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Al–Qiblah and Satellites Signals Coverage over the KSA and the Arab World

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Abstract

This is a brief tutorial on satellite communications. Satellite systems in Fixed Satellite Service (FSS) present viable solutions for two–way communications between distant stations. This includes a wide range of traffic loads, from tens of kbit/s data transmitted via Very Small Aperture Terminals (VSAT), to about a hundred of Mbit/s data rates, voice and video traffic, transmitted via large satellite earth stations. Satellite systems in Broadcast Satellite Service (BSS) are effective in broadcasting audio, video and digital signals to audiences scattered over wide geographical areas. Many hybrid satellites in 6/4 GHz (C–band) and 14/11 GHz (Ku–band) provide both FSS and BSS.
Some of satellite systems serving the Kingdom of Saudi Arabia (KSA), and the Arab World include: Arabsat, NileSat, TurkSat, PanamSat and IntelSat. In this paper azimuth and elevation angles from KFUPM to these satellites are illustrated, a large number of Al–Qiblah directions for locations across the Arab World is tabulated, a satellite link budget and Quality of Service issues are briefly addressed.

1 Introduction

Satellites signal coverage over the KSA and the Arab World includes radionavigation and radiolocation services, Mobile Satellite Service (MSS), FSS and BSS. Examples of radionavigation and radiolocation satellite systems include existing Global Positioning System (GPS), owned and operated by the US Navy [1, 2, 3], GLObal NAvigation Satellite System (GLONASS), of former SSSR and now Russia [4], European Geostationary Navigation Overlay Service (EGNOS) [5], and European radionavigation system proposal Galileo [6]. These systems are addressed in our contribution [16].

Examples of satellite systems providing MSS include Thuraya [8], Inmarsat [9], GlobalStar [10] and Iridium [11]. Thuraya and Inmarsat satellite systems use satellite(s) in a Fixed Earth Orbit (FEO), also known as GeoStationary Orbit (GSO), while GlobalStar and Iridium use constellations of satellites in Low Earth Orbit (LEO), respectively. A range of services include low rate, up to tens of kbit/s, data and voice targeting mobile users on land, sea and in the air. On most occasions, MSS users employ antennas small in size but with an omnidirectional radiation pattern. Consequently, position(s) of respective space segment satellite system(s) is irrelevant, as long as it is above the user's horizon. MSS is vital for particular segments of business community [12–15]. However, in this contribution, attention is focused on FSS and BSS satellite systems, instead.

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2 FSS and MSS Satellites in FEO

An overwhelming majority of operational satellite systems in FSS and BSS uses satellites located along the FEO arc. Presently, there are more than 300 FEO satellites, i.e., approximately, there exist one satellite per orbital degree of arc. To a user located on the surface of the Earth, a satellite in a FEO appears as a fixed star above the local horizon. As such, a user antenna needs to be pointed toward the satellite only once and no further adjustment is necessary. This is an enormous advantage of the FEO. Consequently, the FEO has been treated, practically and legally, as a precious commodity.

Although apparently fixed, a FEO satellite is racing through the space at a speed exceeding 3000 m/s, making the satellite's rotational period of one sidereal day equal to the rotational period of its master, the Earth. It is the job of a satellite control center to keep a FEO satellite — via telemetry, tracking and control (TT&C) link — within a tightly prescribed orbital location box. According to the Third Kepler Law, a FEO satellite should be 42167 km from the barycenter of the Earth–Sun–Moon system, or about 35789 km from the Earth equator but in the equatorial plane [17]. The angular reach of a FEO satellite is $\pm 81.3°$; its nadir angle is $\pm 8.7°$. Therefore, a FEO is suitable serving areas within $\pm 81.3°$ latitudes. For example, a user located on the Earth at a longitude λ and at the latitude $|\varphi| \approx 25°$, such as Ar Riyadh, could access any satellite within approximately $\lambda \pm 75°$ FEO arc, providing the satellite's antenna beam is covering respective user's location and the user's antenna is pointing toward the respective satellite.

2.1 Satellite System Model

A typical satellite system is shown in Figure **1**. It consists of a Satellite Earth Segment (SES) part and a Satellite Space Segment (SSS) part. The SES includes: Earth Station HUB(s), also called Network Management Center(s), or Base Station(s), and Earth Station USER terminal(s), one or many of them. The SSS includes satellite equipment consisting of the transmitting and receiving antennas, a regenerative or a bent–pipe through transponder, solar panels and batteries as a source of energy, and mechanical and propulsion parts necessary to keep the satellite in a designated orbital location. A link from the HUB toward USERs is called the Forward Broadcast Link, since the HUB broadcasts its messages to one or many USERs. The opposite direction from USERs toward the HUB is called the Reverse Access Link, since USERs must first make an attempt to access the system. A part of the connection from the SES toward the SSS is called the uplink, while the opposite direction from the SSS toward the SES is called the downlink. In Figure **1**, f_{Bu} is the frequency in the uplink part of the broadcast direction, while f_{Bd} is the frequency in the downlink part of the broadcast direction. Similarly, f_{Au} is the frequency in the uplink part of the access direction, while f_{Ad} is the frequency in the downlink part of the access direction. Each direction consists of an uplink and a downlink, consuming a pair of frequencies per direction.

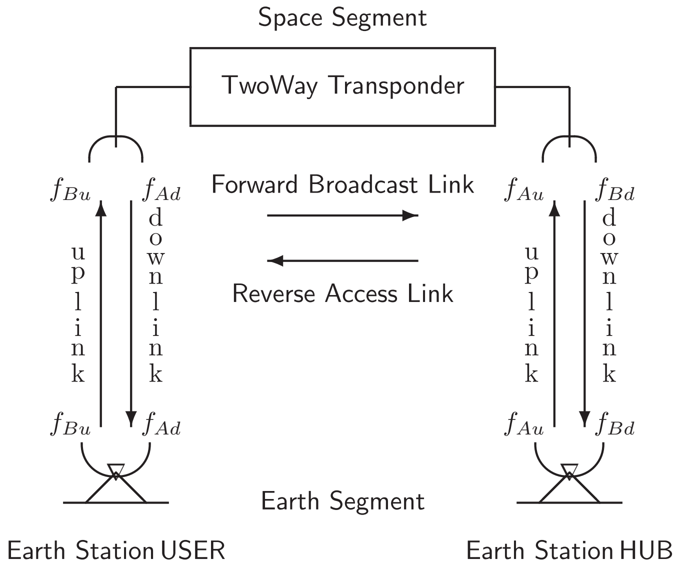

Figure 1: A Model of a Satellite System.

For technical, administrative and historic reasons, a satellite system similar to one shown in Figure 1 is called Fixed Satellite Service (FSS) system, since USERs are using fixed equipment. When USERs are on the move, the system is called Mobile Satellite Service (MSS). If only the forward direction is used to distribute information from a HUB to numerous USERs, the system is called Broadcast Satellite Service (BSS).
Most commercial FEO satellites in FSS and BSS employ 6/4 GHz (C–band) and 14/11 GHz (Ku–band) frequency bands. However, a number of 30/20 GHz (Ka–band) satellites is in operation as well. Here, we used the uplink/downlink frequency convention. A number of radio channels, called transponders, with a typical bandwidth of 36 MHz, ranges between 24 and 72 per satellite. Some satellites are of a hybrid type, consisting of both 6/4 GHz and 14/11 GHz transponders. Some of FSS and BSS satellites carry additional payloads for MSS, radionavigation, scientific and other purposes.

2.2 Coverage/Footprint

A space segment satellite antenna beam keeps pointing toward a planned point on the surface of the Earth called center of coverage. Contours of equal signal strength on the map are called the coverage contours, or footprint contours. An area within the most outer contour, which corresponds to the lowest but still acceptable signal strength, is called the coverage area, or the footprint. The most outer contour itself is called the edge of coverage/footprint. A typical satellite space segment has at least two antennas, transmitting and receiving ones. Characteristics of a particular transponder and antenna system are provided by satellite manufacturer and/or service provider in form of footprints. A footprint in the forward broadcast direction is provided in terms of the effective isotropic radiated power (`eirp`) contours. Here, `eirp` is a sum of transmitter power P_T and transmit antenna gain G_T, all expressed in dB. A footprint in the reverse access direction is provided in terms of the G/T contours. Here, G/T, or more precisely $G_R-\Theta$ in dB, is a difference of space segment receiver antenna gain G_R and effective noise temperature Θ, both expressed in dB, or as a ratio g_R/ϑ. This data, in addition to exact locations of respective stations, are in most cases all what is needed for selection of satellite earth station equipment and analysis of a satellite link budget.

Typically, due to higher frequency and smaller physical size of antennas, Ku–band contours are shaped more closely to desired area of coverage, than respective C–band contours. For example, Ku–band contours for an Arabsat satellite [18] extend from NorthWest Africa to Arabian Peninsula, thus providing adequate signal strength to respective areas. Respective C–band contours are wider in north–south direction covering large parts of Southern Europe as well. A beam with such a wide coverage is usually called a global beam. A narrow spot beam covers much smaller area but may, if administratively permitted, exhibit higher `eirp` and $G_R-\Theta$ values, thus allowing use of either higher capacity or smaller earth station equipment.

Across the KSA, in addition to ArabSat, one could receive signal from NileSat [19], TurkSat (EurAsiaSat) [20], AsiaSat [21], IntelSat [22], EutelSat [23], PanAmSat [24], etc.

Historically, a deployment of C–band satellite systems followed radio–relay point–to–point systems already operational in the same band. Due to sharing constraints, a signal strength from a satellite space segment but on the surface of the Earth, expressed as power flux density (`pfd`), is relatively lower in the C–band, and any shared band, in comparison with an exclusive allocation. Thus, for example, shared C–band `pfd` values of a BSS are effectively lower than respective `pfd` values in an exclusive BSS Ku–band. Consequently, to achieve the same performance, a C–band TeleVision Receive Only (TVRO) antenna has to be electrically and mechanically larger than corresponding TVRO Ku–band antenna.

Early C–band satellites operated in an AWGN limited environment but in the presence of minor interference levels from terrestrial radio systems. Present C–band satellite systems operate in an inter system interference environment. Availability of radio links, including satellites ones, operating at frequencies above 10 GHz is impaired by hydrometeors, and by rain statistics in particular.

2.3 Distance, Elevation, Azimuth, Al–Qiblah

Two points $A_1\{r_1,\,\phi_1,\,\lambda_1\}$ and $A_2\{r_2,\,\phi_2,\,\lambda_2\}$ in 3D space are defined by respective geocentric spherical coordinates $\{r_i,\,\phi_i,\,\lambda_i\}$. Here, r_i is the radius vector, ϕ_i is the latitude and λ_i is the longitude of the ith location. The square of Euclidean line distance between points $A_1\{x_1,\,y_1,\,z_1\}$ and $A_2\{x_2,\,y_2,\,z_2\}$ in the Cartesian coordinate system is defined as

$$d_{12}^2 \overset{\text{def}}{=} (x_2-x_1)^2+(y_2-y_1)^2+(z_2-z_1)^2 \equiv d_{21}^2 \tag{1}$$

Then, after straightforward substitutions

$$\begin{aligned} d_{12}^2 &= r_1^2+r_2^2 \\ &\quad -2\,r_1 r_2\,\overbrace{\left[\cos(\lambda_2-\lambda_1)\,\cos\phi_1\,\cos\phi_2+\sin\phi_1\,\sin\phi_2\right]}^{\rho\,=\,\cos\alpha_{12}} \end{aligned} \tag{2}$$

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By employing the cosine rule, the elevation angle ε_{12} from point A_1 toward point A_2 is

$$r_2^2 \;=\; r_1^2 + d_{12}^2 - 2\,r_1\,d_{12}\,\mathrm{cn}\Gamma(90^\circ + \varepsilon_{12}) \tag{3}$$

$$\boxed{\varepsilon_{12}} \;=\; \mathrm{Tsn}\,\frac{r_2^2 - r_1^2 - d_{12}^2}{2\,r_1\,d_{12}} \;=\; \boxed{\mathrm{Tsn}\,\frac{r_2\,\rho - r_1}{d_{12}}} \qquad \text{elevation} \tag{4}$$

Here, $\mathrm{cn}\Gamma$, $\mathrm{sn}\Gamma$, Tsn are trigonometric cosine, sine and inverse sine functions, respectively. The elevation angle ε_{ij} at location A_i is measured from the horizon plane of the location A_i toward the location A_j. Let assume that the satellite location A_3 has the same latitude and longitude as the point A_2 but different radius $r_3 > r_2$. In this case, point A_2 is called the sub satellite point of the satellite A_3. Corresponding elevation angle from location A_2 toward the satellite A_3 is $\varepsilon_{23} = 90^\circ$.

A directional angle from location A_1 toward location A_2, or generally from location A_i toward location A_j, is calculated as follows. An azimuth angle ζ_{12} (from arabic al-sumut) is defined as an angle from the true north measured at location A_1 in a clockwise right–screw direction toward location A_2.

$$\alpha_1^\sharp \;=\; \mathrm{Tsn}\left[\frac{\mathrm{sn}\Gamma(\lambda_1 - \lambda_2)}{\sqrt{1-\rho^2}}\;\mathrm{cn}\Gamma\phi_2\right] \tag{5}$$

$$\boxed{\zeta_{12}} = \begin{cases} 180^\circ - \alpha_1^\sharp \;,\; \phi_1 > \phi_2,\; \alpha_1^\sharp < 0 \leftrightarrow \mathrm{SW},\; \alpha_1^\sharp > 0 \leftrightarrow \mathrm{SE} \\ \alpha_1^\sharp \bmod 360^\circ \;,\; \phi_1 < \phi_2,\; \alpha_1^\sharp < 0 \leftrightarrow \mathrm{NW},\; \alpha_1^\sharp > 0 \leftrightarrow \mathrm{NE} \end{cases} \tag{6}$$

Here, mod stands for modulo, i.e., a negative angle $\alpha_1^\sharp$ will be converted to $360^\circ + \alpha_1^\sharp$, although a negative azimuth angle can be used as well. Triplet $\{d_{12}, \zeta_{12}, \varepsilon_{12}\}$ is known as topocentric horizon coordinates of the location A_2 at the referent location A_1 ($\tau o \pi o \varsigma$ = place).

A direction from a particular location toward the Holy City of Makkah is known as Al-Qiblah. Using equations (2–6) distances, elevations, azimuths and Al–Qiblah direction for hundreds of locations across the Arab World, but mostly across KSA, toward the Holy City of Makkah and toward a number of FEO satellites were calculated. Some of unconfirmed data is presented in the table on the right. Referenced points are the Holy City of Makkah and a FEO at the longitude of 30° East. For example, the KFUPM is located at (26 degrees, 18 minutes, 30 seconds latitude North) and (50 degrees, 08 minutes, 34 seconds longitude East); its altitude is 50 m; its distance toward the Holy City of Makkah is 1178 km, al–Qiblah is 244.8°. The distance between KFUPM and the FEO at 30° E is 36946 km. The elevation from KFUPM toward the FEO is 52.3°; respective azimuth equals 218.8°.

3 VSAT, Multiple Access

A single transponder about 36 MHz wide could accommodate thousands of analog telephone channels, a single frequency modulated TV channel, TVFM, or up to about 100 Mbit/s data stream. Numerous applications employ much lower data rates such as 2.1 Mbit/s, 1.6 Mbit/s or as low as 64 kbit/s. These applications could share the same satellite transponder in a particular multiple access mode, and might be realized by simpler equipment and smaller antennas.

Terrestrial Location				To Makkah		To 30°E FEO Sat		
Location	latitude	longitude	h,m	d,km	azim	d,km	elev	azim
Makkah	21 N25n19	39 E49e36	300	1	60.4	36401	62.8	204.2
Madinah	24 N30	39 E35	625	343	175.8	36549	59.6	201.1
Riyadh	24 N41n	46 E47e	680	798	244.4	36742	55.8	215.0
Kharj	24 N09n	47 E19e	350	825	249.9	36733	56.0	216.5
Buraydah	26 N20n	43 E58e	750	689	218.5	36746	55.8	208.4
Unaizah	26 N05n	44 E01e	750	671	220.3	36734	56.0	208.7
Dawadmy	24 N30n	44 E23e	750	578	234.6	36660	57.4	210.8
AzZilfi	26 N18n	44 E49e	750	742	224.1	36768	55.4	209.9
Shagra	25 N14n	45 E16e	820	698	233.8	36724	56.2	211.7
Dilam	23 N59n	47 E10e	750	804	250.7	36719	56.3	216.4
Artawiya	26 N31n	45 E21e	750	797	225.9	36795	54.9	210.7
Sulaiyil	27 N16n	42 E16e	750	695	201.3	36757	55.6	204.5
Hufuf	25 N15	49 E45	150	1097	249.2	36876	53.5	219.3
Jubail	28 N26	45 E58	10	994	219.8	36923	52.7	210.2
HafrBatin	28 N26	45 E58	300	994	219.8	36922	52.7	210.2
Jouf	29 N55	40 E05	750	944	181.6	36870	53.6	198.7
Saihat	26 N28n46	50 E02e42	6	1177	243.7	36951	52.2	218.5
Qatif	26 N31n12	50 E01e29	9	1178	243.5	36953	52.2	218.4
TarutIsl	26 N40n22	50 E04e51	1	1190	242.9	36963	52.0	218.4
Jeddah	21 N30n00	39 E10e00	10	69	97.1	36393	63.0	202.6
Yanbu	24 N05n00	38 E03e00	10	347	148.0	36502	60.6	198.0
Masturah	23 N09	38 E51	10	217	152.2	36467	61.3	200.5
Mastabah	21 N09	39 E28	0	48	50.9	36382	63.2	203.6
rTanora	26 N38n	50 E09e	10	1195	243.3	36964	52.0	218.5
HassaAl	25 N20n	49 E36e	10	1086	248.4	36875	53.5	219.0
AbuHadr.	27 N21n	48 E52e	10	1126	236.2	36956	52.1	215.9
Khramah	21 N54n41	42 E01e54	1066	232	257.2	36470	61.2	208.6
Abha	18 N21n13	42 E51e31	2260	465	317.7	36336	64.2	214.8
BahaAl	20 N00	41 E42e25	2000	251	309.4	36376	63.3	210.1
Namas	19 N12n07	42 E12e07	2000	350	315.4	36355	63.8	212.2
Bishah	20 N00	42 E57e35	1200	361	296.5	36408	62.6	212.8
Jizan	16 N55n48	42 E41e51	10	584	329.5	36279	65.7	216.6
Qunfudha	19 N07	41 E05	50	288	333.1	36327	64.5	209.7
Wudaiah	17 N05	47 E09	700	907	303.3	36422	62.3	225.5
Najran	17 N33	44 E15	1000	632	313.6	36345	64.0	219.1
DharanJa	17 N42	43 E31	1700	566	317.6	36329	64.4	217.2
Al Birk	18 N13	41 E32	50	399	333.7	36300	65.2	212.0
Harad	24 N09n00	49 E03e00	240	992	254.0	36795	54.9	219.4
Shaybah	22 N24n46	53 E36e55	145	1422	268.2	36901	53.0	228.2
Rfhah	29 N36n37	43 E36e43	250	984	203.4	36927	52.6	205.2
Khafji	28 N15n	48 E32e	154	1159	231.1	36994	51.5	214.5
Safaniyah	27 N54n	48 E45e	0	1152	233.3	36982	51.7	215.2
Muwayilh	27 N38n48	35 E24e00	951	822	146.1	36665	57.3	190.5
Alwajh	26 N13n48	36 E28e00	60	633	146.6	36596	58.7	193.3
Haql	29 N18n00	34 E57e00	14	1002	149.7	36763	55.5	189.0
Al Rais	23 N36	38 E36	450	273	152.3	36485	60.9	199.6
Al Rogei	29 N05	46 E38	200	1091	220.3	36981	51.7	210.8
Teima	27 N39	38 E32	450	704	169.0	36706	56.5	196.9
Tabuk	28 N24	36 E32	900	843	156.1	36723	56.2	192.5
Thol	22 N17	39 E07	450	121	142.5	36429	62.1	201.8
hagel	29 N18	34 E57	900	1002	149.7	36762	55.5	189.0
nassab	29 N12	44 E43	450	994	210.7	36932	52.5	207.4
wSarhan	31 N00	37 E55	200	1081	169.4	36904	53.0	194.2
arar	30 N59	41 E01	450	1069	186.6	36956	52.1	199.8
skaka	29 N58	40 E13	450	950	182.4	36876	53.5	198.9
Ta'if	21 N16	40 E27	1500	67	285.1	36406	62.6	205.8
Hail	27 N41n	41 E42e	750	721	195.6	36768	55.4	203.1
RuKhali	21 N20n	51 E00e	200	1155	272.5	36740	55.9	225.8
Marjan	28 N27n29	49 E38e13	1	1257	233.8	37045	50.7	216.1
Suda	18 N16n12	42 E22e50	2976	440	323.3	36320	64.6	213.8
Tiran	28 N00	34 E30	0	907	142.5	36680	57.0	188.5
J.Unaizah	32 N14	39 E18	951	1202	177.4	37006	51.3	196.2
Eastern	22 N00	55 E42	20	1636	269.3	36985	51.6	231.5
Southern	15 N40	45 E23	1000	867	318.4	36313	64.8	224.5
KFUPM	26 N18n30	50 E08e34	50	1178	244.8	36946	52.3	218.8
Ankara	39 N55n60	32 E52e00	932	2150	160.2	37508	43.8	183.7
Baghdad	33 N20n19	44 E23e38	40	1396	199.9	37187	48.5	204.2
Kuwait	29 N14n08	47 E58e30	44	1191	225.1	37032	50.9	212.8
Sana	15 N21n17	44 E12e24	2254	817	326.3	36264	66.0	222.6
Tehran	32 N42n13	51 E09e07	1799	1675	224.5	37356	45.9	214.9
Rabat	34 N00n00	-6 E50e25	50	4505	95.7	38168	35.3	127.9
Giza	30 N03n47	35 E12e30	20	1064	153.2	36812	54.6	189.3
Jerusalem	31 N46n29	35 E13e24	700	1236	157.2	36924	52.7	188.9
Damascus	33 N31n5	36 E17e42	100	1387	164.6	37054	50.5	190.4

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The commercial name for such systems is Very Small Aperture Terminals (VSAT). While first generation Earth Station satellite equipment employed huge 30–10 m diameter antennas, VSAT antennas are 3–1 m in diameter. Technological advances and relieved administrative burden lead to modest price and ease of deployment, including on rooftops. This created a synergy, and a successful VSAT market segments developed.

Early satellite systems used a Single Channel Per Carrier (SCPC) principles and Frequency Division Multiple Access (FDMA) mode of operation. In FDM mode many individual carriers jointly share the same transponder. Resulting signal exhibits high peak–to–average fluctuations and requires space segment High Power Amplifier operation in a linear but highly inefficient mode; however, an SCPC user Earth Station terminal is simple and inexpensive. A Time Division Multiple Access (TDMA) mode of operation requires only a modest back–off of the HPA. This results in more efficient mode of operation. However, TDMA system requires a complex network synchronization in addition to high peak–to–average transmit power for each Earth Station terminal. A Code Division Multiple Access (CDMA) mode of operation may offer some advantages in particular applications. However, this mode exhibits the highest peak–to–average signal fluctuations at the space segment HPA input, thus resulting in low efficiency, [17].

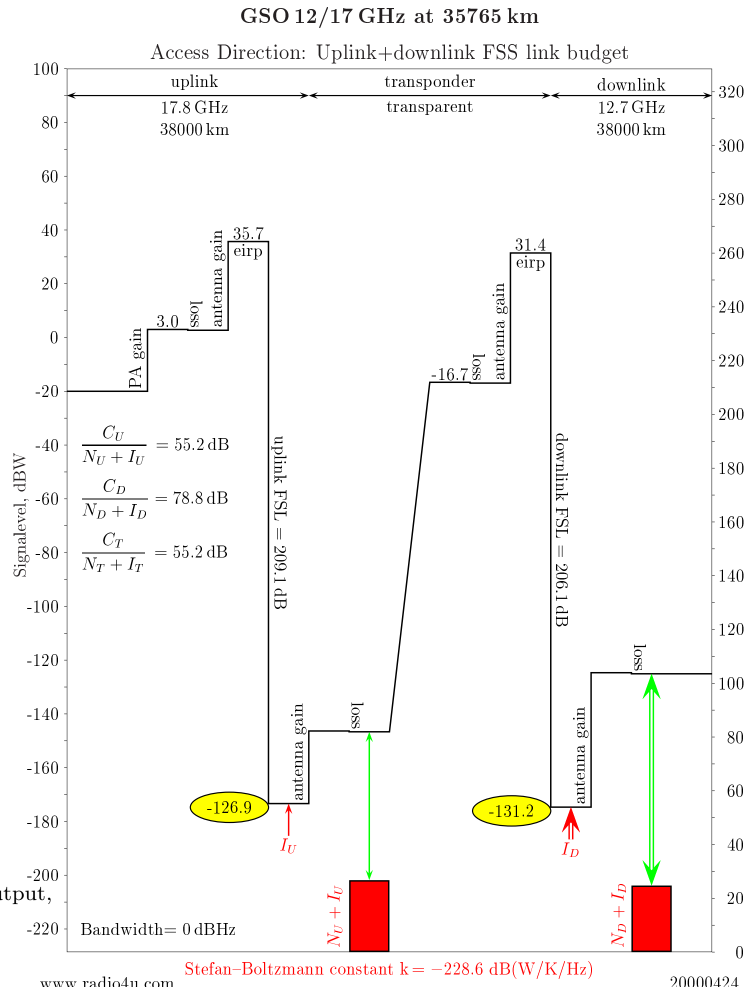

Figure 2: A Link Budget of a Light Traffic 12/17 GHz System.

C = a desired Carrier level at the receiver end

P_{ETU} Earth station TX UpLink signal at RF High Power Amplifier output,

$-\ L_{ECU}$ Earth station Cable UpLink signal loss, dB

$+\ G_{ETU}$ Earth station transmitter UpLink Antenna Gain, dBi

$\mathtt{EIRP}_{ETU} = P_{ETU} - L_{ECU} + G_{ETU}$ Effective Isotropic Radiated Power, dBWi (8)

$-\ L_{0UL}$ UpLink Basic Loss, $L_{0UL} \approx 92.45 + 20\log f_{UL\ \mathrm{GHz}} + 20\log d_{UL\ \mathrm{km}}$

$-\ L_{1UL}$ Additional UpLink Losses due to scintillation, hydrometeors, etc.

$\mathtt{PFD}_{SRU} \approx \mathtt{EIRP}_{ETU} - 71 - 20\log d_{UL\ \mathrm{km}}$, dBWi/m^2 (9)

$+\ G_{SRU}$ Space station Receiver UpLink Antenna Gain, dBi

I_{SUO} Space station UpLink Outside/External Interference Level, dBW

$-\ L_{SCU}$ Space station Cable Uplink signal loss, dB

N_{SUI} Space station UpLink Internal Noise Level, dBW

I_{SUI} Space station UpLink Internal Interference Level, dBW

$(G/T)_{SRU}$ Space station Receiver Uplink (Gain − Temperature), dBi/K (10)

$(C/N+I)_{SRU}$ Space station Receiver Uplink $c/(n_{SUI} + i_{SUO} + i_{SUI})$, dB (11)

$+\ G_{SUD}$ Space station Gain of UpLink − DownLink Transponder, dB

P_{STD} Space station TX DownLink signal at RF High Power Amplifier output, dBW

$-\ L_{SCD}$ Space station Cable DownLink signal loss, dB

$+\ G_{STD}$ Space station transmitter DownLink Antenna Gain, dBi

$\mathtt{EIRP}_{STD} = P_{STD} - L_{SCD} + G_{STD}$ Effective Isotropic Radiated Power, dBWi (12)

$-\ L_{0DL}$ DownLink Basic Loss, $L_{0DL} \approx 92.45 + 20\log f_{DL\ \mathrm{GHz}} + 20\log d_{DL\ \mathrm{km}}$

$-\ L_{1DL}$ Additional DownLink Losses due to scintillation, hydrometeors, etc.

$\mathtt{PFD}_{ERD} \approx \mathtt{EIRP}_{STD} - 71 - 20\log d_{DL\ \mathrm{km}}$, dBWi/m^2 (13)

$+\ G_{ERD}$ Earth station Receiver DownLink Antenna Gain, dBi

I_{EDO} Earth station DownLink Outside/External Interference Level, dBW

$-\ L_{ECD}$ Earth station Cable DownLink signal loss, dB

N_{EDI} Earth station Downlink Internal Noise Level, dBW

I_{EDI} Earth station Downlink Internal Interference Level, dBW

$(G/T)_{ERD}$ Earth station Receiver Downlink (Gain − Temperature), dBi/K (14)

$(C/N+I)_{ERD}$ Earth station Receiver Downlink $c/(n_{EDI} + i_{EDO} + i_{EDI})$, dB (15)

$$\left(\frac{C}{N+I}\right)_{TOT} = -10\log\left[10^{-0.1\,(C/N+I)_{SRU}} + 10^{-0.1\,(C/N+I)_{ERD}}\right] \quad (16)$$

4 Link Budget

A link budget is a summary of all signal levels, gains and losses (attenuations), along a radio link, from a transmitter to a receiver side. An example of a self–explanatory but detailed calculation of a satellite link budget is summarized in equations (7–16) on the left side. A link budget of a very light traffic 17/12 GHz satellite system is presented in Figure **2**. A signal at the earth segment transmitter of −20 dBW is amplified in a power amplifier (PA), attenuated by a cable loss, and amplified by an antenna gain, resulting in an uplink `EIRP` = 35.7 dBWi. An uplink free–space–loss (`fsl`) of 209.1 dB gives a power–flux–density (`pfd`) of −126.9 dBWi/m^2 in front of the space segment antenna. Both, a signal and uplink interference I_U are amplified by a space segment antenna and attenuated by respective cable. Resulting uplink $C_U/(N_U + I_U) = 55.2$ dB. This composite signal is amplified and translated to a downlink frequency of 12.7 GHz, attenuated by a cable and/or transmitter multiplexer manifold, amplified by a space segment transmitter antenna to a level of `eirp` = 31.4 dBWi and sent toward the earth. A downlink `fsl` of 206.1 dB gives a power flux density (`pfd`) of −131.2 dBWi/m^2 in front of the earth segment antenna. Both, this signal and downlink interference I_D are amplified by an earth segment antenna and attenuated by respective cable. Resulting downlink $C_D/(N_D + I_D) = 78.8$ dB.

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5 Quality of Service

Quality of Service (QoS) is a figure of merit involving complex interrelationships between numerous parameters, including equipment itself, [17]. Satellite systems involve a diverse types of services. This includes large stations transmitting and receiving high streams of important information, VSAT satellite earth stations and TeleVision Receive Only (TVRO) antenna systems for reception of television signals. While TVRO systems involve inexpensive antennas and receivers, large transmit and receive stations require antenna systems with precisely shaped antenna pattern and may aim to achieve an availability of service better than 99.9999%. Corresponding unavailability of $0.0001\% = 10^{-6}$ is equivalent to $10^{-6} \times 3600 \cdot 24 \cdot 365.25 = 10^{-6} \times 31551600 = 31.55$ seconds per Iulian year, or about a half minute per year.

Here, we briefly address only interesting but important natural phenomena, which impact QoS of a satellite system. Satellite space segment may, during its lifetime of 10–15 years, experience about two partial or total solar eclipses caused by the moon. While partial solar eclipse causes a reduced solar panel power output, total moon caused solar eclipse may require a reduction of the total satellite power due to limited capacity of back–up battery system. In addition to rare moon caused solar eclipses, a satellite space segment experiences, twice a year, regular solar eclipses caused by the earth. At every equinox, around midnight of a satellite local time, the earth shadows the sun for about 72 minutes. Further away from the equinox datum, for up to ±21 days, shorter in duration eclipses of a satellite space segment occur, [17]. During these equinoxes eclipses, satellite space segment batteries may not be able to provide enough power for all available transponders and some of transponders may be shut down.

Twice a year, around equinoxes but at location dependent time, sun aligns behind respective satellite space segment but within antenna beam of respective earth station. The earth station receiver will experience an increased noise temperature levels due to the sun within its antenna beam. This will degrade C/N ratio, thus degrading performance, such as increasing a number of degraded minutes, increasing a number of degraded seconds, or even causing a complete outage, [17].

In Figure **3**, on 20020310 and 20021004, as seen from the KFUPM, sun apparent orbit coincided with the respective FEO arc. Thus, as seen from KFUPM, at a particular instant of time each satellite in FEO was aligned with the sun. For example, on 20021004, ArabSat 2B satellite appeared aligned with the sun at around 13 h, TurkSat about an hour before, etc. Around those times, respective customers may had experienced a reduced reception quality. Users with smaller antennas experience a shallow degradation lasting for a few minutes. Users with larger antennas experience deeper degradation lasting for a shorter period of time.

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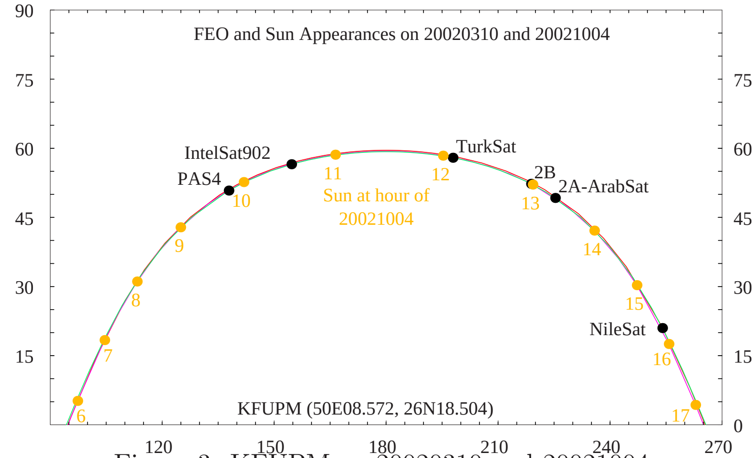

Figure 3: KFUPM on 20020310 and 20021004.

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