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**Broadband access by
fixed-satellite service systems**

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REPORT ITU-R S.2361-0

Broadband¹ access by fixed-satellite service systems

(2015)

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¹ In this Report, the term “broadband” implies a data rate of 2 Mbit/s or higher.

1 Introduction

Satellite telecommunication technology is accelerating the availability of high-speed broadband services including to developing countries, least-developed countries, and land-locked and island countries, and economies in transition. This Report includes the technical and operational characteristics of fixed-satellite service (FSS) systems that facilitate the mass-production of simple user terminal equipment at affordable prices for the delivery of high speed broadband as well as examples of their implementation; this includes broadband access at high data-rates via small user terminals, and existing systems having a variety of earth station sizes designed also for other applications and using a variety of frequency bands.

Broadband access over the FSS has been deployed in the 4/6 GHz, 11/14 GHz and 20/30 GHz band allocations. New systems are expected to soon be deployed making use of the 40/50 GHz band allocation as well. While the technology is particularly well suited to reach underserved and unserved areas, the initial development has occurred in major industrialized regions. In the interest of promoting deployments in less developed regions, this Report provides a summary of the enabling regulatory environment and technologies and also provide a repository of case studies to use as reference.

2 System architectures

Two system topologies are available, and two architectures can be supported by either one. One topology is the star topology, where every terminal is connected to a “base station” through the satellite link. Generally, in this topology, there is far more traffic going from the base stations to each of the terminals (forward link) than from each of the terminals to the base stations (return link). Thus base stations will have larger antennas to accommodate higher gains for the broader bandwidths transmitted. The terminal antenna size is based on the amount of return link bandwidth desired, and may make use of very small or ultra-small aperture antennas, as described in § 6.1.

The second topology is known as “mesh”, where any terminal communicates with any other terminal directly through the satellite. There are no base stations and thus all earth stations operate on similarly designed uplinks and downlinks.

Within either topology, one architectural option is for every user to have its own very small aperture terminal (VSAT) or ultra-small aperture terminal (USAT) (e.g. direct-to-home service). The second option is one that employs “community” earth stations antennas and local terrestrial distribution. Associated with each local “community” earth station would be a terrestrial radio system equipped to serve a number of subscribers within a radius of about 3 km. The number of users that could be supported at any one time would depend upon the bit rates they were using and the activity factors on their connections. This architectural choice may also be implemented without any use of VSATs or USATs, nor the spot beam technology described in § 5.

3 Regulatory considerations

Advantageous deployment of technological advances is made possible by encouraging transparent and clear regulatory environment. Satellite systems are high risk, costly ventures that can only be afforded when there are policies in place to ease those inherent burdens and provide certainty to operators. Administrations must consider how to provide reasonable means of market entry and set forth clear rules on how this occurs. Through the creation of such a regime, satellite broadband can serve as an important complement to terrestrial broadband services, reaching those in underserved and unserved areas.

An important consideration for satellite broadband entry into a market is the ability to ubiquitously deploy earth stations with minimum regulatory burdens. As seen in the previous section, one

architectural option is for every user to have its own VSAT or USAT. An earth station licensing scheme must be in place that allows for large quantities of these types of earth stations and its associated equipment to be economically and efficiently authorized for use.

Finally, yet most importantly, FSS spectrum allocation must be protected. Broadband applications require availability of large amount of spectrum in a low interference environment. Much care must be taken when considering spectrum sharing schemes that might impact the ability to operate these applications economically and allow such uses to expand to meet consumer demand.

4 Useable spectrum

The 4/6 GHz and 11/14 GHz frequency bands are already heavily utilized for delivering satellite services including broadband applications. The heavy use of these bands makes it difficult for earth stations with wide beamwidths to share frequencies with the existing services.

The 20/30 GHz FSS allocations are also being used to deliver broadband services. Although the use is lighter than for the lower frequency bands, several new satellite systems are planned for deployment in the near future. At these frequencies the wavelength is consistent with the use of very small antennas and antenna technology continues to develop allowing for new types of antennas that can meet the growing broadband needs. The 40/50 GHz band is also well suited for broadband, offering many of the same advantages as the 20/30 GHz band.

5 Spot beam technology

The space-sector cost per bit of information is optimized by designing each satellite for frequency reuse via multiple spot beams. It is, however, important to note that, as the beamwidth is reduced, the pointing accuracy requirement increases, and hence the difficulty and cost of controlling the beam footprints increases.

Due to spacecraft developments in recent years, it is common to assume antenna feed arrangements that compensates for the curvature of the Earth's surface to enable all beams generated by a given satellite to have circular footprints of the same diameter regardless of pointing direction. Thus, with the exception of a beam pointing at the sub-satellite point, each beam will have an elliptical cross-section, and its axial ratio and orientation will depend on its pointing direction relative to the direction of the sub-satellite point. Annex 1 provides details on the beam formation.

6 Earth station considerations

6.1 Very small aperture terminals

Higher operating frequencies make it possible to decrease terminal size because the signals can be appropriately received by smaller antennas. The current market has seen antenna diameters decrease to as much as 60 cm for a fixed terminal. Driving the antenna diameter down so far has greatly enhanced the affordability of broadband satellite systems. As use of higher frequencies increase, one may aspire to see developments for even smaller antenna sizes, but the pointing accuracy requirement is also likely to increase. Therefore, transitioning from VSATs to USATs requires advances beyond the use of Q band (30/40 GHz) and V band (40/50 GHz) transmissions.

6.2 Other size earth stations

The system architecture discussed above was largely driven by the choice of 30 cm antennas for the user earth stations, which fall within the category sometimes termed "ultra-small aperture terminals",

or USATs. If larger user antennas are assumed, the requirements of broadband access via satellite (excepting portability of terminals) may be met by various system architectures.

Although the size of user antenna is less dominant on system design for terminals other than USATs, it still has significant influence and therefore it is appropriate to select a popular size for analysis. In the replies to an ITU Radiocommunication Bureau Questionnaire which covered 20/30 GHz earth stations with antennas from 0.3 m to 7.6 m in diameter, the diameter occurring most often was 1.2 m. Replies to the same Questionnaire covered 11/14 GHz earth stations with antennas from 0.4 m to 18.0 m in diameter, and for those also the diameter occurring most frequently was 1.2 m.

Thus 1.2 m was chosen for the present example, noting that earth stations using antennas of this size are among those referred to as “very small aperture terminals”, or VSATs. Annex 3 is an example using this size earth station.

7 Example implementations

Implementations of the technology which permits broadband connectivity is now taking place. One example is found in Annex 2.

8 Additional reference documents

Many reports and recommendations are available to use in the design of broadband satellite systems, addressing various aspects. This section offers a quick look-up table of helpful material for design of broadband systems in the GSO FSS.

TABLE 1
Relevant ITU-R Recommendations

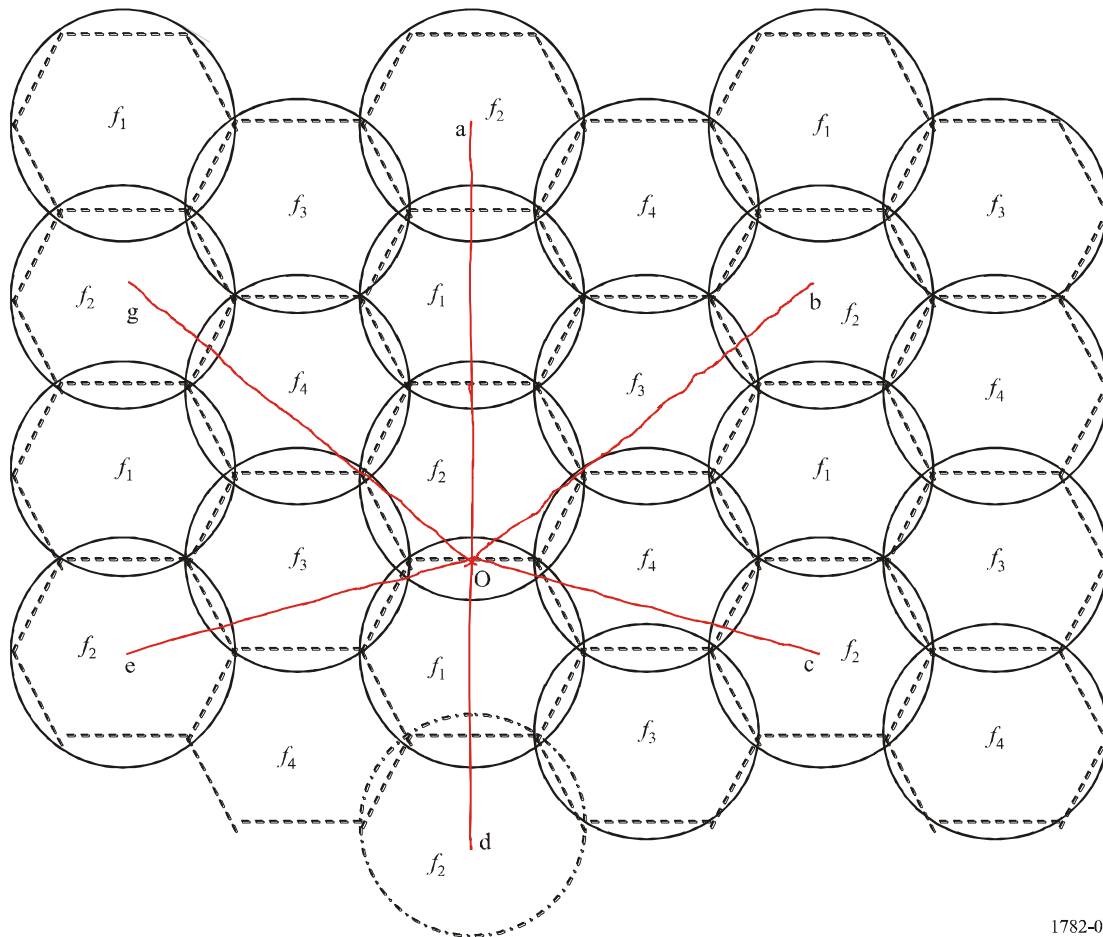
ITU-R Recommendations for earth stations	ITU-R Recommendations for space stations	Topic
S.465 S.731 S.1855		Reference radiation patterns for use in coordination and interference assessment in the frequency range from 2 to 31 GHz
S.524		Maximum permissible levels of off-axis e.i.r.p. density for the fixed-satellite service in the 14 GHz and 30 GHz bands
S.580	S.672	Radiation diagrams for use as design objectives
S.1594		Maximum emission levels associated requirements in the 30 GHz range
S.725		Technical characteristics for very small aperture terminals (VSATs)

Annex 1

Spot beam configurations used in the delivery of broadband

The beamwidths of the major (φ_a) and minor (φ_b) axes will be such that $((\varphi_a) \cdot (\varphi_b))^{0.5} = (\varphi_0)$, where (φ_0) is the -3 dB beamwidth of the (circular) beam pointing to the sub-satellite point. Terminals in the service are then assigned a beam based on their position with respect to the hexagonal pattern of overlaps, as illustrated in Fig. A1-1.

FIGURE A1-1
Hexagonal pattern for footprints of overlapping satellite beams



1782-01

A one-in-four frequency reuse pattern is shown in Fig. A1-1, and each beam is assumed to be dual-polarized. Given practicable rates of roll-off and first-sidelobe levels such as those described by the equations in Recommendation ITU-R S.672, the discrimination between the center of a beam and the nearest edge of the next co-frequency beam will be just about adequate to support this mode of operation. For example, at point “o” at the edge of one of the hexagonal areas served by a frequency f_2 beam, the interference contributions from the nearest six co-frequency beams can be calculated from the off-axis angles oa , ob , oc , od , oe , and og , subtended at the satellite.

From the geometry of the diagram:

$$oa = 5(\varphi_0/2) \cdot \cos(30^\circ) = 2.165(\varphi_0)$$

$$ob = og = (\{2(\varphi_0/4) + \varphi_0\}^2 + \{3(\varphi_0/2) \cdot \cos(30^\circ)\}^2)^{0.5} = 1.984(\varphi_0)$$

$$oc = oe = (\{(\varphi_0/2) \cdot \cos(30^\circ)\}^2 + \{2(\varphi_0/4) + \varphi_0\}^2)^{0.5} = 1.561(\varphi_0) \text{ and}$$

$$\text{od} = 3(\varphi_0/2) \cdot \cos(30^\circ) = 1.299(\varphi_0)$$

In replies to a Radiocommunication Bureau Questionnaire, ninety of the 11/14 GHz links for which data was supplied included satellite receive antenna peak gain values greater than 30 dBi. These gain values ranged from 30.1 to 45.6 dBi, with an average of 36.5 dBi, corresponding to beamwidths of 5.5° (maximum), 0.93° (minimum) and 2.7° (average) respectively^{A1}. With corresponding half-power beamwidths of less than 6° , the beams can be regarded as spot beams.

Annex 2

Broadband satellite with on-board processing case study: UKSAT-10

1 Introduction

In early 2007, UKSAT-10 was launched to provide FSS in the 19.7-20.2 GHz space-to-Earth and 29.5-30 GHz Earth-to-space bands. The services provided through this satellite network include high-speed broadband access, narrow-band data, high-speed data, videoconferencing, high capacity two-way communications, managed networks, and direct-to-home IP-based services.

This satellite network uses onboard signal processing, which means that signals from any uplink beam can be dynamically routed via onboard packet switch to any downlink beam. The uplink spectrum is received by the satellite, fully demodulated, and “re-packaged” for re-transmission back to Earth. In this mode of operation there are no “transponders” in the classical sense of the word.

The satellite beams are formed by a 1 500 element active phased-array which provides 896 uplink half-link combinations and 784 downlink half-link combinations. This system uses both left- and right-hand polarizations (LHCP and RHCP) together with beam separation to achieve full frequency re-use at acceptable levels of co- and cross-polarized intra-system interference.

A variety of user terminal antennas could be chosen to communicate through the network based on desired availability and preferred data rate. Most earth stations currently in operation use antenna sizes between 0.75 to 3.5 metres. The appropriate antenna size can be chosen to ensure the desired availability as well as to achieve the desired performance at the preferred data rate.

The overall capacity of the system is dependent on a number of factors. For example, the downlink phase array is capable of dynamically switching between spot beam or wide-area beam modes. The spot beam mode supports higher data rates than the wide-area beam mode, consequently higher capacity. However, depending on the mix of traffic that is being transmitted, the phased array can spend varying amounts of time in spot beam vs. wide-area beam coverage, and hence the system can

^{A1} The beamwidths were derived from the corresponding peak gain figures as follows:

For a dish antenna $G_m = 10 \log((4\pi)/\lambda^2(\pi D^2/4)\eta)$

where: G_m : peak gain (dBi)

D : diameter (m)

λ : wavelength (m)

η : aperture efficiency, say 0.65.

Hence $D/\lambda = (10^{0.05G_m})/(\pi\sqrt{(0.65)})$.

Also, an empirical expression for the half-power beamwidth is $\varphi_{-3} = 70\lambda/D$ degrees, so substituting for D/λ gives: $\varphi_{-3} = (177.3)10^{-0.05G_m}$ degrees.

have varying overall capacity. In general terms, the maximum overall capacity that can be achieved with the satellite is greater than 10 Gbit/s.

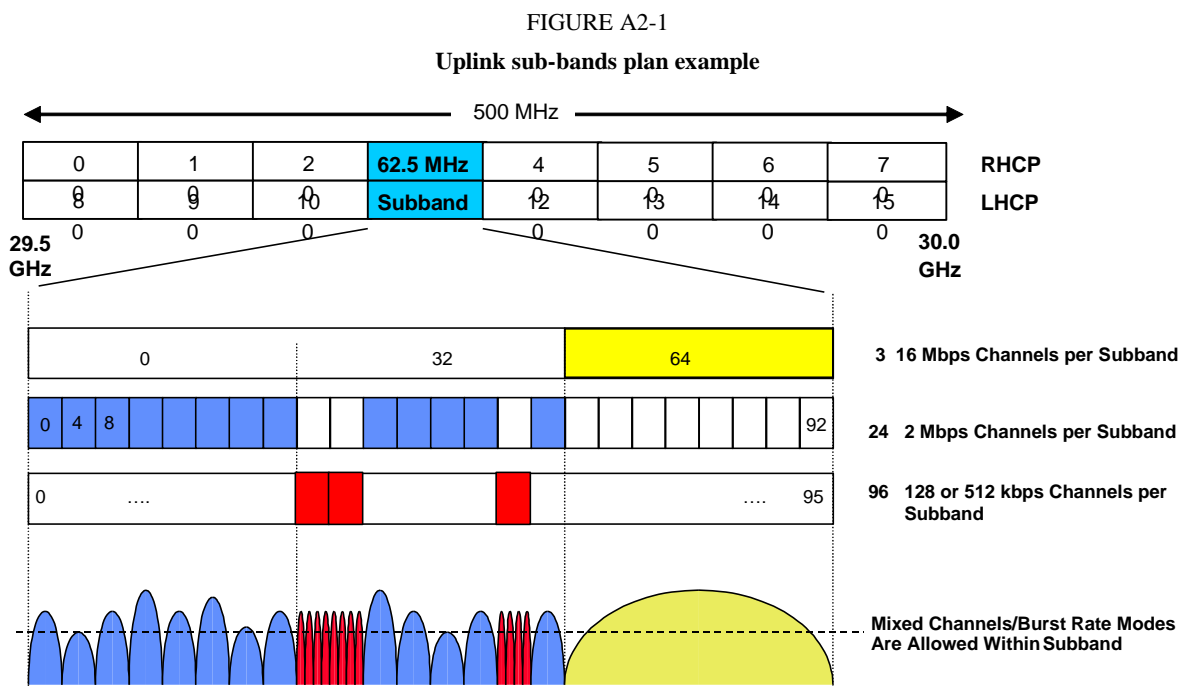
1.1 Frequency and polarization plan

The frequency bands on both the uplink and the downlink use the full FSS allocation. The entire band 29.5-30.0 GHz is received by the satellite and translated down to 19.7-20.2 GHz for re-transmission to Earth. For this satellite, the uplink and downlink transmissions are essentially separated by the on-board processor. To allow this type of operation, the uplink in each beam is FDMA/TDMA and the downlink is either hopping spot beams or a wide-area beam. As such, there are no “transponders,” in the conventional sense of the word, on the satellite.

Given that the downlink antenna used for the 19.7-20.2 GHz band is a phased array, it can produce an almost infinite number of possible beam configurations. This phased array antenna is used to produce both RHCP and LHCP transmissions and create up to twenty four simultaneous 0.5° spot beams, or a single wide-area beam. The beam polarization and placement, and the actual input channels routed to any given downlink channel or beam, can be controlled from the ground but are dictated by limitations on intra-system interference.

1.1.1 Uplink transmissions

In the 29.5-30.0 GHz frequency band, the satellite supports three uplink signal data rates of 520.83 kbit/s, 2.083 Mbit/s and 16.666 Mbit/s respectively, using an FDMA-TDMA format. Each uplink beam can access any one of up to eight 62.5 MHz sub-bands, depending on the user demand within that beam (see Fig. A2-1). Adjacent beams with the same polarization in the uplink beam grid will carry signals using separate sub-bands (see also Fig. A2-2). Once received, the uplink signals are filtered by bandpass filters centered on each of the 62.5 MHz sub-bands (or channels). The receiving system noise temperature is 650 K.



1.1.2 Downlink transmissions

For downlink transmissions in the 19.7-20.2 GHz band, each of the 24 hopping 0.5° spot beams are always operated, through an adaptive power-control mechanism. They operate at the minimum

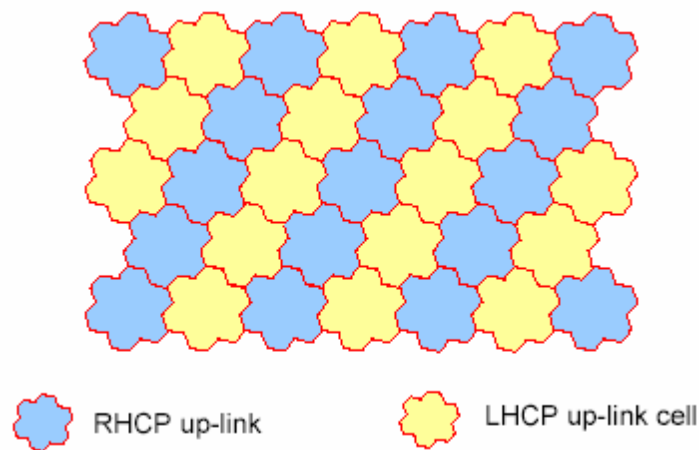
required e.i.r.p. and at beam peak to close the link at the desired performance threshold under clear and rainy weather conditions in different parts of the coverage area. A single wideband 400 Mbit/s carrier is transmitted in each beam. The beam dwells at each location only long enough to service the terminals at that location.

1.2 Antenna gain contours

1.2.1 Uplink traffic beams

In the uplink direction for the 29.5-30.0 GHz frequency range, 112 cells are created by the satellite on the surface of the Earth that are grouped in LHCP and RHCP polarized stripes as shown in the representative pattern in Fig. A2-2.

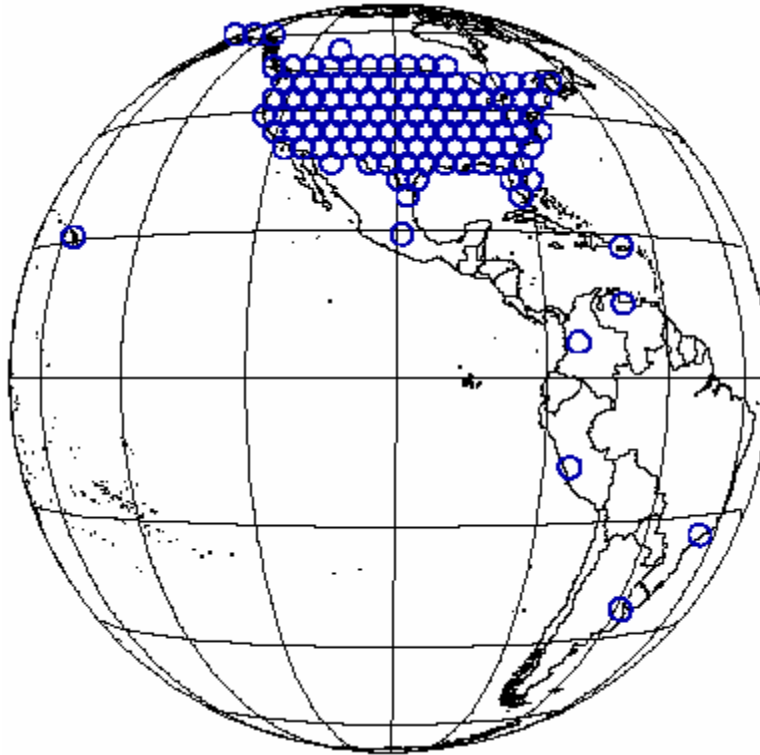
FIGURE A2-2
Representative hexagonal array of spacecraft receive beam service cells



A representative collection of spot beams used for coverage from the 94.95° W.L. orbital location is shown in Fig. A2-3. All uplink beams can be simultaneously activated at all times. Although nine of the uplink beams in Fig. A2-3 cover territory beyond that of the United States, this built in capability has not been in use.

FIGURE A2-3

Current implementation of beam use at 94.95° W.L. (Including inactive non-U.S. beams)

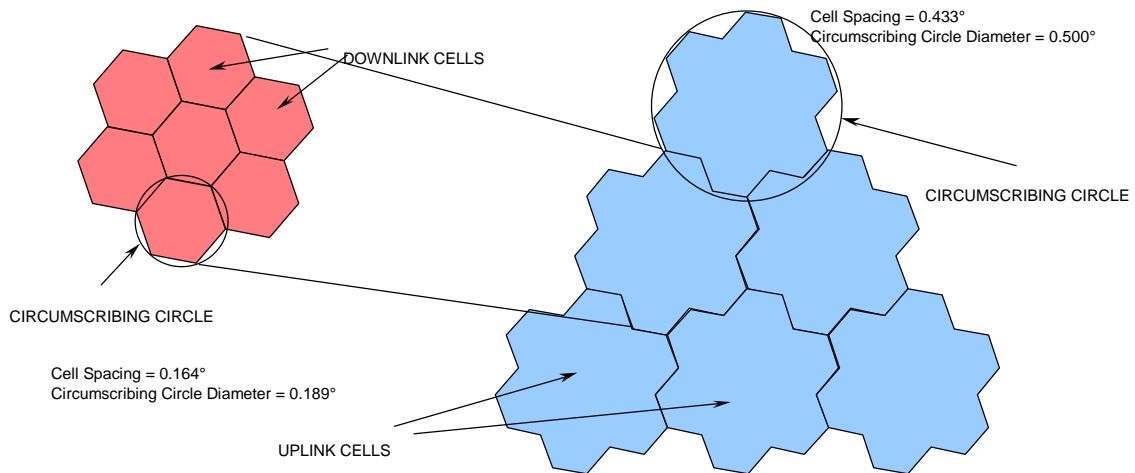


1.2.2 Downlink traffic beams

The downlink antenna for the 19.7-20.2 GHz band is a 1 500 element active phased array. Each element is driven by a solid state power amplifier module, and the modules are grouped into three maximum output power levels. This grouping was done to maximize the antenna sidelobe performance. The maximum output power for the modules at each of these three levels is 1.06, 0.45 and 0.11 watts. The active antenna will be operated so as to generate a maximum e.i.r.p. of 70.9 dBW at the center of any downlink cell and of 70.2 dBW at the edge of the cell.

The phased array antenna is extremely flexible and can be configured from the ground to create multiple 0.5° spot beams, a single wide-area beam, or virtually any beam combination in between these two extremes. In this configuration, the 0.5° spot beams will be steered towards individual cells on the Earth's surface that are spaced 0.19° apart. The downlink cells overlap and align with the coverage area of the uplink cells (see Fig. A2-4) with seven adjacent downlink cells corresponding to an uplink cell as shown in Fig. A2-4.

FIGURE A2-4

Relationship between uplink and downlink cells**1.3 Link description and performance**

Forward error correction coding will be used for all downlink communication links. On the downlink, communications links in the 19.7-20.2 GHz band have bandwidths of 167 MHz, 125 MHz and 500 MHz respectively.

The UKSAT-10 satellite network supports a variety of uplink data rates ranging from 520.8 kbit/s to 16.666 Mbit/s, applying derivatives of QPSK modulation with forward error correction coding. The associated allocated bandwidths of the communications uplinks are 651 kHz and 20.8 MHz, respectively. The supportable uplink data rate is dependent upon the size of the transmitting antenna and its associated transmitter, the rain zone, the link elevation angle, and the location of the transmit antenna relative to the gain contour of the satellite's receive beam. The uplink also benefits from the use of power control algorithms.

Tables A2-1 and A2-2 show a representative set of point-to-point link budgets. In each case, the analysis includes the effects of adjacent satellite interference in evaluating whether the system accommodates the various data rates at acceptable $C/(N+I)$ thresholds. Note that the assumed link availability is at least 99.5%.

TABLE A2-1
Uplink link budget example

Antenna	(m)	0.74	0.74
Scenario		Clear Sky	Rain
Uplink bandwidth	(MHz)	0.651	0.651
Power @ flange	(dBW)	−3.0	7.3
E/S antenna diameter	(m)	0.74	0.74
E/S antenna gain	(dBi)	45.6	45.6
e.i.r.p.	(dBW)	42.6	52.9
ATM Loss	(dB)	0.8	0.8
FSL	(dB)	213.5	213.5
Rain fade (99.5% rain Zone N)	(dB)	0	10.3
Satellite antenna gain (peak)	(dB)	50.1	50.1
Satellite antenna gain (toward E/S)	(dB)	44.6	44.6
Satellite noise temp	(°K)	650	650
Satellite G/T (edge of coverage)	(dB/K)	16.5	16.5
C/N thermal	(dB)	15.2	15.2
C/I INTRASYSTEM up	(dB)	11	11
C/I INTRASYSTEM up	(dB)	16.6	16.6
C/(N+I) Total	(dB)	8.8	8.8
Required C/(N+I)	(dB)	7.7	7.7
Margin	(dB)	1.1	1.1

TABLE A2-2
Downlink link budget example

Antenna	(m)	0.74	0.74
Scenario		Clear Sky	Rain
Downlink bandwidth	(MHz)	500	500
e.i.r.p. (Beam peak)	(dBW)	65	70.9
e.i.r.p. (Edge of coverage)	(dBW)	64.3	70.2
ATM Loss	(dB)	0.8	0.8
FSL	(dB)	210	210
Rain fade (99.5% rain Zone N)	(dB)	0	5.4
E/S antenna diameter	(m)	0.74	0.74
E/S G	(dBi)	42.1	42.1
E/S T	(°K)	225	225
E/S G/T	(dB/K)	18.6	15.8
C/N thermal	(dB)	13.7	11.4
C/I INTRASYSTEM down	(dB)	15.6	15.6

TABLE A2-1 (*end*)

C/I INTRASYSTEM down	(dB)	13.0	13.0
$C/(N+I)$ Total	(dB)	9.2	8.2
Required $C/(N+I)$	(dB)	7.7	7.7
Margin	(dB)	1.5	0.5

1.4 Spacecraft's physical characteristics

Table A2-3 summarizes the key spacecraft characteristics. The satellite is designed for a 12.6-year life once on station. The probability of the entire satellite successfully operating to that date is estimated at 0.77 with the probability for each of the bus and payload being of 0.89 and 0.86 respectively.

TABLE A2-2

Summary of UKSAT-10 characteristics

Orbital slot:	94.95 degrees West Longitude
Contract life:	12.6 years
Launch date:	14 August 2007
Payload	
Ka-band	19.7-20.2 GHz (space-to-Earth) 29.5-30.0 GHz (Earth-to-space)
Antennas	
Receive:	Multi-beam side fed offset Cassegrain antenna
Transmit:	19.7-20.2 GHz phased array, 2 meter diameter, forms multiple hopping spot or shaped beams.

Annex 3

High throughput satellite (HTS) case study: UKSAT-14

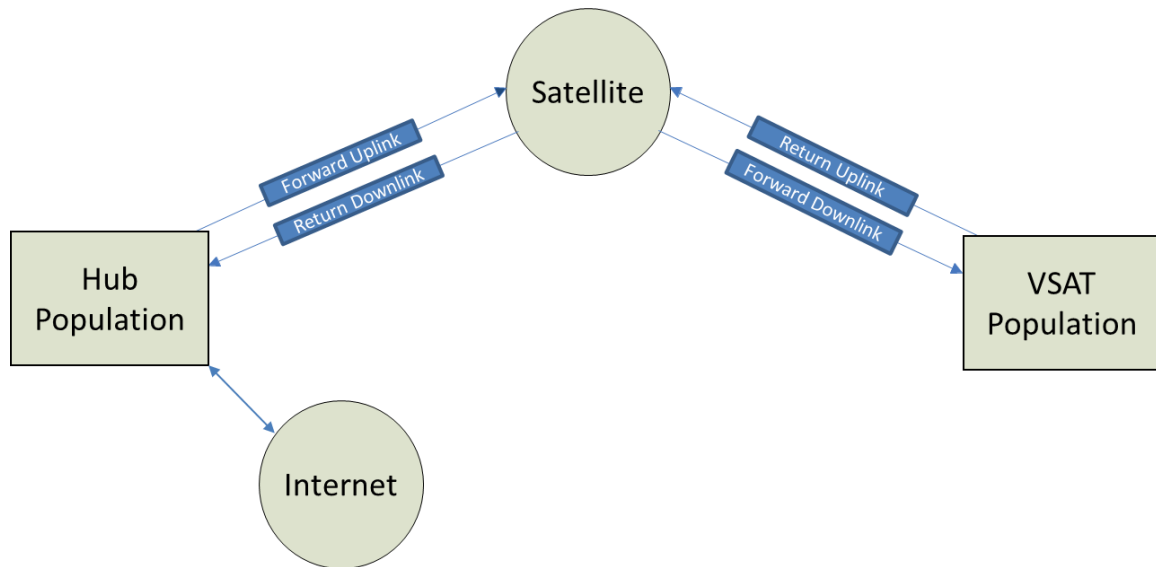
1 Introduction

In mid-2012, UKSAT-14 was launched to provide FSS in the 28.35-29.1 GHz and 29.25-30.0 GHz bands (Earth-to-space) and the 18.3-19.3 GHz and 19.7-20.2 GHz bands (space-to-Earth) primarily to CONUS, but also to parts of Canada. The services provided through this satellite network include high-speed data transmission, high definition video programming, on-demand entertainment, digital music, interactive television and high-speed Internet access, videoconferencing and high capacity two-way communications. This satellite boasts capacity in excess of 100 Gbit/s, and provides 60 spot beams operating through 15 gateway earth stations. There are also two backup gateway spot beams used to provide redundancy in the event of a failure.

The satellite utilizes a bent-pipe architecture with asymmetric forward (gateway-to-subscriber) and return (subscriber-to-gateway) links, as depicted in Fig. A3-1. Forward links consist of a single TDM 250 MHz wide carrier, while the return links use MF-TDMA with a variety of bandwidths/data rates

employed. The network uses adaptive coding and modulation to combat rain fades. That is, the modulation type, amount of coding and/or user data rate is dynamically varied to meet the link requirements during rain events. The satellite uses both LHCP and RHCP together with beam separation to achieve full frequency re-use at acceptable levels of co- and cross-polarized intra-system interference.

FIGURE A3-1
Asymmetric Bent-Pipe Architecture



1.1 Frequency and polarization plan

This satellite's frequency plan is shown in Fig. A3-2. The forward links are divided into 250 MHz channels, while the return links are divided into 125 MHz channels. Circular polarization is used on both the uplink and downlink with the downlink polarization being orthogonal to the uplink polarization. The satellite will employ a four-frequency re-use pattern such that any channel is re-used multiple times by a combination of polarization and spatial isolation.

FIGURE A3-2
Frequency Plan

