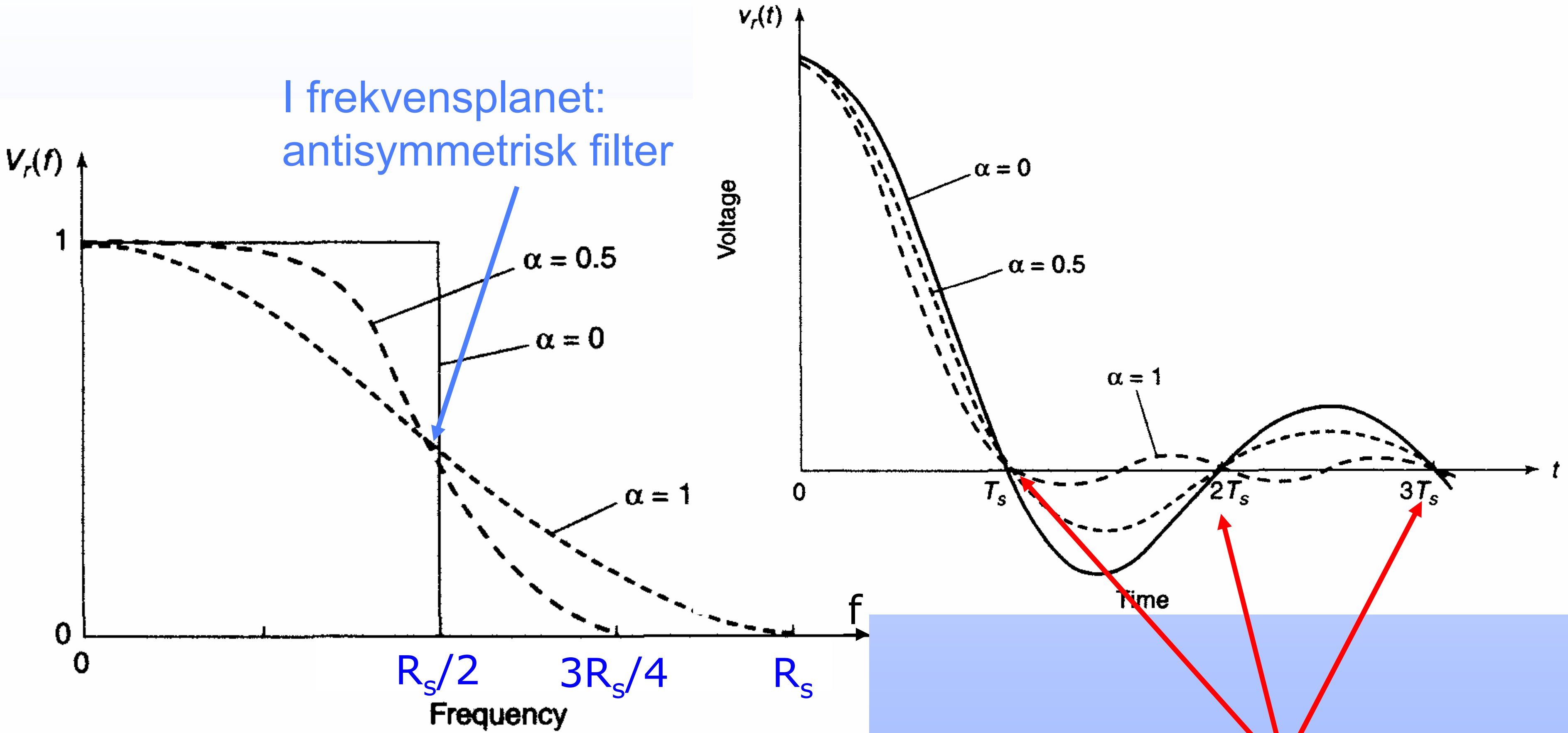
Filterets utgangssignal er:

$$v_r(t) = F^{-1}\left[V_r(f)\cdot S(f)\right]$$

Hvis inngangssignalet er: $s(t) = \delta(t) \Leftrightarrow S(f) = 1$ blir:

$$v_r(t) = \int_{-\infty}^{\infty} V_r(f)\cdot e^{j\omega t}df = \underbrace{\frac{\sin \pi R_s t}{\pi R_s t}}_{\text{Sørger for null-gjennomgangene}} \cdot \underbrace{\frac{\cos \pi\alpha R_s t}{1-\left(2\alpha R_s t\right)^2}}_{\text{Reduserer halen på pulsen med økende t}}$$

Overføringsfunksjon uten ISI (InterSymbol Interference)



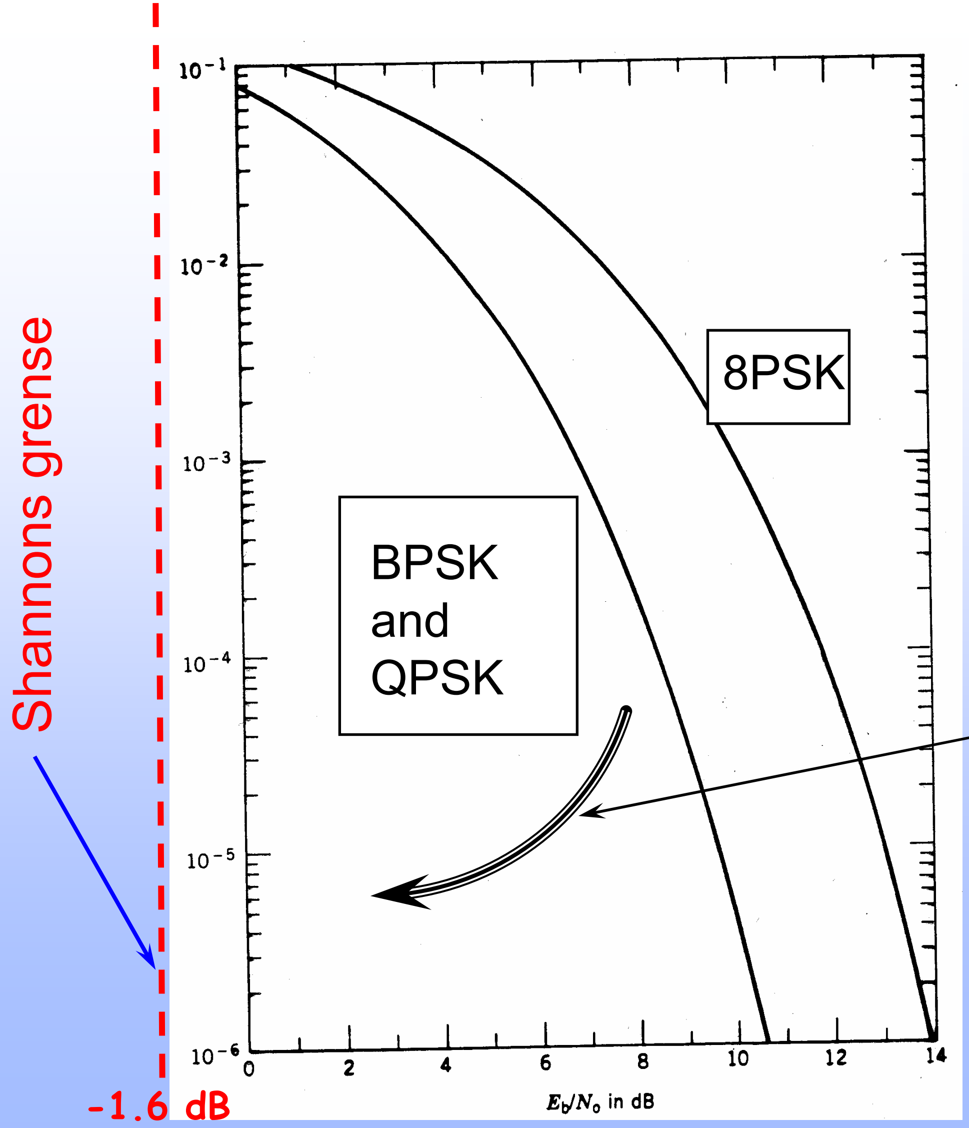
I frekvensplanet:
antisymmetrisk filter

I tidsplanet:
ekvidistante nullpunkter

Ved modulert bærebølge er:

$$B_{nødvendig} = R_{symbol} \cdot (1+\alpha)$$

TRANSMISJONSYTELSE

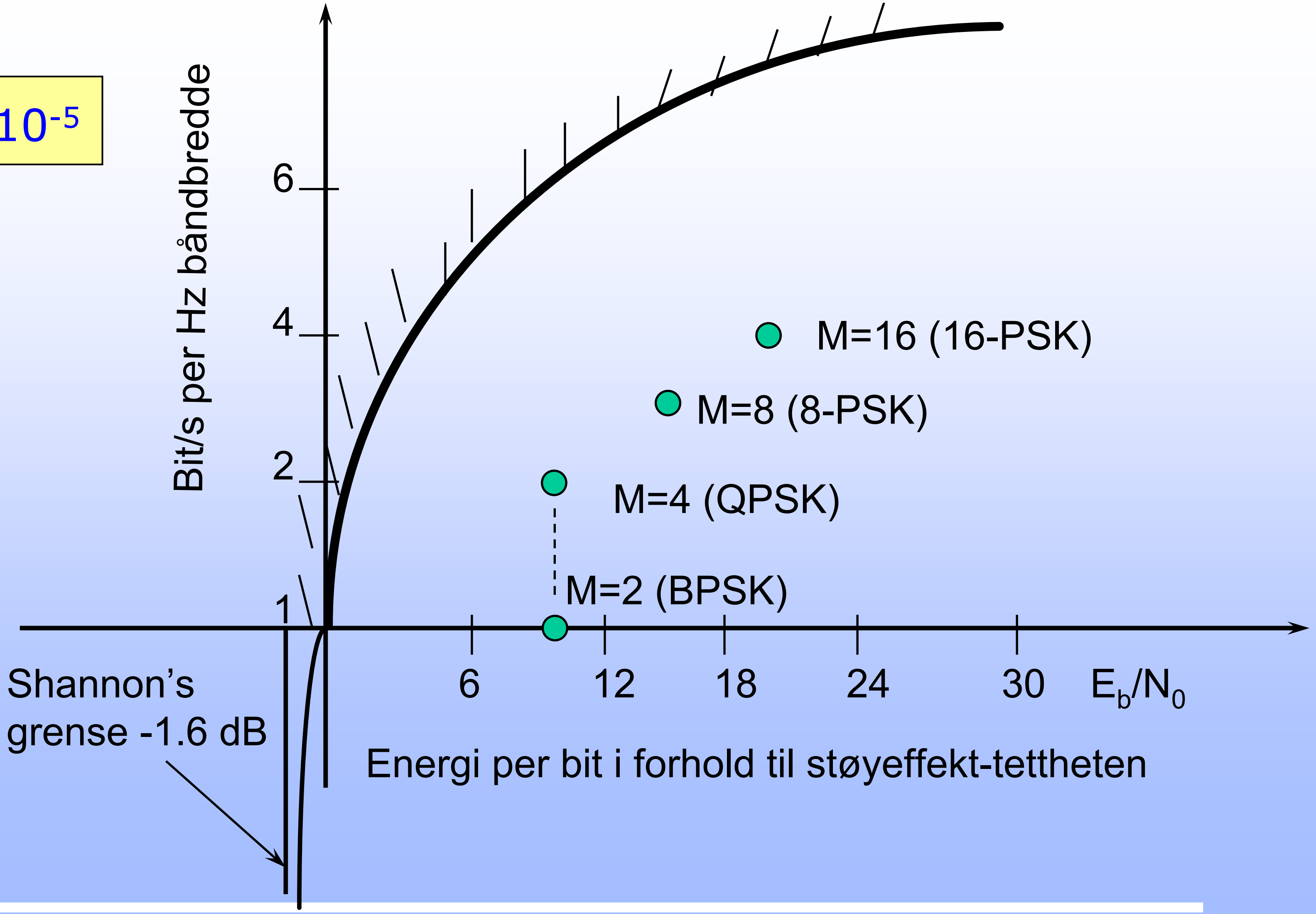


Bit error rate som funksjon av E_b/N_0 for BPSK, QPSK og Octal PSK (8PSK).

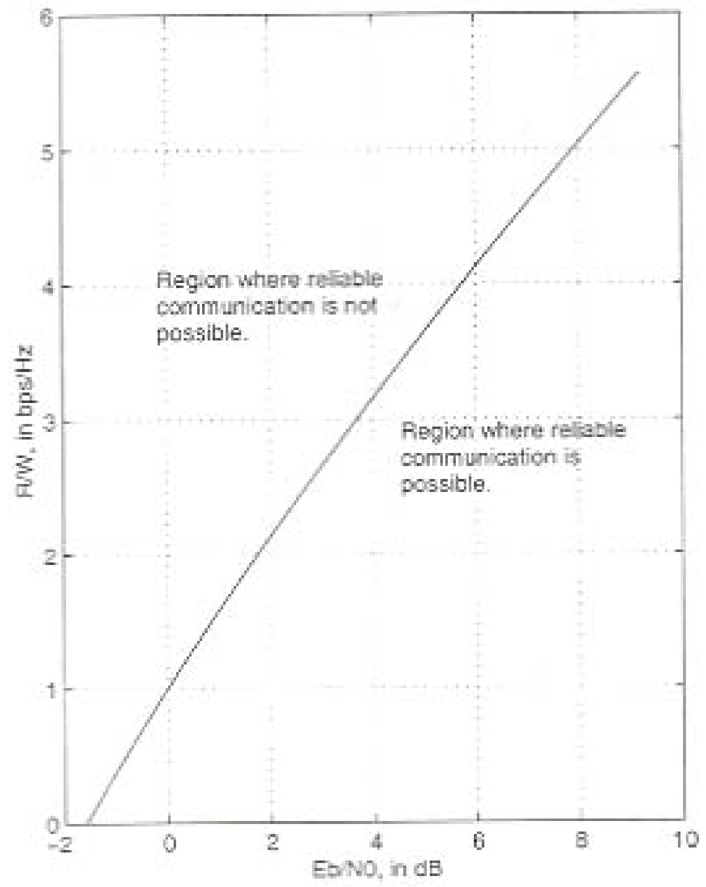
Utfordringen innen feilkorrigerende koding FEC: hvordan komme nærmere Shannons teroretiske grenser.

NØDVENDIG ENERGI OG BÅNDBREDDE

BER=10^{-5}



Shannons grense for R_b/B og E_b/N_o



$$\mathbb{C} = B \cdot \log_2(1 + \frac{C}{N})$$

$$R_{\max} = B \cdot \log_2(1 + \frac{E_b}{N_0}\frac{R_b}{B})$$

Grensen mellom regionene defineres av

$$R_b = R_{\max} \qquad \frac{R_b}{B} = \eta$$

hvor η er båndbreddeutnyttelsen

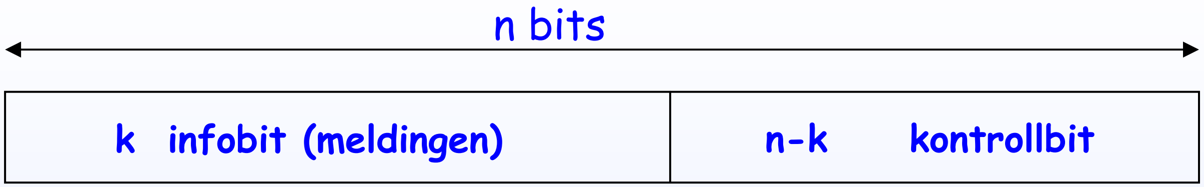
$$\eta = \log_2(1 + \left(\frac{E_b}{N_0}\right) \cdot \eta) \Rightarrow 2^{\eta} = \left(1 + \left(\frac{E_b}{N_0}\right) \cdot \eta\right)$$

$$\left(\frac{E_b}{N_0}\right) = \frac{2^{\eta} - 1}{\eta}$$

$$\left(\frac{E_b}{N_0}\right)_{\min} = \lim_{\eta \to 0}\left(\frac{2^{\eta} - 1}{\eta}\right) = \frac{\ln 2}{1} = \ln 2 = 0,69 \text{ tilsvarende -1,6 dB}$$

Blokkoder – grunnleggende begreper

(n,k)-blokkode:



n bits

k infobit (meldingen) **n-k kontrollbit**

$M = 2^k$ – mulige meldinger

Koderate: $R = k/n = R_b/R_c$

Hamming vekt $w(\mathbf{v})$: antall 1-ere i kodeordet

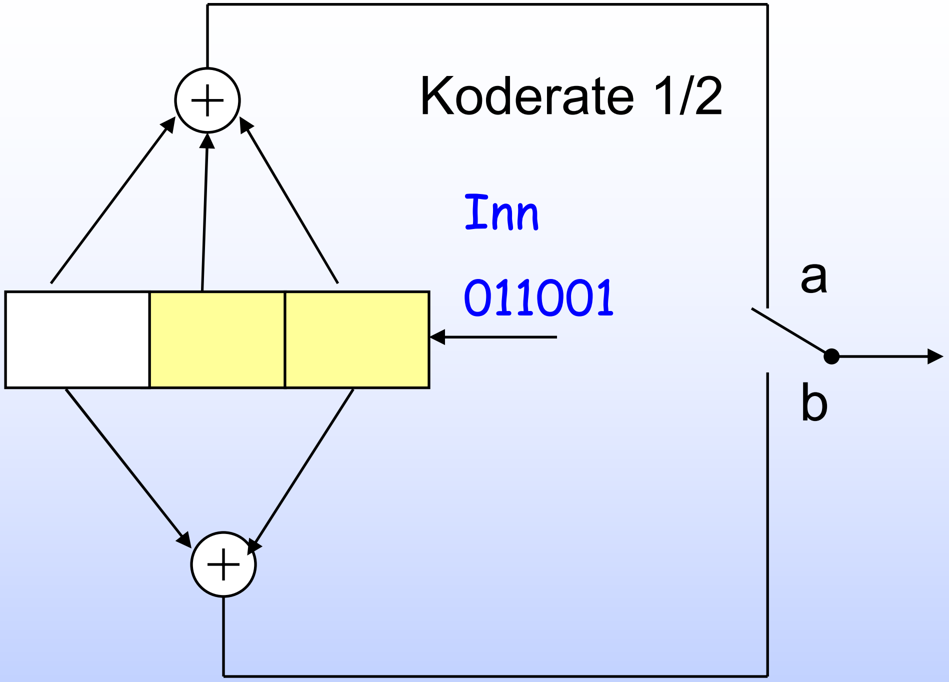
Hamming avstand $d(\mathbf{v},\mathbf{u})$: antall posisjoner hvor de to kodeordene er forskjellige

$d(\mathbf{v},\mathbf{u}) = w(\mathbf{v} \oplus \mathbf{u})$ dvs at $d_{min} = w_{min} = \min\{w(\mathbf{v}),\ \mathbf{v} \neq 1\}$

Antall feil som kan rettes: $e = \frac{1}{2}(d_{min} - 1)$

Antall feil som kan detekteres: $e = (d_{min} - 1)$

Foldingskode K=3



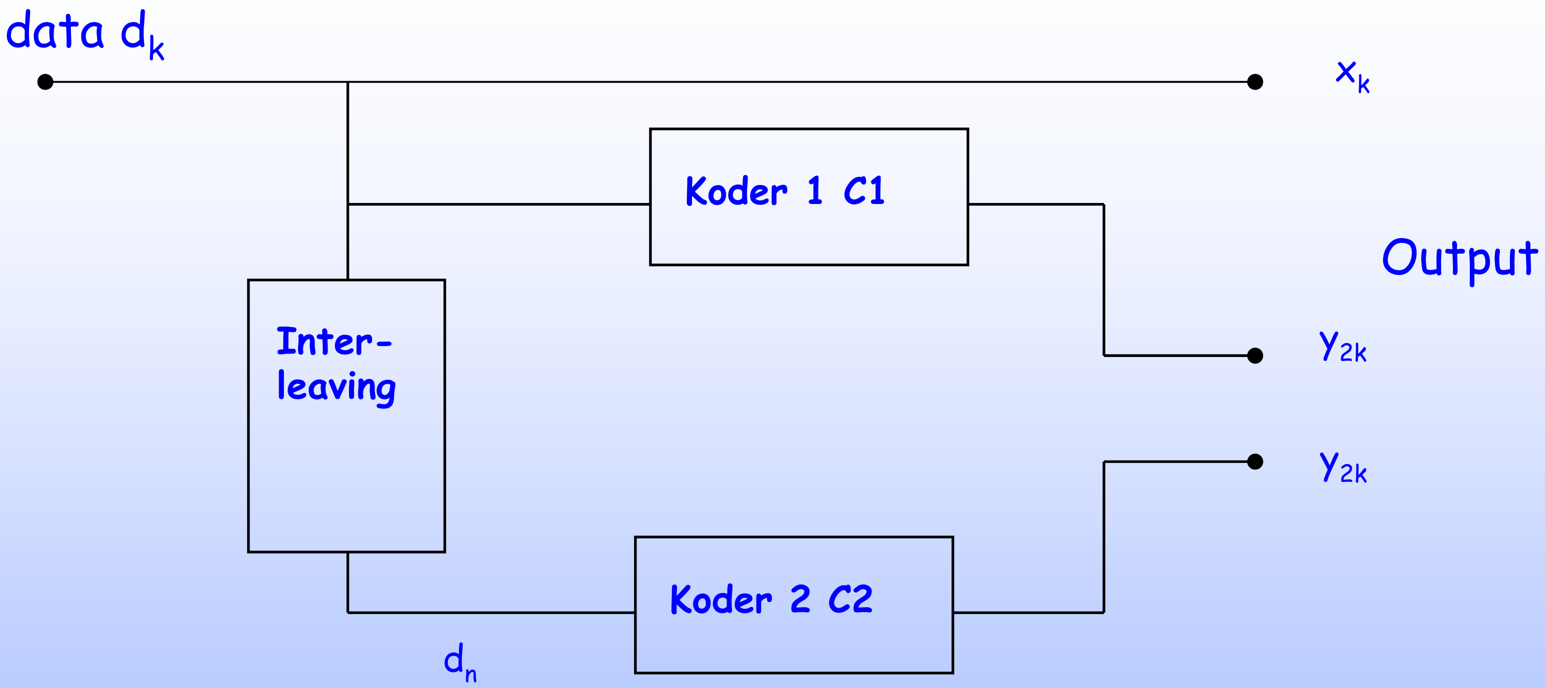
Ut

00 11 01 01 11 11

Reg innhold	Utgang
0 0 0	0 0
0 0 1	1 1
0 1 1	0 1
1 1 0	0 1
1 0 0	1 1
0 0 1	1 1

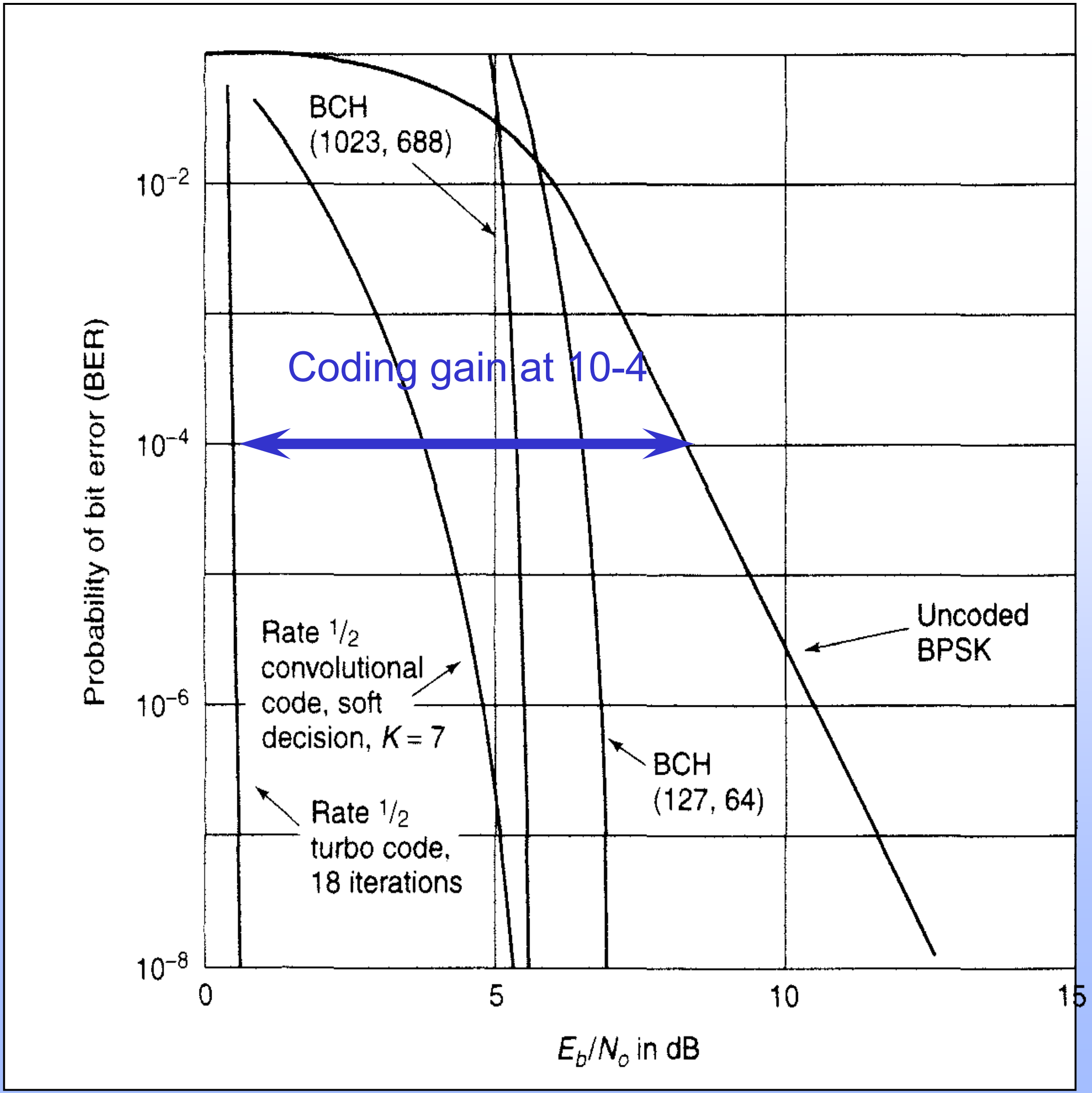
K = 3

Prinsippiell oppbygning av turbokoder (1/3 rate)

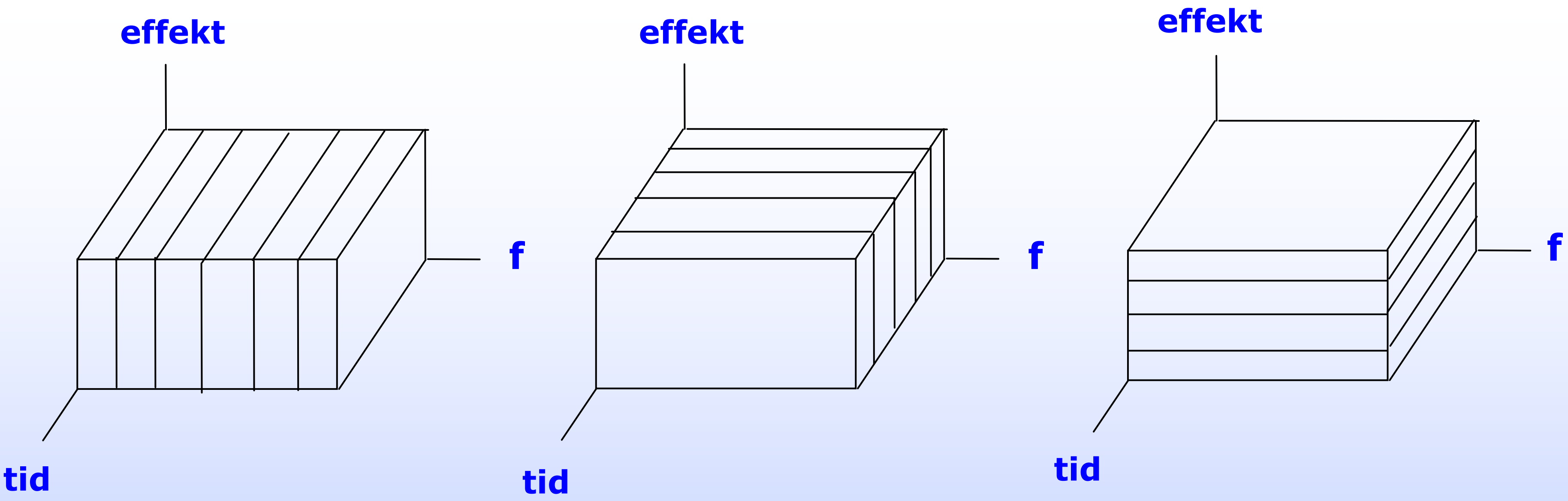


Turbokoder har oppnådd en bitfeilhyppighet på 10^{-6} ved en E_b/N_o=0.7 dB

BER vs E_b/N_0 for ulike koder



Aksessmetoder



FDMA
Time Division
Multiple Access

- continous full time
- fraction of the power
- fraction of the bandwidth

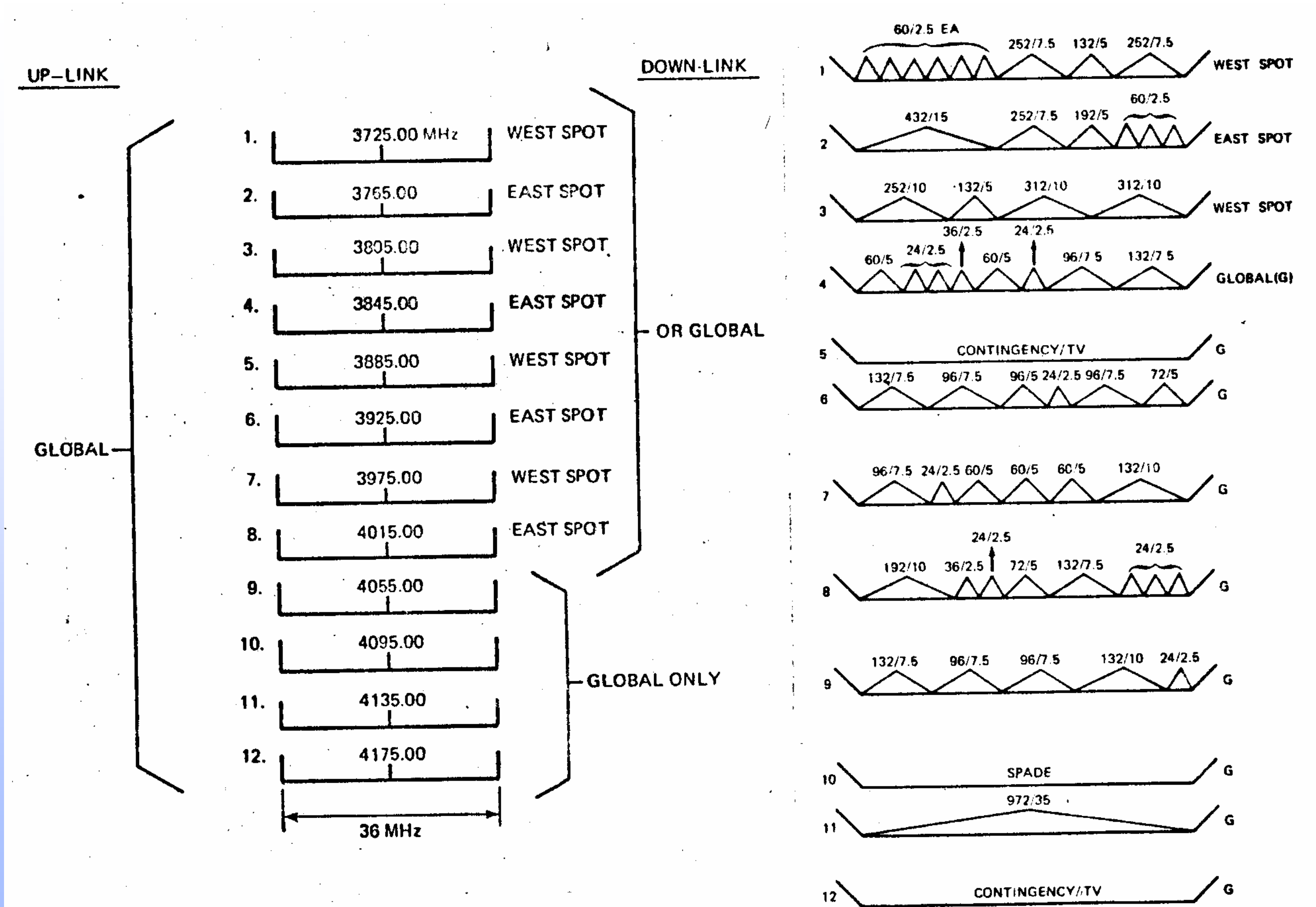
TDMA
Time Division
Multiple Access

- fraction of the time
- full power
- full bandwidth

CDMA
Code Division
Multiple Access

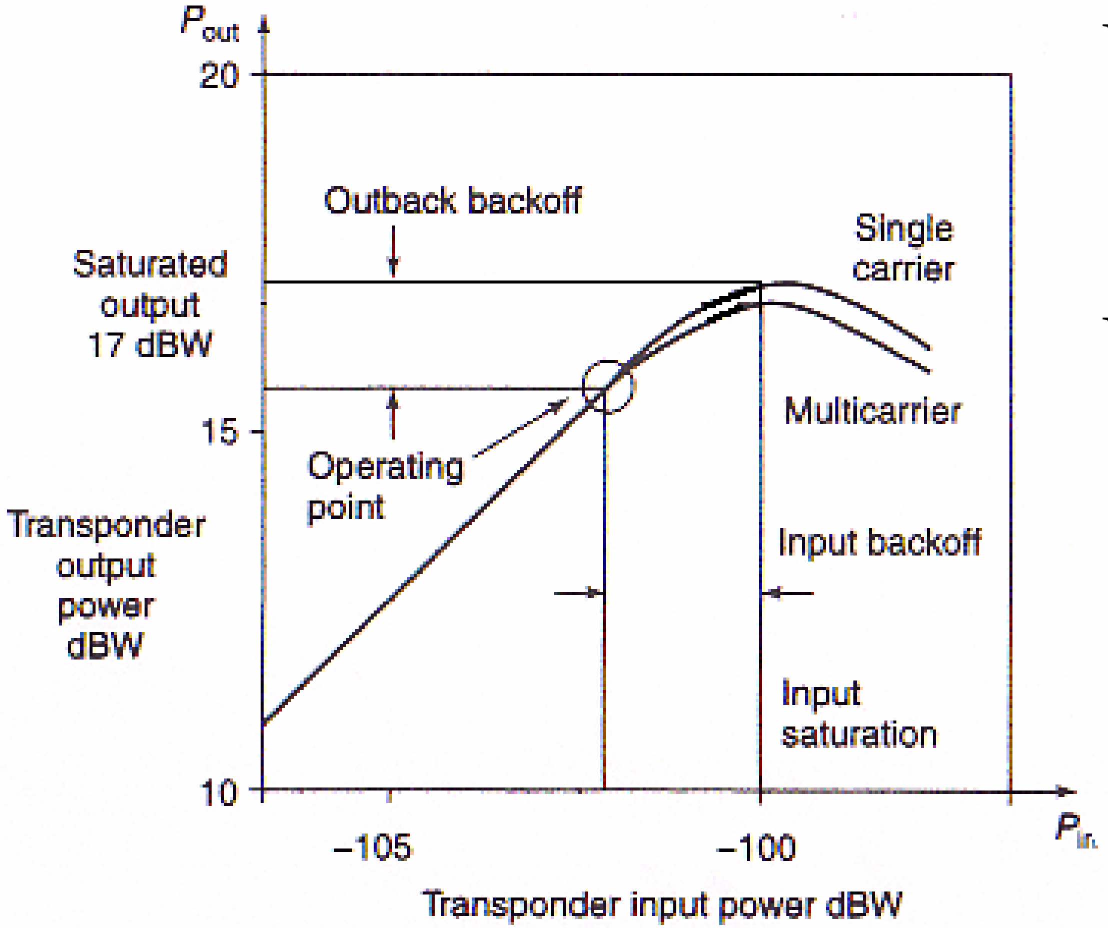
- continous full time
- fraction of the power
- full bandwidth

INTELSAT IV TRANSPONDERS



Flexible use of INTELSAT transponders
different carrier size and composition in each transponder

Typisk TWTA karakteristikk

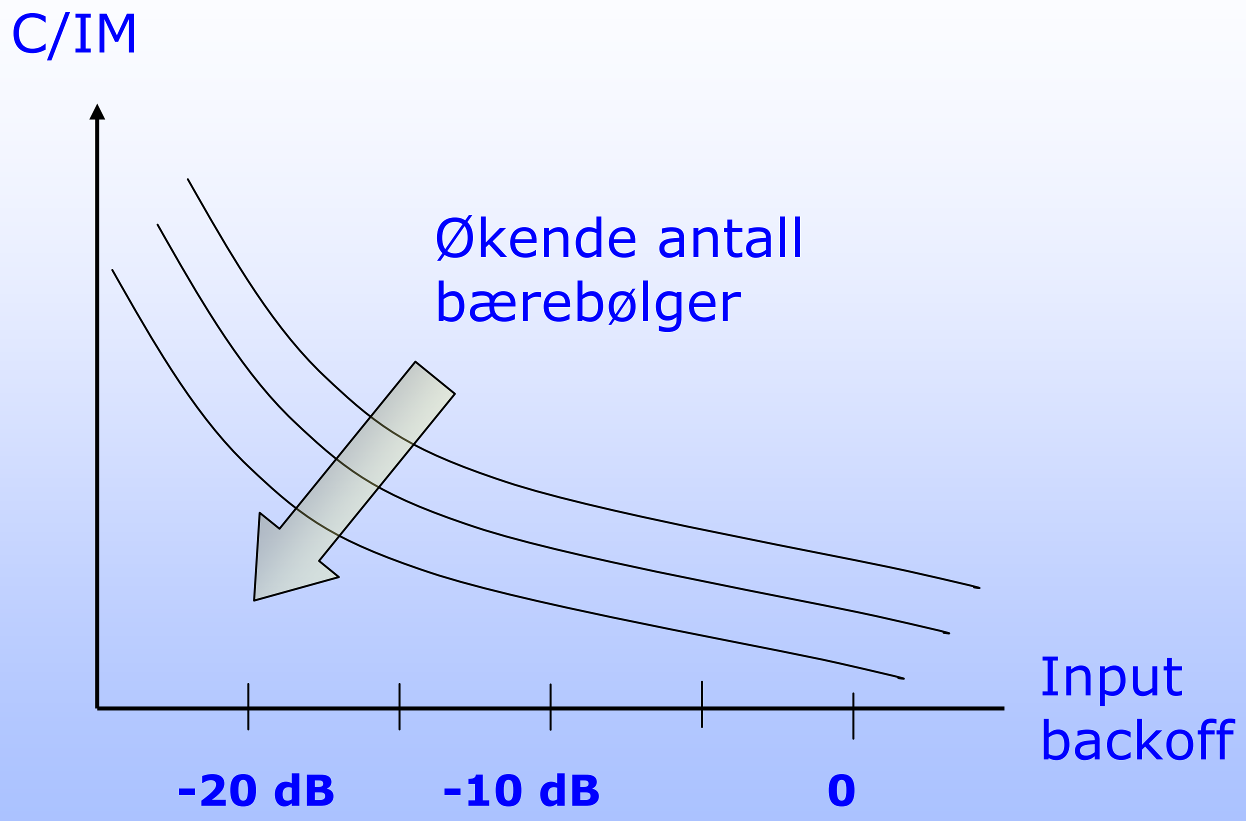


$$V_{out} = aV_{in} + bV_{in}^{3}$$

$$\text{hvor} \;\; a \gg b$$

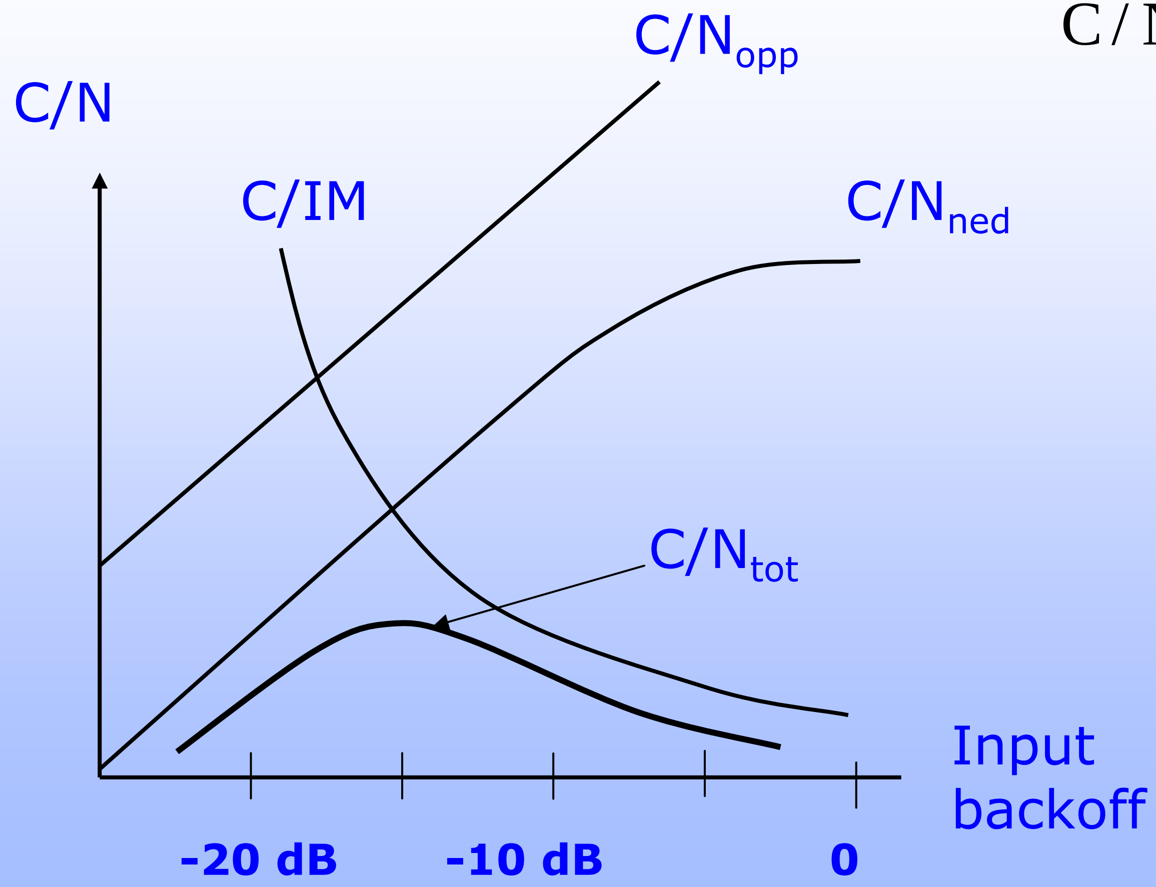
$$V_{in} = V_1 \cos \omega_1 t + V_2 \cos \omega_2 t$$

Intermodulasjon

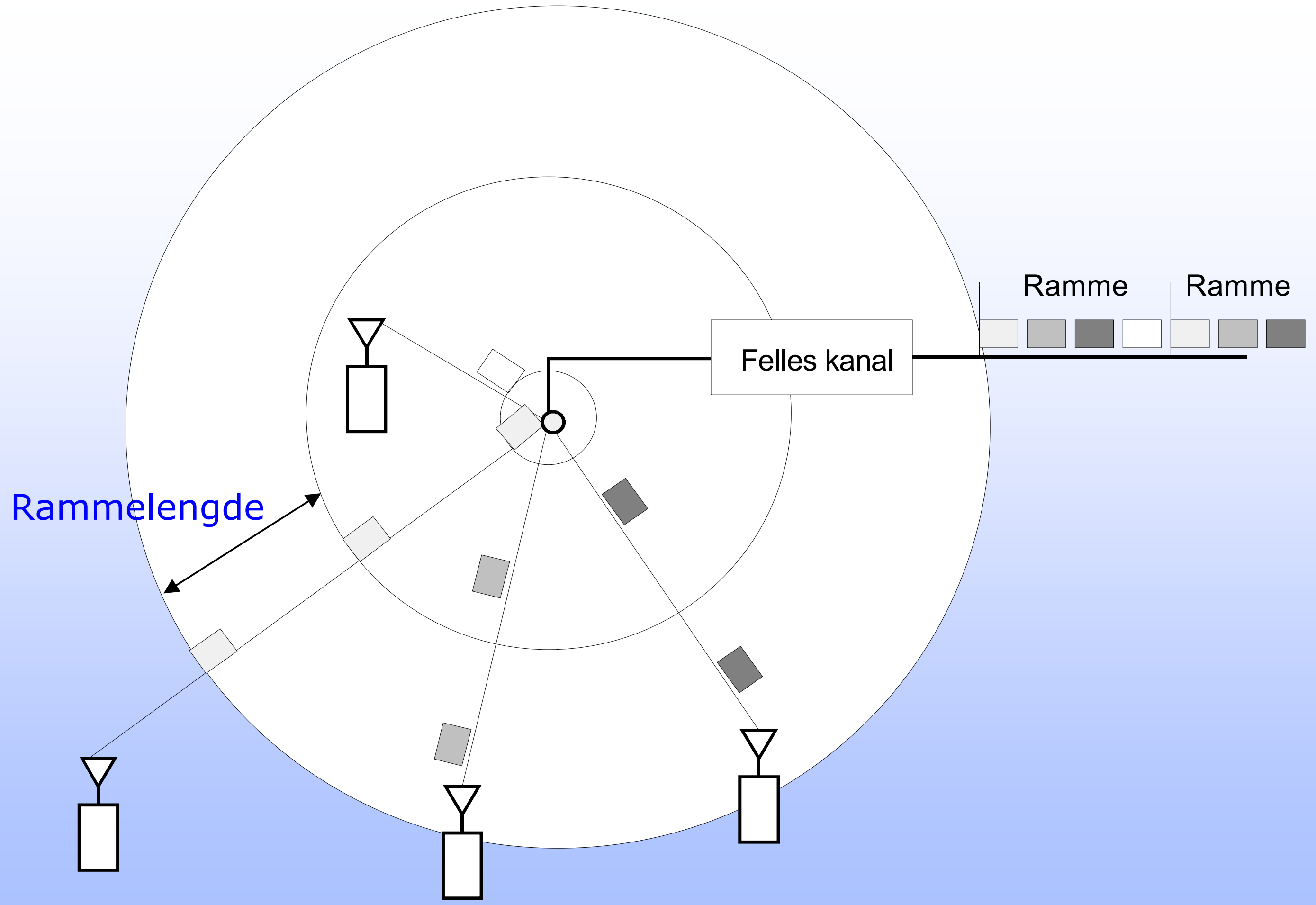


Intermodulasjon

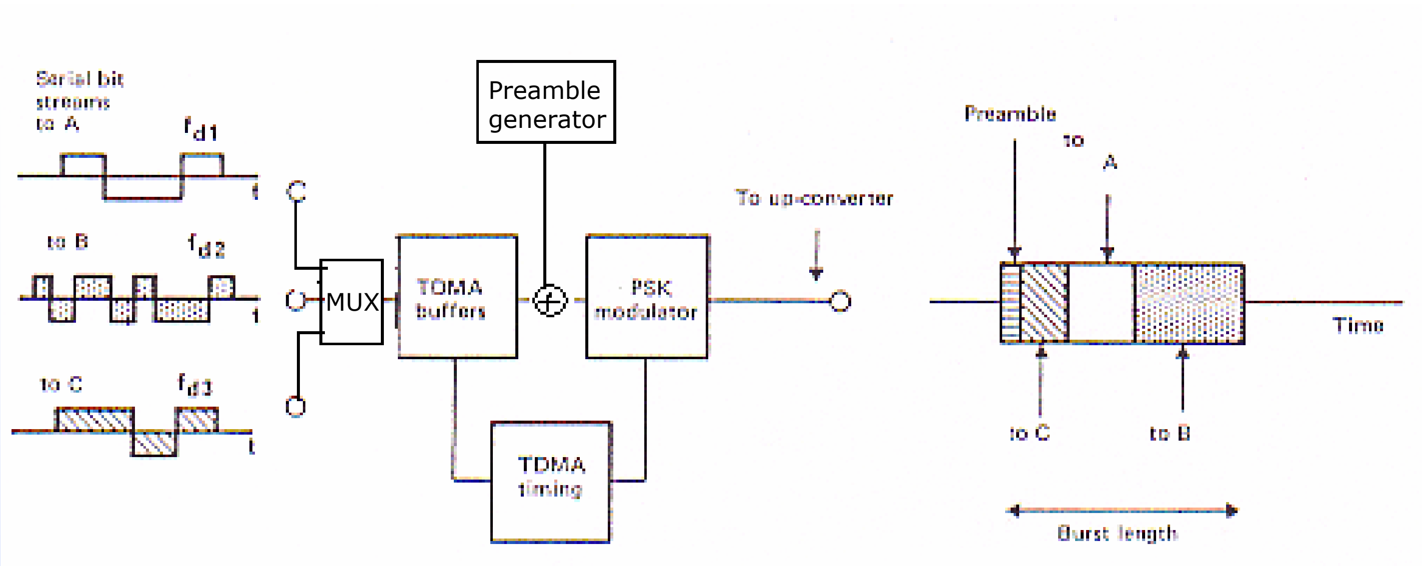
$$\frac{C}{N_{tot}} = \frac{1}{\frac{1}{C/N_{opp}} + \frac{1}{C/N_{ned}} + \frac{1}{C/IM}}$$

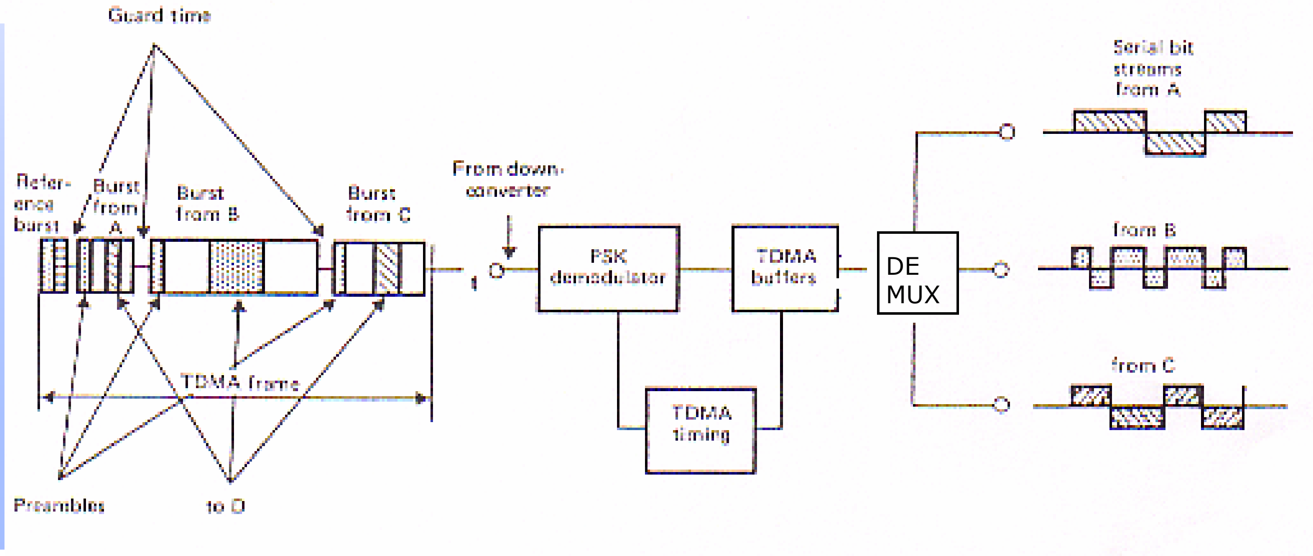


Prinsipp for TDMA



TDMA sender - mottaker

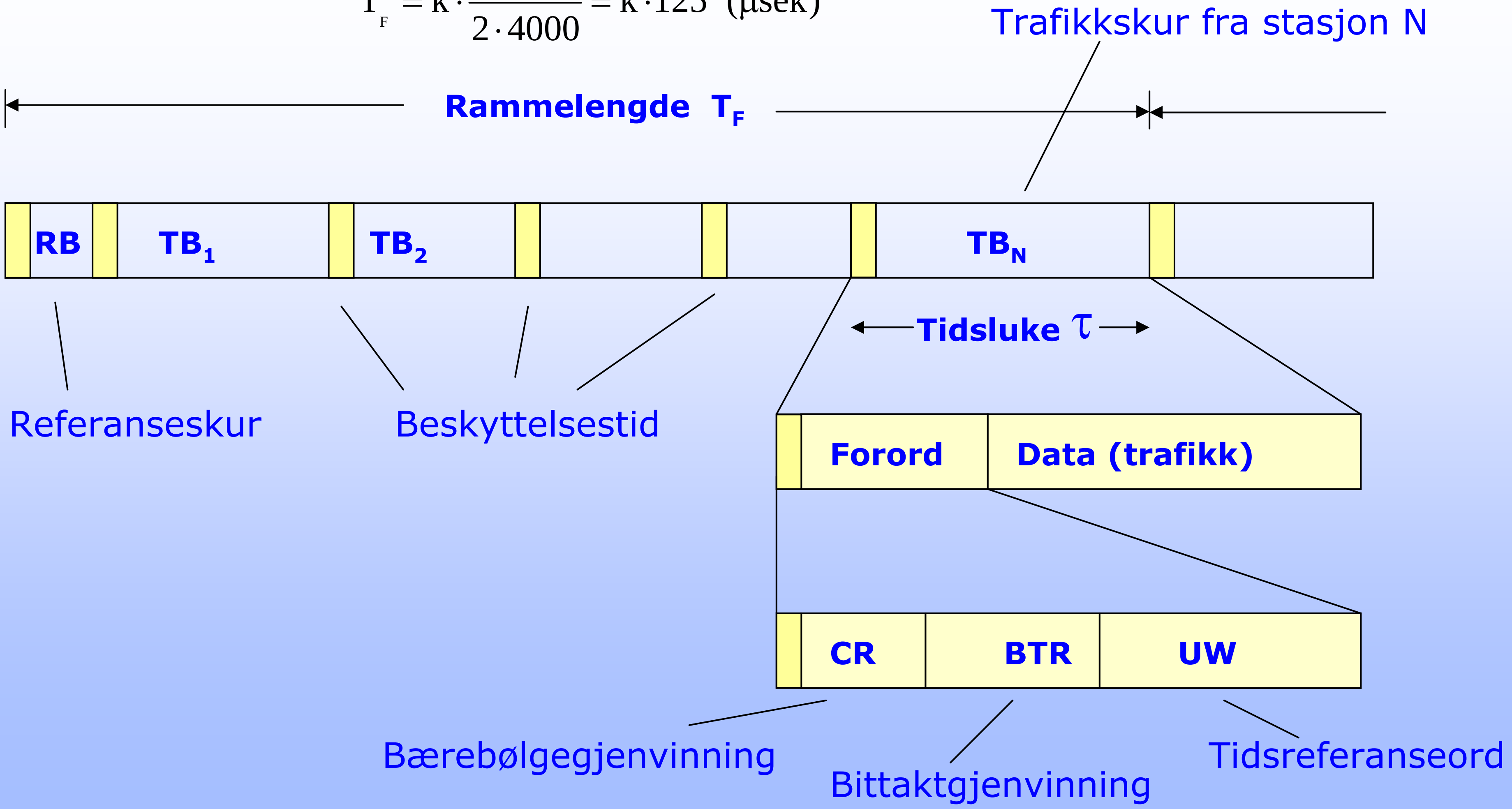




$$R_b = R_{in} \frac{T_{frame}}{T_{burst}}$$

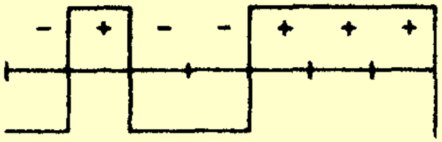
TDMA-rammestruktur

$$T_F = k \cdot \frac{1}{2 \cdot 4000} = k \cdot 125 \ \ (\mu\text{sek})$$



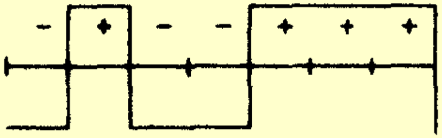
Code Division Multiple Access

Ønsket signalkode C_n

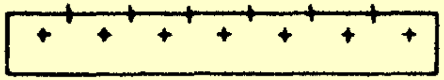


7 bit (chips) kode

Mottatt referansekode C_n

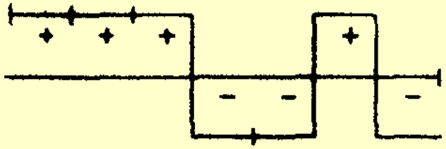


Produkt $C_n x C_n$

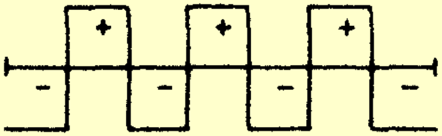


Integral = 7

Uønsket signalkode C_m



Produkt $C_m x C_n$

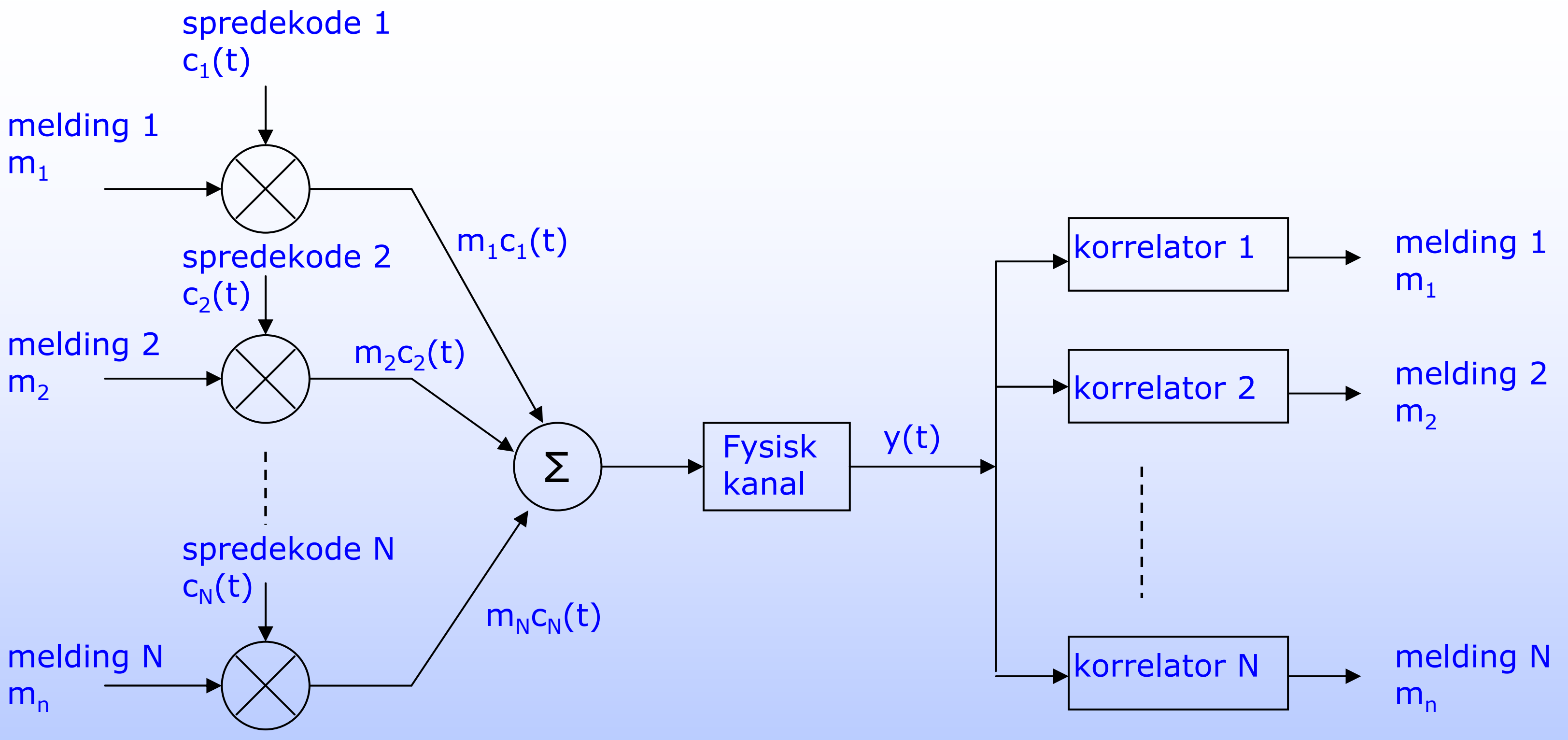


Integral = -1

$$\int_0^T c_n \cdot c_m \cdot dt = 0 \quad \text{for } n \neq m$$

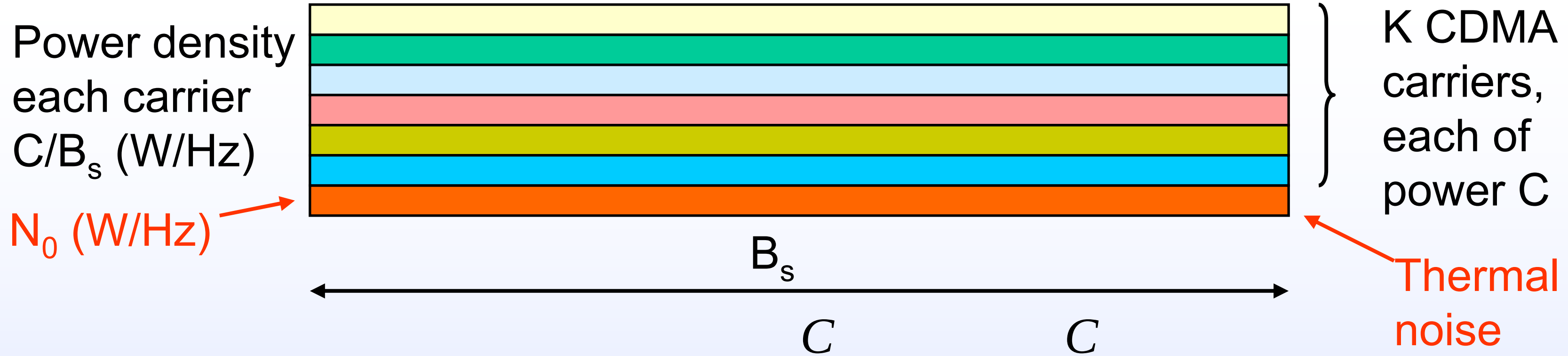
$$\int_0^T c_n \cdot c_m \cdot dt = 1 \quad \text{for } n = m$$

Modell for et CDMA-system



$$y_j = m_j \int_0^T c_j c_j \, dt + \sum_{i \neq j} m_i \int_0^T c_i c_j \, dt + \int_0^T n(t) c_j \, dt \quad = m_j + n_{CDMA} + n_{th}$$

CDMA performance analysis



Power density each carrier C/B_s (W/Hz)

N_0 (W/Hz)

K CDMA carriers, each of power C

B_s

Thermal noise

"Seen" by one particular carrier:

$$\frac{C}{N_0} = \frac{C}{(K-1)\cdot\frac{C}{B_s} + N_{th0}}$$

Case 1

$$(K-1)\cdot\frac{C}{B_s} << N_{th0}$$

Power limited, MAI negligible, increase of the carrier powers would improve the performance

Case 2 $(K-1)\cdot\frac{C}{B_s} >> N_{th0}$

Data rate per carrier: R (bit/s)

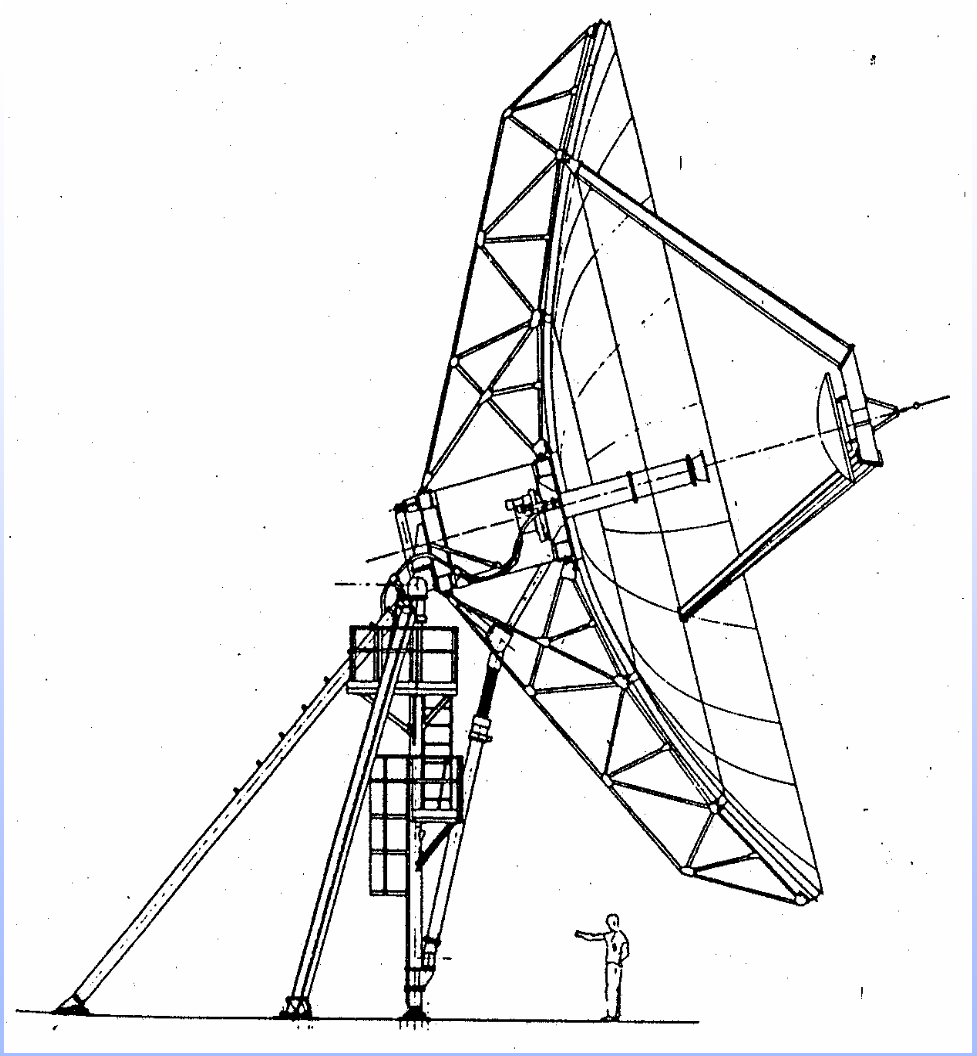
$$\frac{C}{N_0} = \frac{E_b \cdot R}{N_0} = \frac{C}{(K-1)\cdot\frac{C}{B_s}} = \frac{B_s}{(K-1)}$$

$$(K-1) = \left(\frac{B_s}{R}\right)\cdot\frac{1}{\left(\frac{E_b}{N_0}\right)_{required}}$$

The number of users

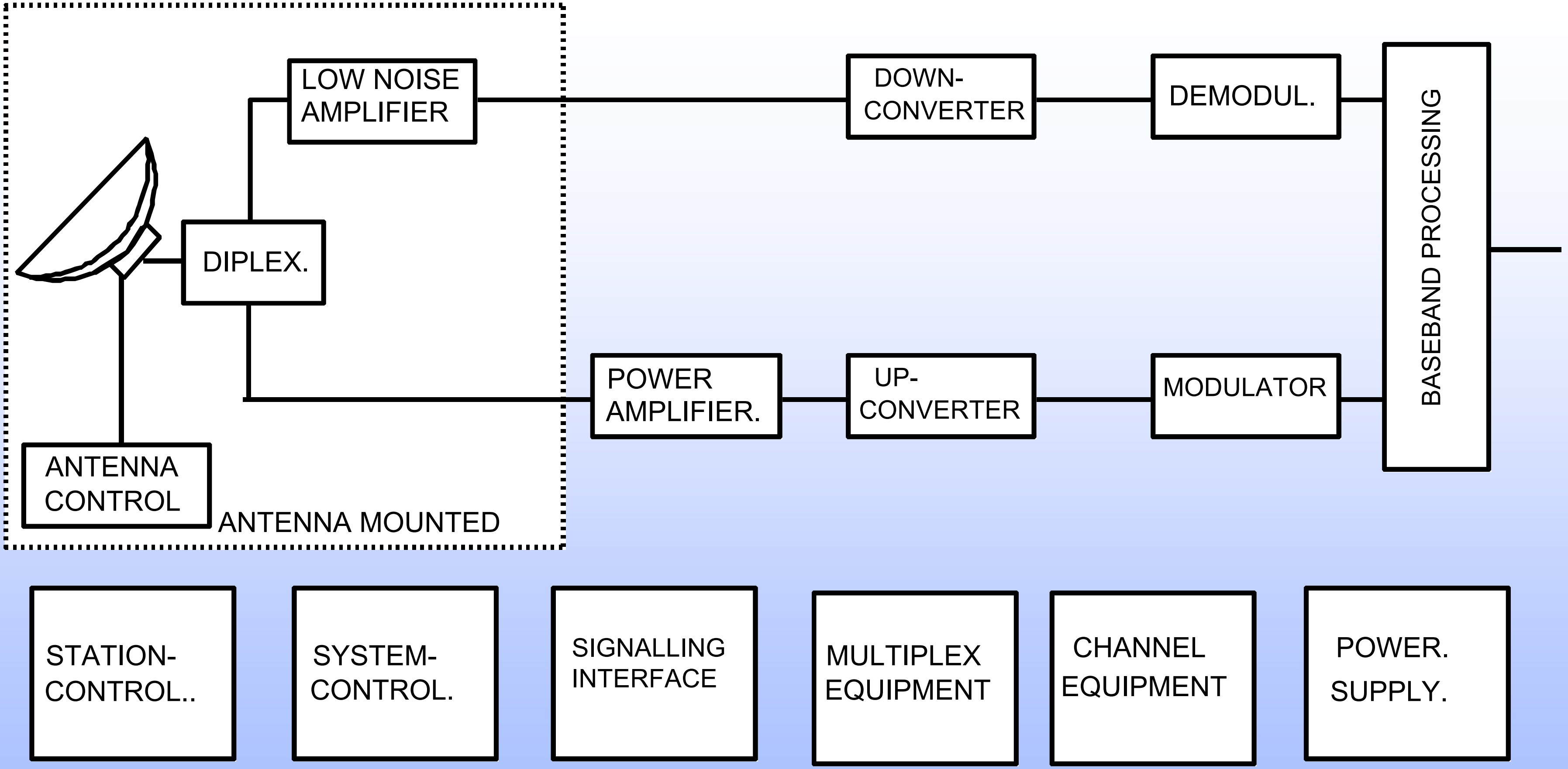
- increases with B_s
- decreases with R
- increases with reduction in E_b/N_o (coding).

INTELSAT Standard B antenna



Cassegrain feed
Typical diameter
 11 meter

Earth Station Block Diagram



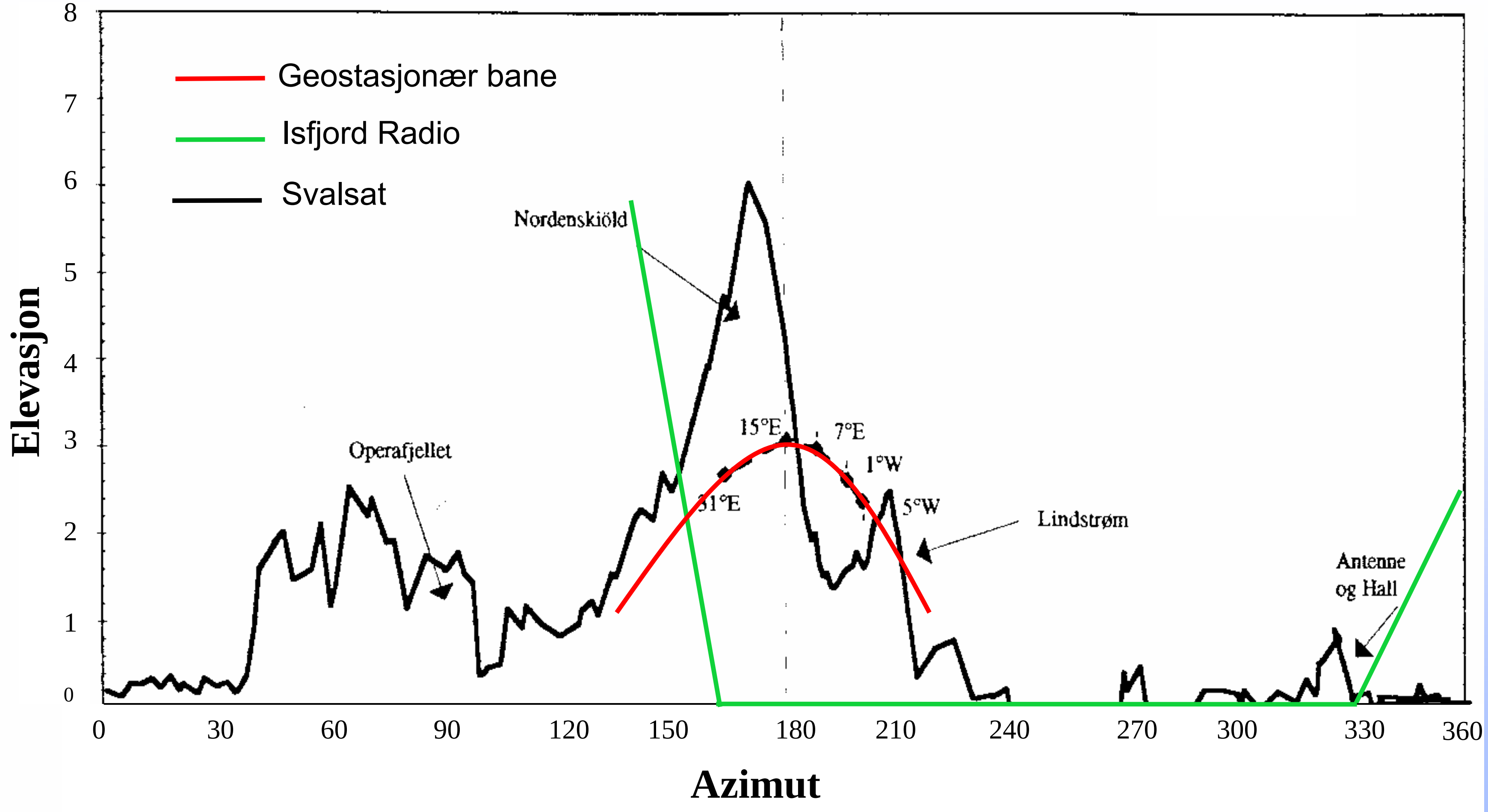
950109h.wpg

Important parameters: G/T-value → Antenna dia.,
EIRP values noise temp. etc.

Ulike reflektorantenner

Studenter i arbeid

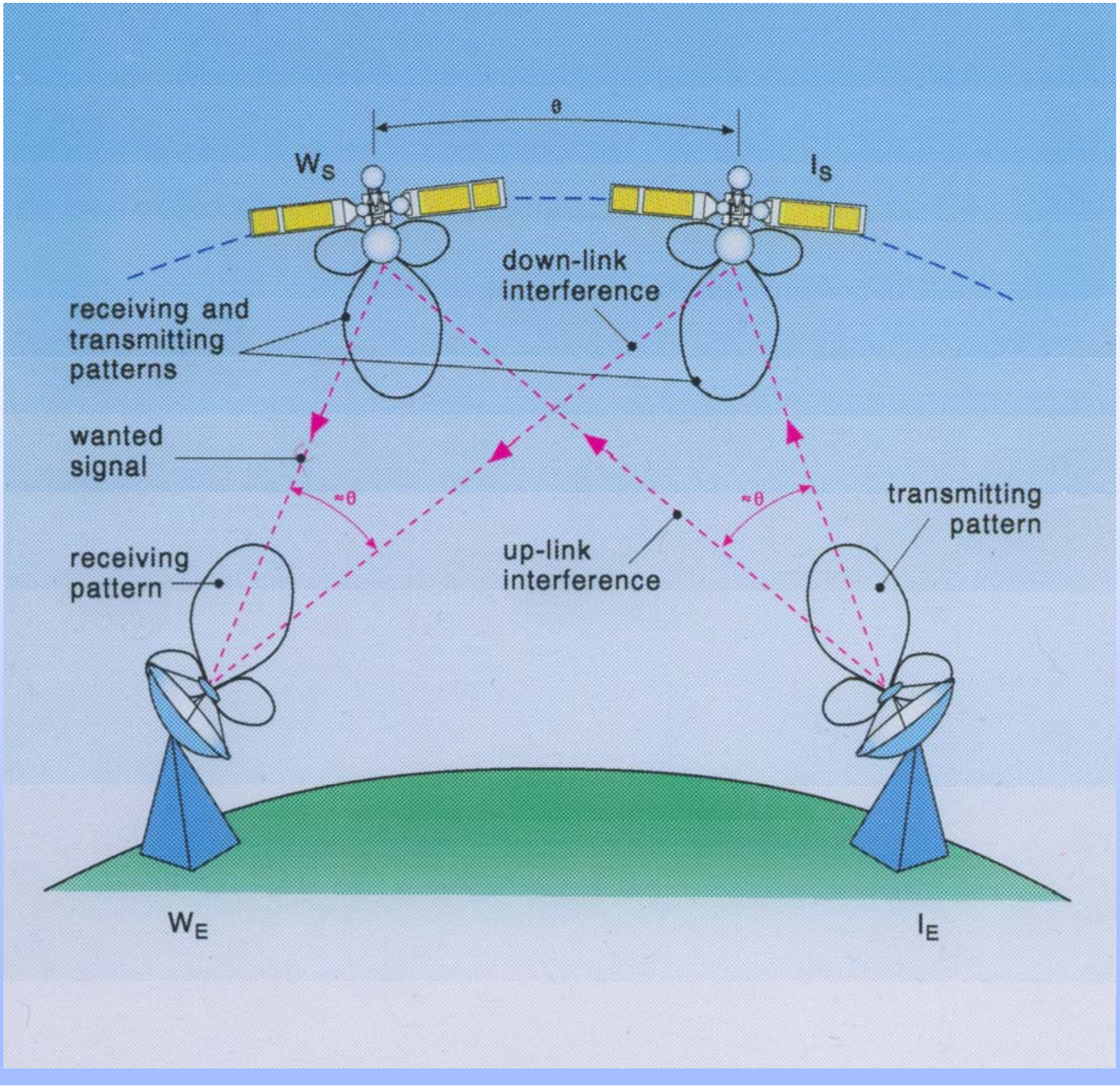
Eksempel på horisontdiagram - Svalbard



Eik jordstasjon

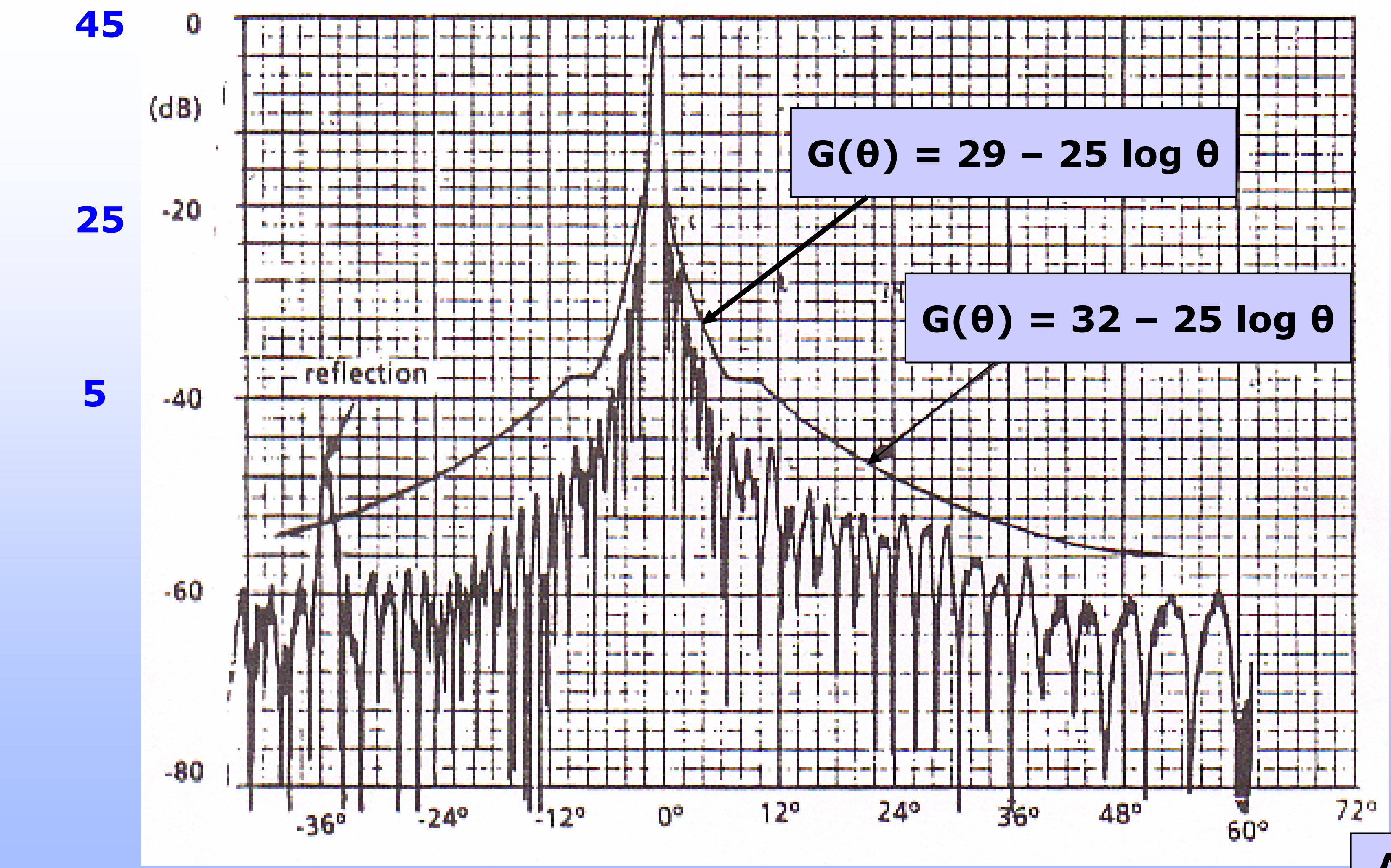
Nittedal jordstasjon

Interferens



Strålingsdiagram for jordstasjonsantenne 1.8 m, 11.7 GHz

Gain (dB)

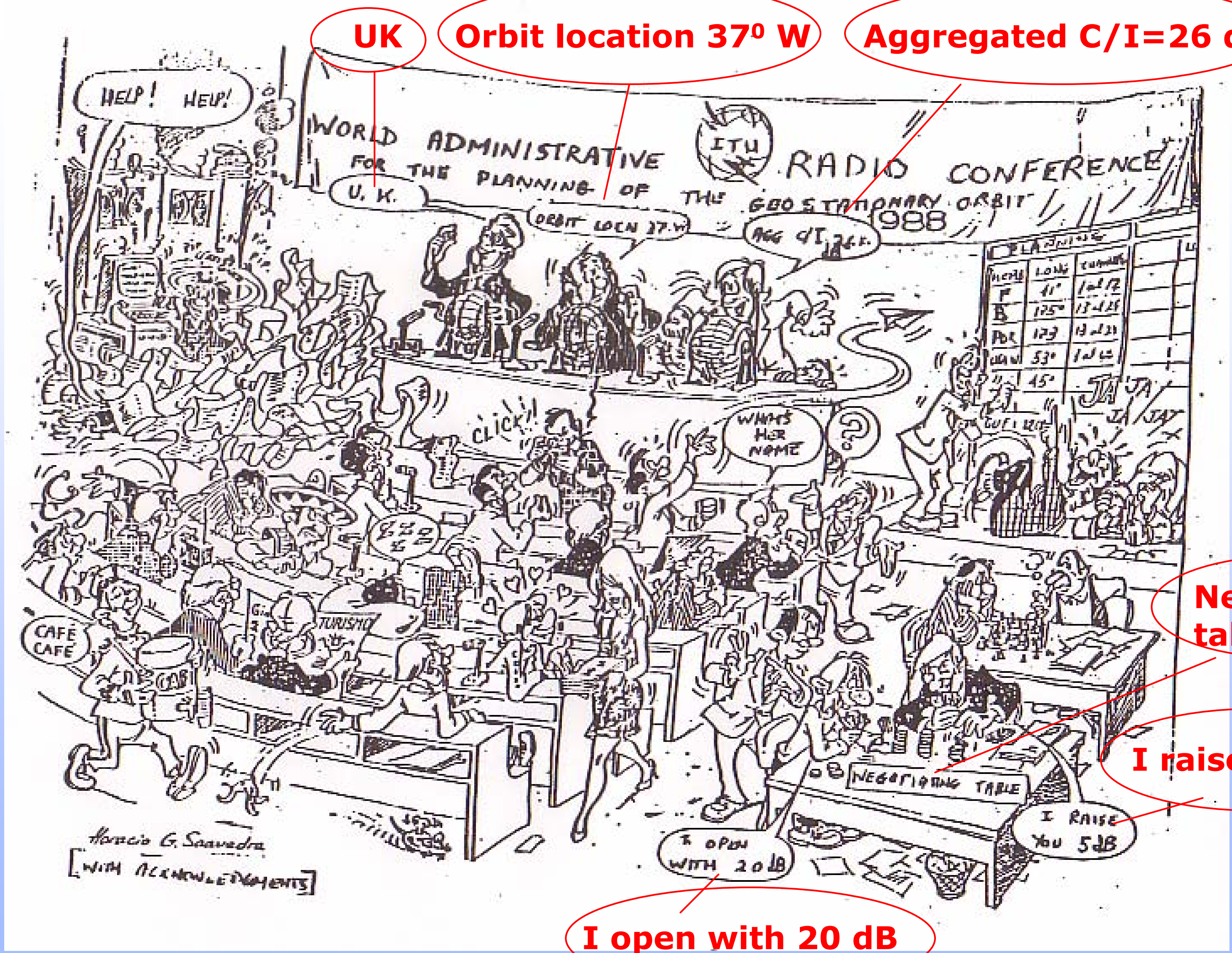


G(θ) = 29 – 25 log θ

G(θ) = 32 – 25 log θ

Asimut

World Administrative Radio Conference for the planning of the geostationary orbit - 1988



UK

Orbit location 37^0 W

Aggregated C/I=26 dB

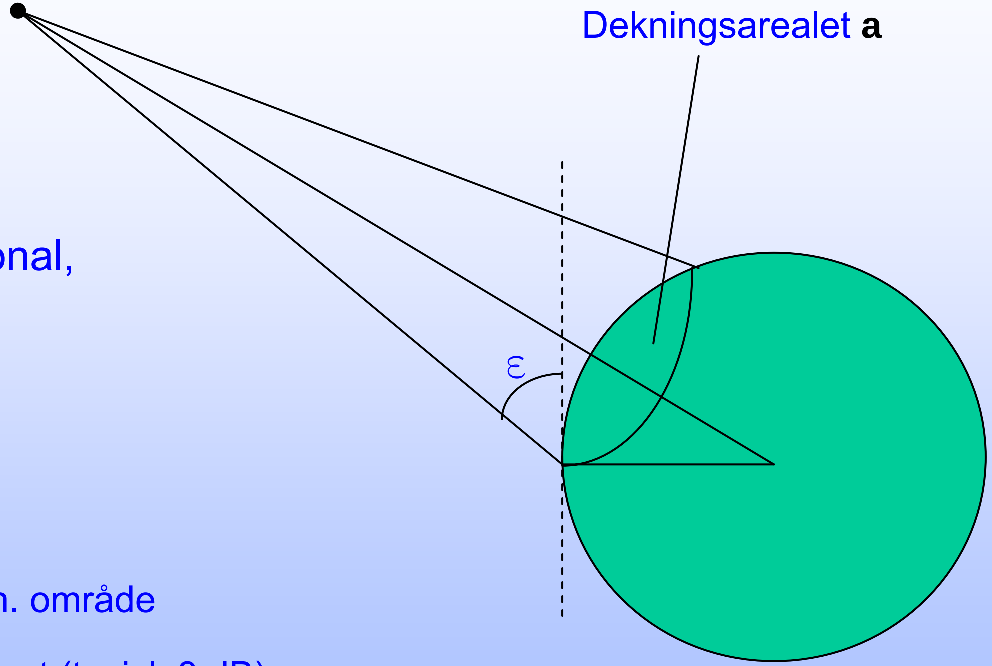
Negotiating table

I raise you 5 dB

I open with 20 dB

Mobil satellittkommunikasjon

Gjennomsnittelig flukstetthet I dekningsområdet: $$\Phi = \frac{P_t G_t}{a}$$



Mottakerens antenne nær omnidireksjonal,
typisk G_r = 3 dB

$$A_{eff} = \frac{G_r}{4\pi / \lambda^2}$$

Mottatt effekt blir da:

Definerer dekn. område

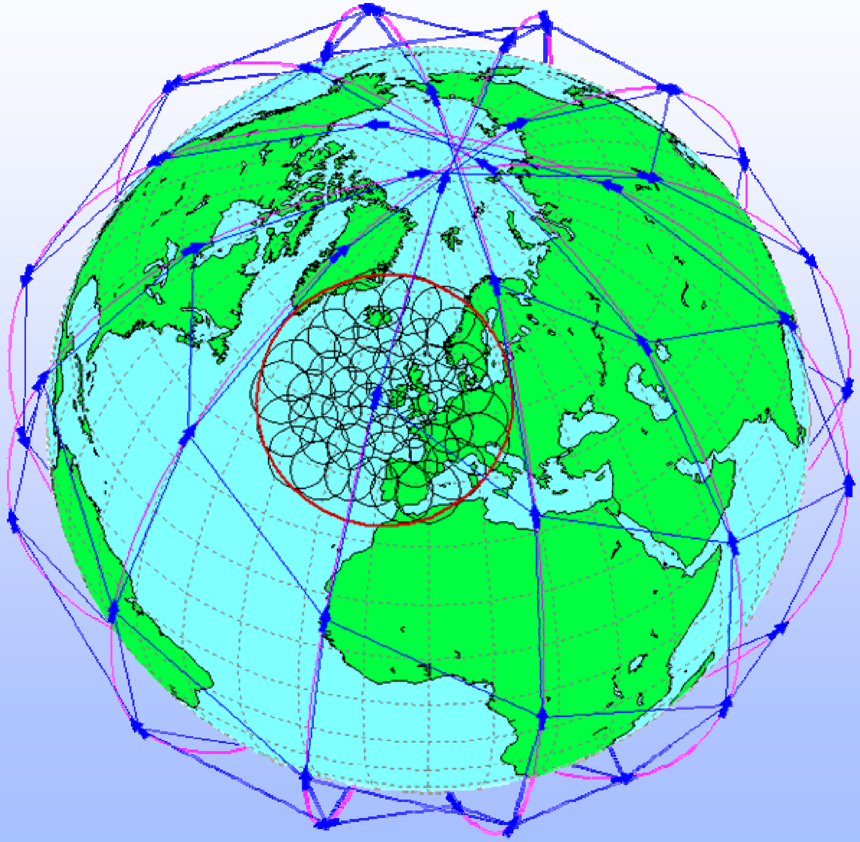
Fast (typisk 3 dB)

$$P_r = \Phi \cdot A_{eff} = \frac{(P_t G_t)}{a} \cdot G_r \cdot \frac{\lambda^2}{4\pi} \propto \frac{1}{f^2}$$

for et gitt dekningsområde

Iridium World Satellite Coverage

- Satellites in a Near Polar Low Earth (880 km) Orbit (LEO)
- Each satellite footprint is approximately 5200 km in diameter
- All satellite footprints overlap
- Each satellite has 48 spot beams
- Size of each spot beam is approximately 460 km in diameter
- All spot beams overlap



TRANSPONDER TYPES

SINGLE CONVERSION TRANSPONDER ("bent pipe")

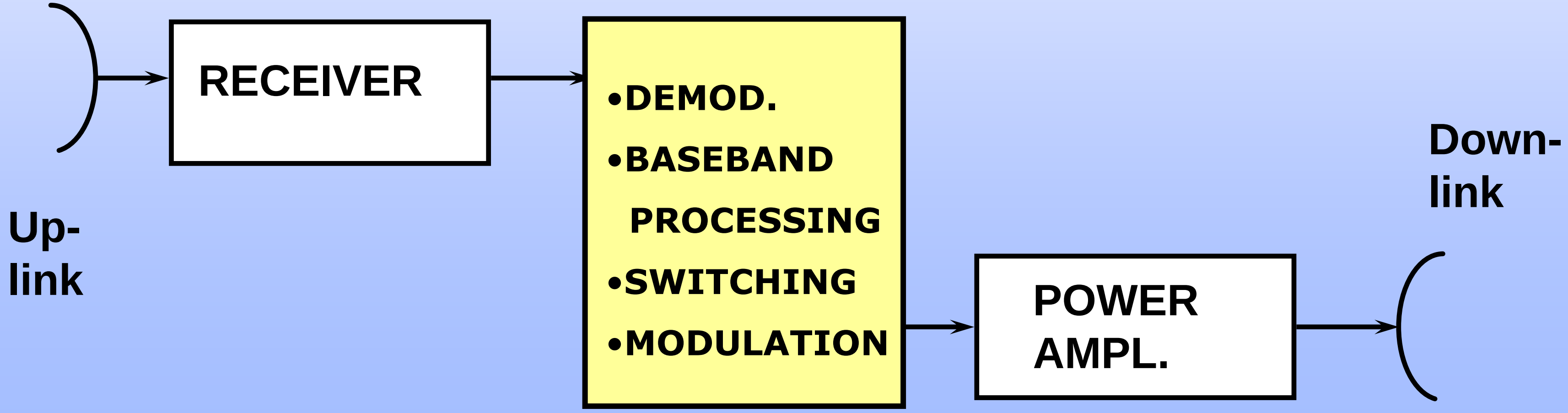
Up-
link

INPUT
AMPL.

POWER
AMPL.

Down-
link

PROCESSING TRANSPONDER



Up-
link

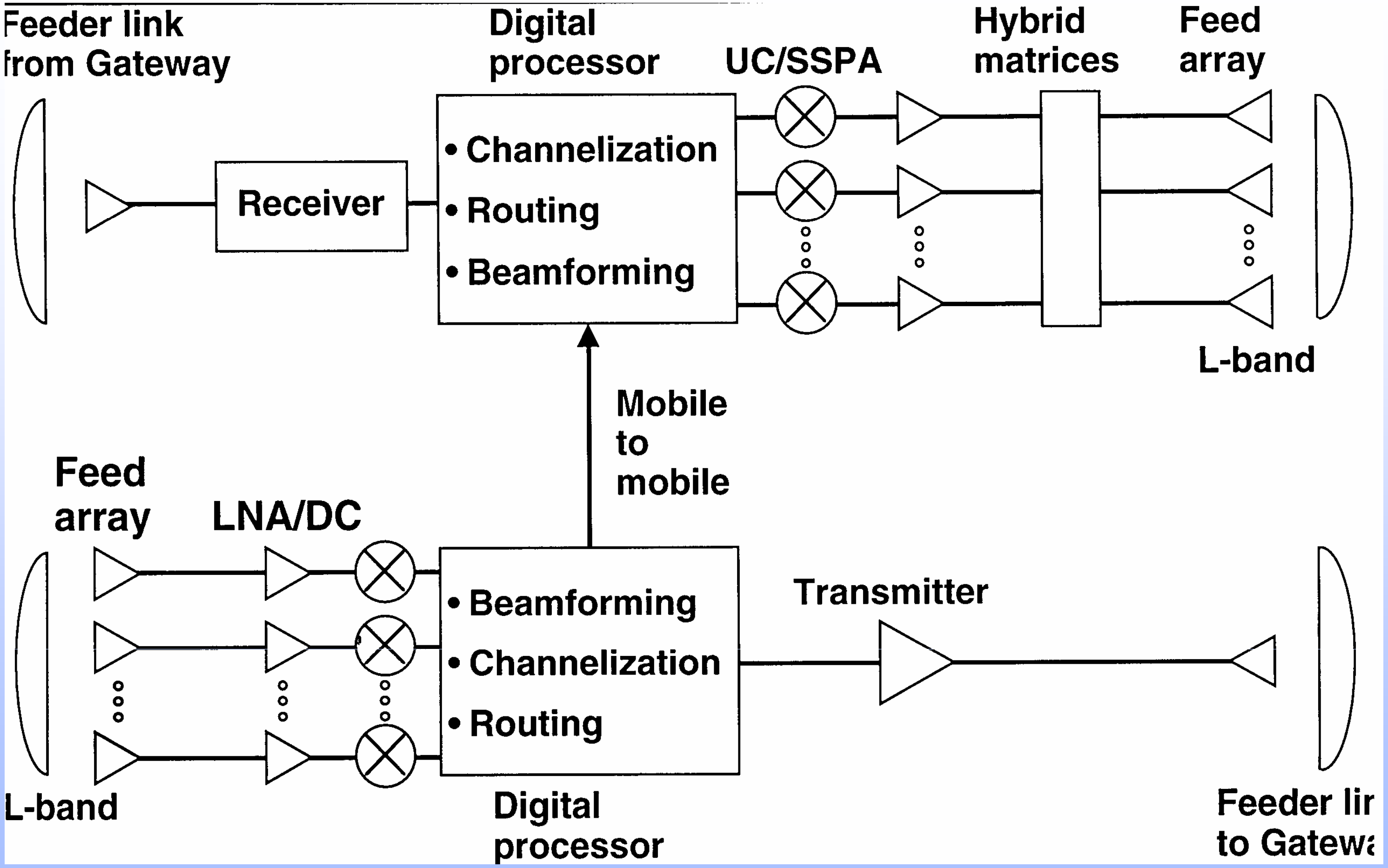
RECEIVER

- DEMOD.
- BASEBAND PROCESSING
- SWITCHING
- MODULATION

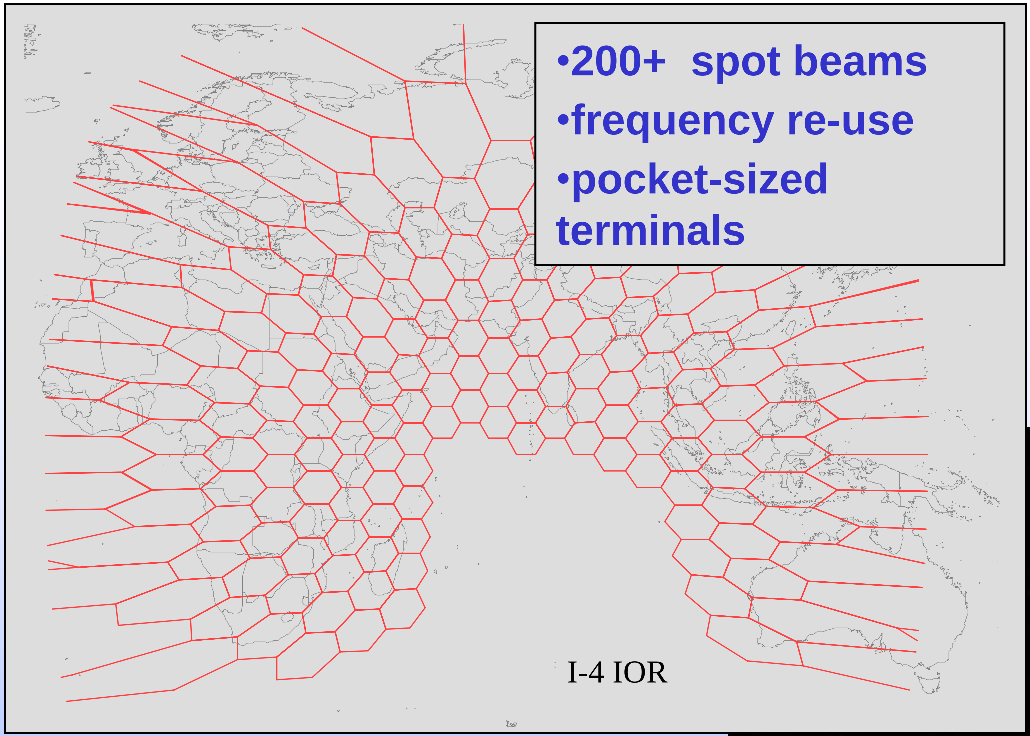
POWER
AMPL.

Down-
link

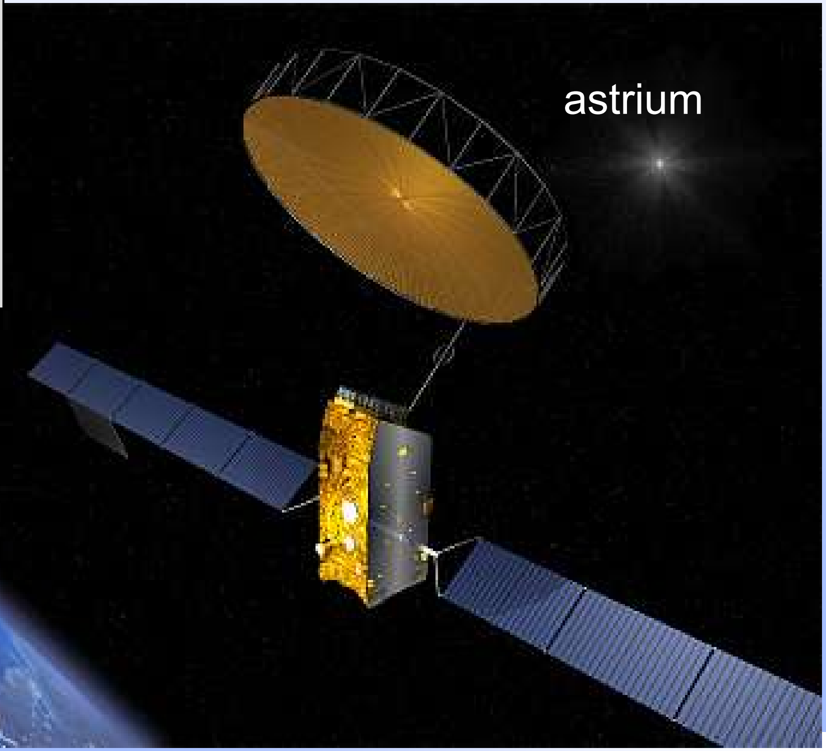
Nyttelasten i Boeing GEM (Thuraya)



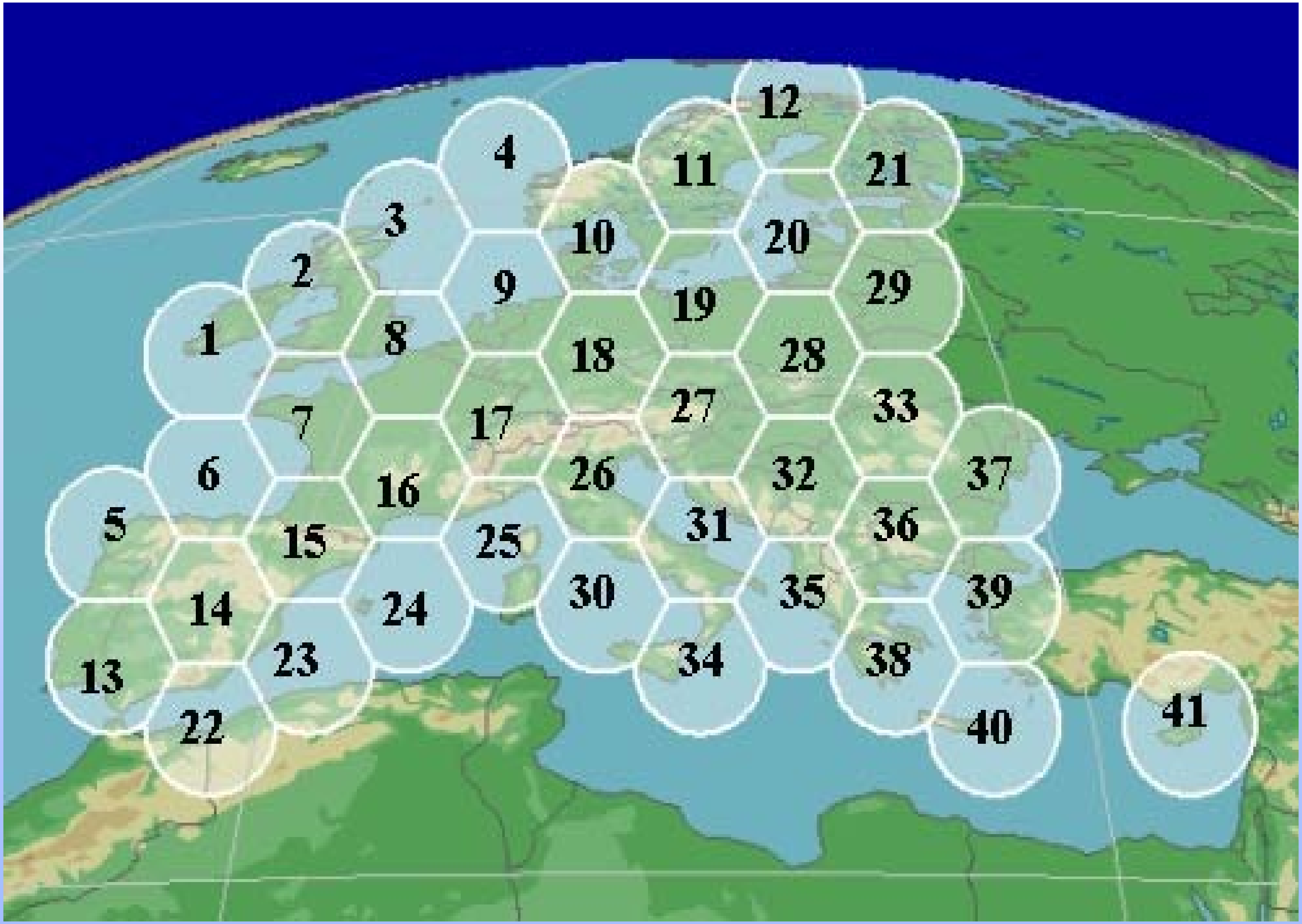
A new generation of satellites: INMARSAT-IV



- **200+ spot beams**
- **frequency re-use**
- **pocket-sized terminals**



System assumptions – Service areas (@sat)



Spot-Beam Coverages from Two Positions with Inter-Satellite Linking (ISL)