Broadband from the Sky-
welche Satelliten brauchen wir dafür?

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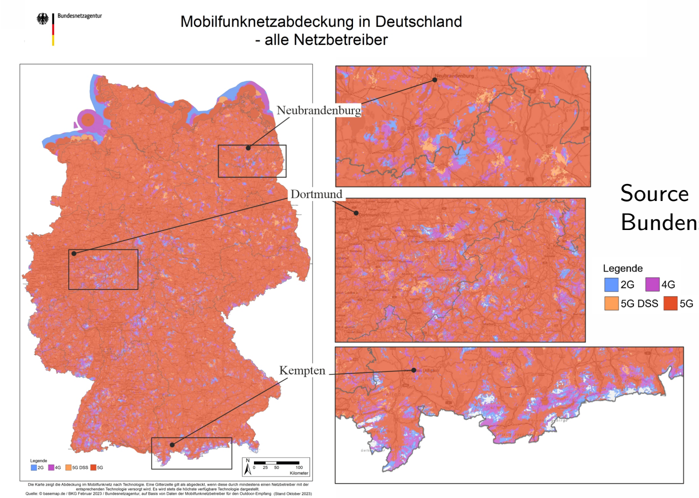
Übersicht

Übersicht

Status Coverage Januar 2024

Bundesnetzagentur



Source
Bundensnetzagentur [4]

VITES Ku-Band

Example of a High End Terrestrial SatCom Antenne

- 1024 active elements
- steering angle up to 60°
- full programmable arbitrary polarization

RX Performance

$$G/T > 10\,\mathrm{dB}(\mathrm{K}^{-1})$$

How to Close the Gaps

Use an unmodified Cell Phone!

Target is to close gaps using unmodified cell phones
As example see T-Mobile US and SpaceX, Satellite System MARS-ULS
or Vodafone and AST Space Exploration, Satellite System Blue Walker 3

2. Liste deutscher Satellitennetzanmeldungen (Umlaufende Systeme) bei der ITU (Stand 03/2023)
List of German Satellite filings (non-geo systems) at the ITU (dated 03/2023)

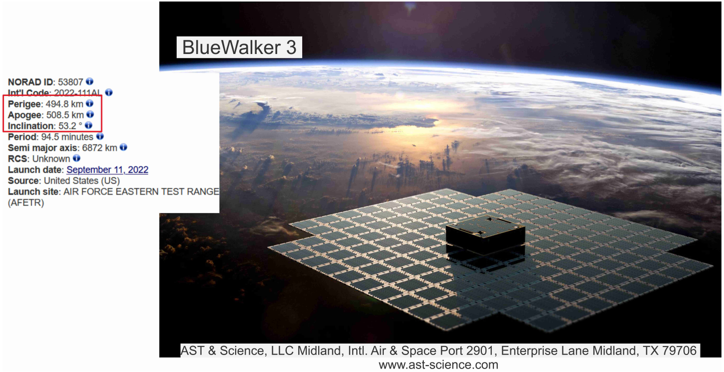
Satellitensysteme Satellite Network	Orbitdaten Orbital Plane	Uplink (R) (Erde-Weltraum) (Earth-to-Space)	Downlink (E) (Weltraum-Erde) (Space-to-Earth)	Week.-Circ./ Spec.-Sect	Datum Date
MARS-ULS	288 Orbitebenen Polar- und Inclined Orbit 340-614 km 29988 Satelliten	614-960 MHz 1427-1518 MHz 1675-1980 MHz 2010-2025 MHz 2110-2170 MHz 2300-2483.5 MHz 2500-2690 MHz	614-960 MHz 1427-1518 MHz 1610-1610.6 MHz 1626.5-1645.5 MHz 1656.5-1660.5 MHz 1670-2025 MHz 2110-2170 MHz 2300-2483.5 MHz 2500-2690 MHz	2984/API/A/13167	23.08.2022
		2049 – 2060 MHz			

Extract from [3]

Übersicht

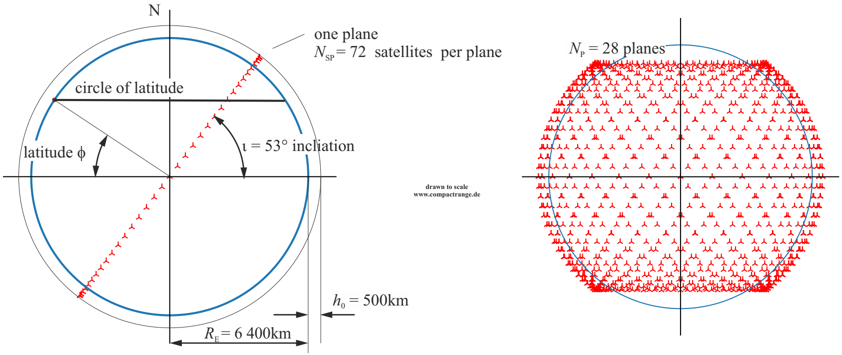
Bluewalker 3

Prototype in Space



Extract from [2]. Some Technical for MARS-ULS you find in *Attachment A, SpaceX's German-licensed direct to cellular System, December 2022*, [6] and more actual in *Request for Special Authority to Conduct Experimental operations, December 2023* [5].

Assumptions: Constellation Configuration
Example SapceX Gen2, Equatorial View

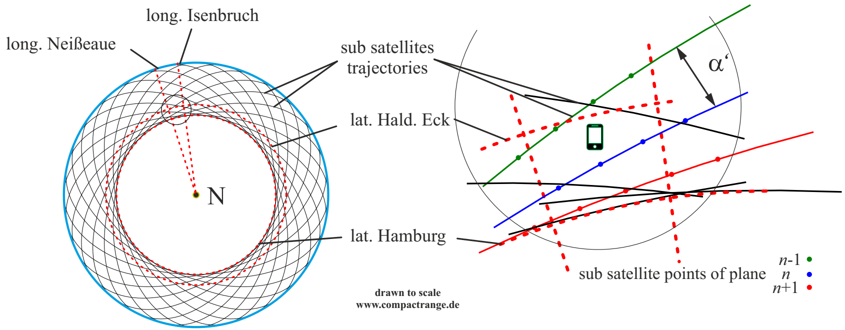


$$N = N_P \cdot N_{SP} = 2016 \text{ satellites}$$

Data from [6]

Assumptions: Constellation Configuration

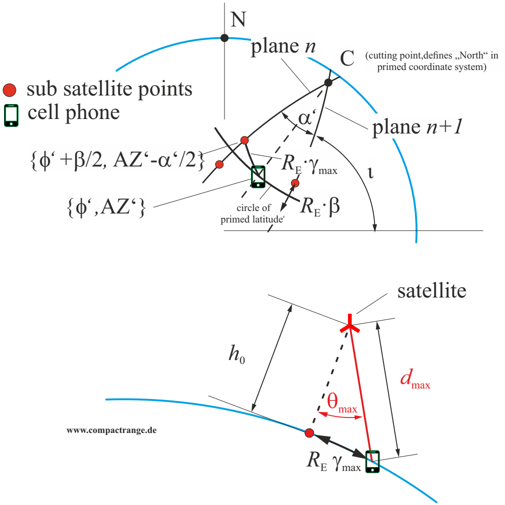
Example SpaceX Gen2, Polar View



Cite (1) Status See space Exploration

Free Space distance and Satellite's Scan Angle

Some spherical geometry ...

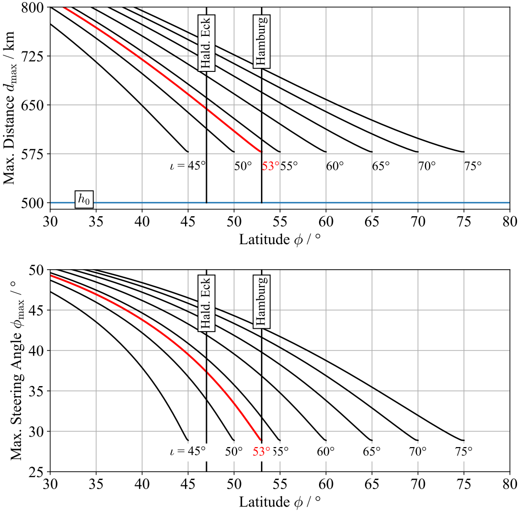


$d_{\max}$ and $\theta_{\max}$

- ϕ: latitude of cell phone, somewhere in Germany between Haldenwanger Eck, lat. 47° and Hamburg, lat. 53°
- ι: 53∠, inclination of each plane
- α': $\approx 10.3° < N_{\text{sat. per plane}}/360°$
- β: $360°/N_{\text{sat. per plane}} = 360°/72 = 5°$
- h_0: 500 km, satellite flight height

Free Space distance and Satellite's Scan Angle

Results



Somewhere in Germany between Haldenwanger Eck / Hamburg and Neißenaue / Isenbruch

Result d_{max} and θ_{max}

$500\,\text{km} \leq d \leq 648\,\text{km}$

$0 \leq \theta \leq 37.5°$

Übersicht

Unmodified Cell Phone for UP- and Down-Link

SNR per Bit

Target Performance Sat2Cell and Cell2Sat

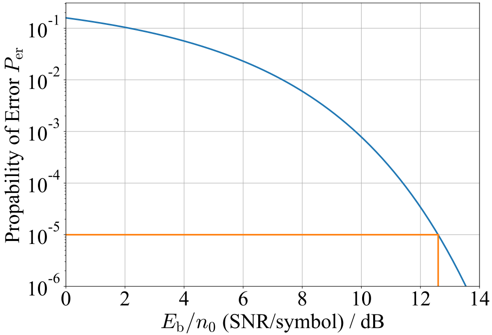
Bit Rate	R_b	$10\,\mathrm{Mbit\,s^{-1}}$
Bit Error Probab.	P_er	1×10^{-5}

Modulation and Noise Type

Coherent Frequency Shift Key Modulation (FSK)
Orthogonal Signals
Additive White Gaussian Noise

$$\Downarrow$$

$$\frac{E_\mathrm{b}}{n_0} = 12.6\,\mathrm{dB}$$



Übersicht

Unmodified Cell Phone, UP-Link: Cell Phone to Satellite
Assumptions for PCS / LTE Band

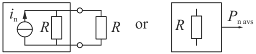
Parameter	Symbol	Value
Frequency Range		1850 MHz to 1910 MHz
Mid. Frequency	f_{up}	1880 MHz
Mid. Wavelength	λ_{up}	0.16 m
Bandwidth	Δf	10 MHz
Modulation		FSK, coherent
Bandwidth Efficiency	$R_{\text{b}}/\Delta f$	1
Ouput Power Level	L_{TXup}	0 dB(W)
Part. real. antenna Gain (lin.)	G_{TXup}	−1 dB

TX for UP

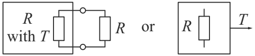
Free Space Loss	$\text{FSL}_{\text{up}} =$	154.2 dB	$= 20\lg\left(\frac{4\pi d_{\max}}{\lambda_{\text{up}}}\right)\,\text{dB}$
Equiv. Rad. Pow. Level	$\text{EIRP}_{\text{up}} =$	−1 dB(W)	$= L_{\text{TXup}} + G_{\text{TXup}}$

Active Receiving Antenna
School Book Part I

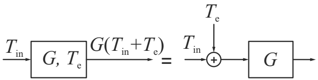
Available Noise Power $\quad P_{\text{n avs}} = \frac{1}{4} R \langle i_{\text{n}}^2 \rangle$



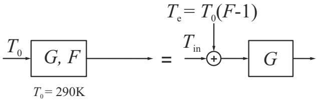
Noise Temperature $\quad T = P_{\text{n avs}}/(k_{\text{B}} \Delta f)$



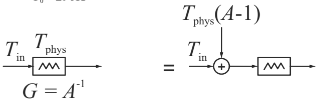
2-Port:
Equivalent Noise Temperature $\quad T_{\text{out}} = (T_{\text{in}} + T_{\text{e}})\, G$



Noise Figure $\quad T_{\text{e}} = T_0(F - 1)$



Passive 2-Port with physical Temperature $\quad T_{\text{e}} = T_{\text{phys}}(A - 1)$



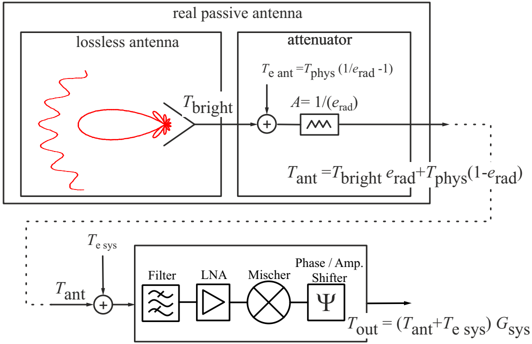
Active Receiving Antenna
School Book Part II

Brightness T_{bright} of receiving antenna results from its directivity D and background radiation T_{back} seen by the antenna.

$$T_{\text{bright}} = \frac{\int_{4\pi} T_{\text{back}}(\Omega)D(\Omega)\mathrm{d}\Omega}{\int_{4\pi} D(\Omega)\mathrm{d}\Omega}$$

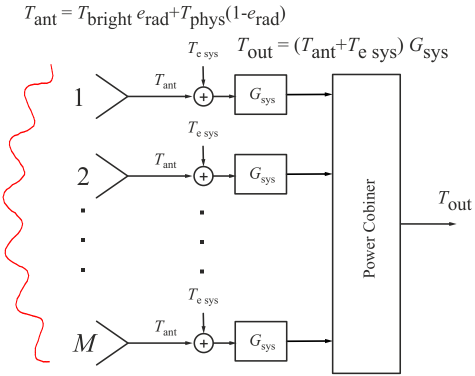
Worst case: Sat. antenna sees only “hot“ earth with surface temperature $T_{\text{earth}} < 300\,\text{K} = 27\,°\text{C}$

$$T_{\text{bright}} \approx 300\,\text{K}$$



Active Receiving Antenna

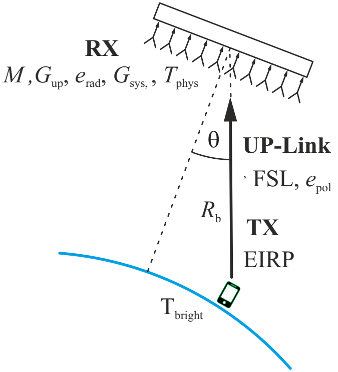
School Book Part III



Phased Array Antenna, M similar active antenna blocks:
Combiner adds only coherent signals!

$$\frac{T_{out}}{G_{sys}} = M\, T_{bright}\, e_{rad} + M\, T_{phys}\,(1 - e_{rad}) + M\, T_{e\,sys}$$

UP Link
Results as Equations



Received Signal Power:

$$\frac{P_{s\ RXup}}{G_{sys\ up}} = \frac{EIRP_{up}\, e_{pol\ up}}{FSL_{up}} \underbrace{M\, G_{element}}_{G_{RXup},\text{estimated}} \cos(\theta)$$

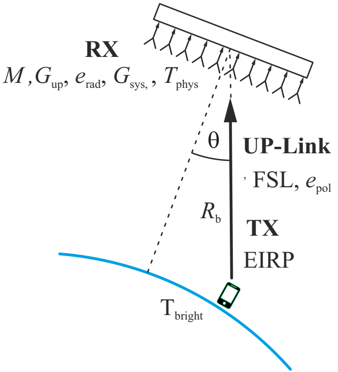
Received Noise Power:

$$\frac{P_{n\ RXup}}{G_{sys\ up}} = k_B R_b \underbrace{\left(T_{bright}\, e_{rad} + T_{phys}\,(1 - e_{rad}) + T_{e\ sys}\right)\Big|_{RX}}_{T_{up}}$$

$$\Rightarrow \frac{E_B}{N_0} = \frac{1}{k_B R_b} \frac{G_{RXup}}{T_{up}} \frac{EIRP_{up}\, e_{pol\ up}}{FSL_{up}} \cos(\theta)$$

UP Link

Results as G/T



$$\frac{G_{\text{RXup}}}{T_{\text{up}}} = \frac{E_B}{N_0}\, k_B\, R_b\, \frac{\text{FSL}_{\text{up}}}{\text{EIRP}_{\text{up}}}\, \frac{1}{e_{\text{pol up}}}\, \frac{1}{\cos(\theta_{\max})}$$

or with numbers in Dezibel

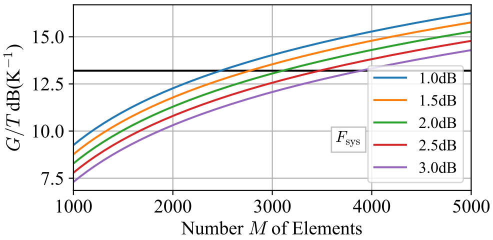
$$\frac{G_{\text{RXup}}}{T_{\text{up}}} = 12.6\,\text{dB} + (-228.6\,\text{dB}(\text{W}\,\text{Hz}^{-1}\text{K}^{-1})) + 70\,\text{dB}(\text{Hz})$$

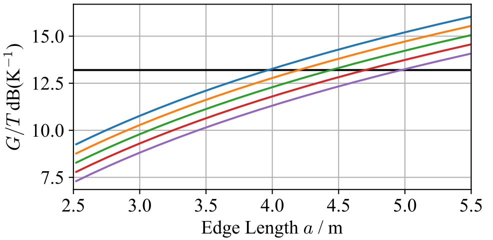
$$+ 154.2\,\text{dB} - (-1\,\text{dB}(\text{W})) + 3\,\text{dB} + 1.0\,\text{dB}$$

$$= 13.2\,\text{dB}(\text{K}^{-1})$$

UP Link
Result in Numbers I

Cell Phone	EIRP	-1	dB(W)
Free Space	FSL	154.1	dB
	e_{pol}	-3	dB
	θ_{max}	37.5	°
Satellite	$D_{element}$	6	dB(ic)
	e_{rad}	-1	dB
	T_{bright}	300	K
	F_{sys}	?	dB
$G/T = 13.2\,\text{dB}(\text{K}^{-1})$	T_{phys}	300	K
	M	?	
	$\lambda_{up}/2$	80	mm





UP Link

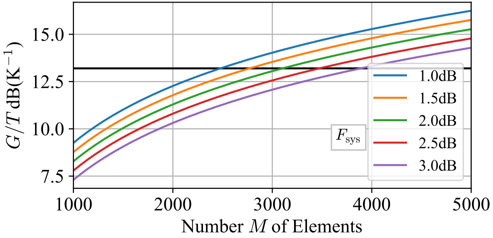
Result in Numbers II

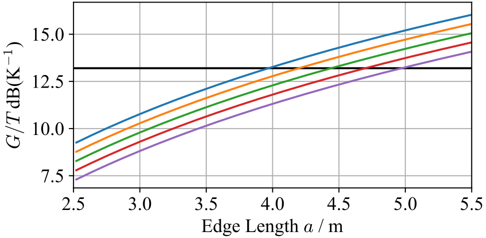
M and a

Prerequisite for UP-link data rate of $10\,\mathrm{Mbit\,s^{-1}}$ with unmodified cell PCS-phone is a phased array antenna with

$$G/T = 13.2\,\mathrm{dB(K^{-1})}$$
$$1\,\mathrm{dB} < F_{\mathrm{sys}} < 3\,\mathrm{dB}$$
$$2460 < \text{Number of elements } M < 3860$$
$$3.9\,\mathrm{m} < \text{edge length } a < 4.9\,\mathrm{m}$$
$$38.9\,\mathrm{dB} < G_{\mathrm{RXup}} < 40.9\,\mathrm{dB}$$

Square lattice with period $\frac{1}{2}\lambda_{\mathrm{up}} \Rightarrow$ antenna's edge length is $a = \sqrt(M)\,\frac{1}{2}\lambda_{\mathrm{up}}$





Übersicht

Unmodified Cell Phone, Down-Link: Satellite to Cell Phone
Assumptions for PCS / LTE Band

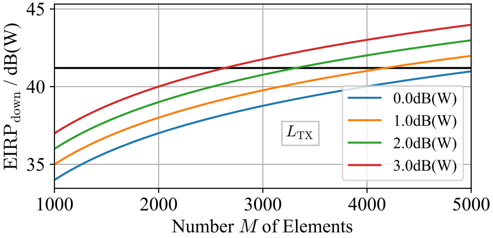
Parameter	Symbol	Value
Frequency Range		1930 MHz to 1990 MHz
Mid. Frequency	f_{down}	1960 MHz
Mid. Wavelength	λ_{down}	0.153 m
Bandwidth	Δf	10 MHz
Modulation		FSK, coherent
Bandwidth Efficiency	$R_b / \Delta f$	1
Directivity	D_{RXdown}	0 dB(i)
Radiation Efficiency	$e_{rad\ TXup}$	−1 dB
Pol. Efficiency	$e_{pol\ down}$	−3 dB
Noise Figure	$F_{sys\ down}$	3 dB
Free Space Loss	FSLdown	154.5 dB

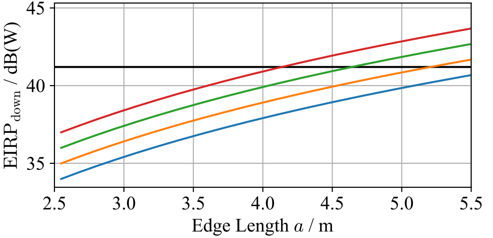
$EIRP_{down}$

Given	G/T	−28.7 dB(K^{-1})
Required	EIRP	41.2 dB(W)

Down Link
Result in Numbers I

Cell Phone	G/T	$-28.7\,\mathrm{dB(K^{-1})}$
Free Space	FSL	$154.4\,\mathrm{dB}$
	e_{pol}	-3 dB
	$\theta_{\max}$	$37.5\,°$
Satellite	D_{element}	6 dB(ic)
	e_{rad}	-1 dB
$EIRP = 41.2\,\mathrm{dB(W)}$	L_{TX}	? dB(W)
	M	?
	$\lambda_{\mathrm{up}}/2$	80 mm





HM

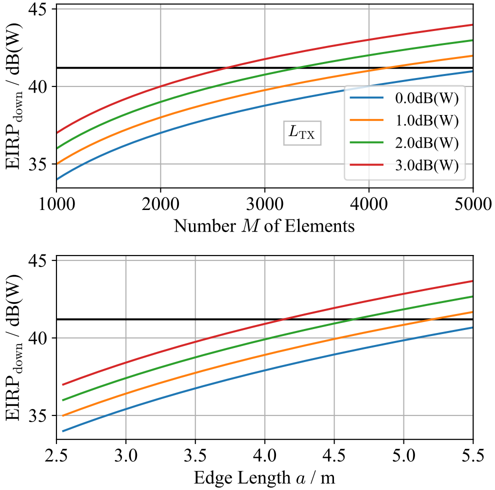
Down Link
Result in Numbers II

M and a

Prerequisite for Down-link data rate of $10\,\mathrm{Mbit\,s^{-1}}$ with unmodified cell PCS-phone is a phased array antenna with

$$\mathrm{EIRP_{down}} = 41.2\,\mathrm{dB(W)}$$
$$0\,\mathrm{dB(W)} < L_{\mathrm{TXdown}} < 3\,\mathrm{dB(W)}$$
$$5255 > \text{Number of elements } M > 2634$$
$$5.8\,\mathrm{m} > \text{edge length } a > 4.1\,\mathrm{m}$$
$$42.2\,\mathrm{dB} < G_{\mathrm{TXdown}} < 39.2\,\mathrm{dB}$$

Square lattice with period $\frac{1}{2}\lambda_{\mathrm{up}}$ ⇒ antenna's edge length is $a = \sqrt{(M)}\,\frac{1}{2}\lambda_{\mathrm{up}}$



Übersicht

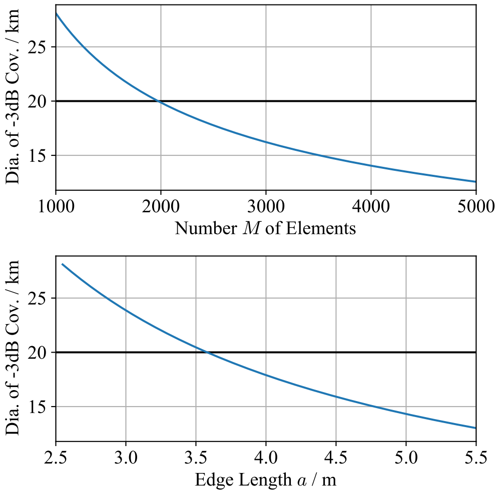
Beam Coverage
Rough Estimations

For half power beamwidth we approximate (untapered array)

$$\theta_{\mathrm{HPBW}} = \sqrt{\frac{41\,253}{D_{\mathrm{sat}}}}$$

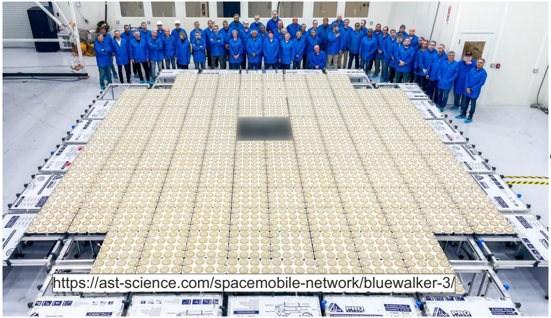
and find as diameter $\varnothing_{-3\,\mathrm{dB}}$ of the $-3\,\mathrm{dB}$-coverage

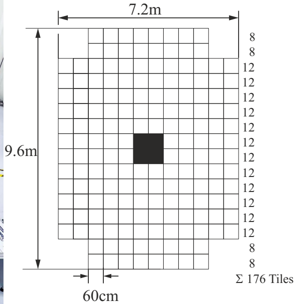
$$\varnothing_{-3\,\mathrm{dB}} = 2\,h_0\,\tan\theta_{\mathrm{HPBW}}$$



Übersicht

Blue Walker 3
Details 1





Information found in [1]
Active area is 693 feet^2, 176 tiles counted

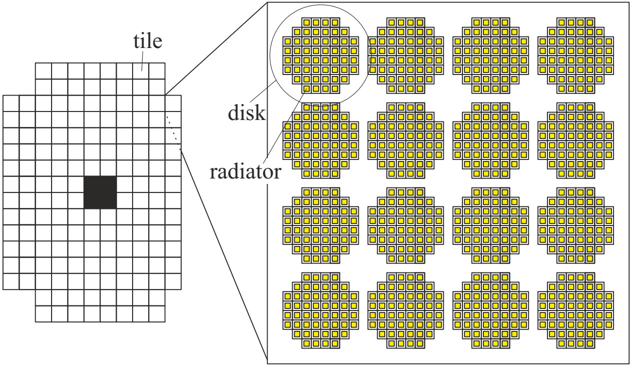
$$\Rightarrow 693\,\text{feet}^2 \approx 176\,\text{tiles} \cdot \frac{(2\,\text{feet})^2}{\text{tile}}$$

size of on tiles is $2\,\text{feet} \times 2\,\text{feet} \approx 60\,\text{cm} \times 60\,\text{cm}$

Outer dimensions $\approx 9.6\,\text{m} \times 7.2\,\text{m}$

Blue Walker 3

Details 2



There are

$$(52-2)\frac{\text{radiators}}{\text{disk}} \times 8\frac{\text{disks}}{\text{tile}} \times (176-4)\text{tiles}$$

$$= 68\,800\text{radiators}$$

Übersicht

Requirements for Satellites

Comparison of estimated data with data from sources

To achive an up- and down-link with $R_b = 10\,\text{Mbit}\,\text{s}^{-1}$ at PCS-frequencies (approx. 2000 MHz) between unmodified cell phone and constellation with 2016 satellites and 500 km-height requires Satellites phased array antennas with:

parameter	estimated	found in [5], [6]
EIRP	$> 41.2\,\text{dB(W)}$	$49\,\text{dB(W)}$ to $58\,\text{dB(W)}$!
L_{TX}	$\approx 3\,\text{dB(W)}$	?
$\varnothing_{-3\,\text{dB}}$	15 km to 20 km	33 km
G/T	$\approx 13.2\,\text{dB}(\text{K}^{-1})$	up to $12.5\,\text{dB}(\text{K}^{-1})$
F_{sys}	$\approx 1\,\text{dB}$	?
$D_{element}$	6 dB(ic)	?
e_{rad}	$-1\,\text{dB}$	?
pitch	80 cm	?
M	≈ 2500	?
$a \times a$	$< 4\,\text{m} \times 4\,\text{m}$	$< 8\,\text{m} \times 6\,\text{m}$
G	39 dB(ic) to 41 dB(ic)	29 dB(ic) to 39 dB(ic)

Let's do it

Yes, it is possible to close the white spots worldwide with internet from the sky!

Unmodified cell phones can do it.

We "only" need the satellite technology to support it.

It already happens, let's do it ourselves!

Thanks for your Attention

Questions and comments are welcome!

Übersicht

References

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