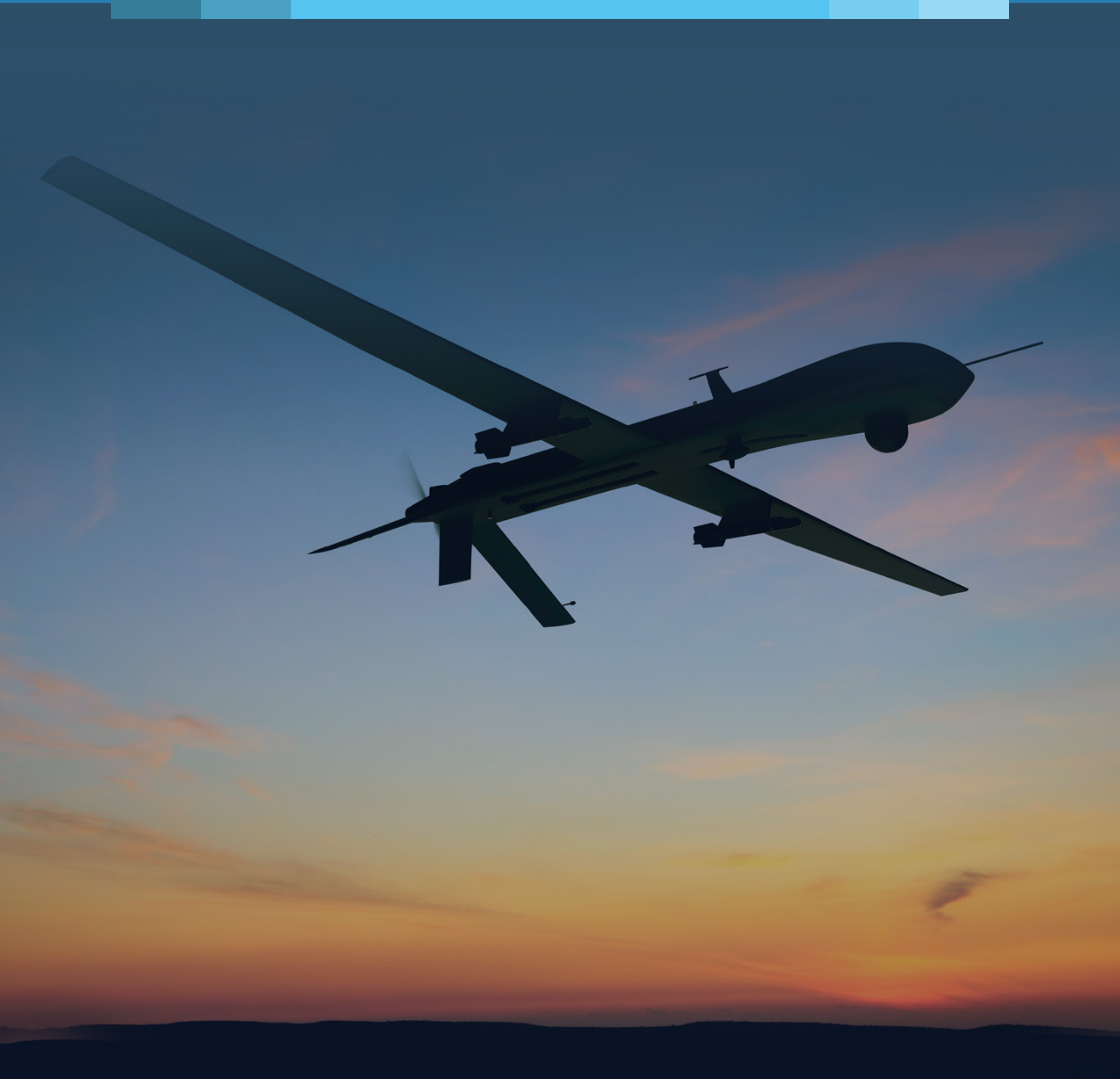
WHITE PAPER

AISR Missions on Intelsat Epic Ku-band



C4ISR

Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) systems currently rely heavily on transponded satellites, both military and commercial at X-, Ku- and Ka-bands, for missions requiring beyond line of sight connectivity. Ku-band commercial satellites are the work-horse for both manned and unmanned Airborne ISR (AISR) operations today. In the future, C4ISR systems will require higher throughput, greater protection and improved affordability to align with future mission needs, mitigate threats, and fit within budgetary constraints. Intelsat Epic satellites provide cost-effective, nextgeneration, Ku-band capabilities including spot beams, higher throughput, improved effi ciencies, and protection using existing deployed infrastructure. In this paper, the Epic architecture is described with comparisons to the legacy Ku-band systems and its application to the unique performance and mobility management needs of AISR systems. A detailed performance analysis is presented using representative AISR systems against a set of manned and unmanned mission/platform scenarios; again with comparisons to legacy Ku-band and WGS Ka-band performance. It is shown that the Epic Ku-band constellation offers unique performance and affordability opportunities for AISR missions and enables the next generation military Ku/Ka-band C4ISR infrastructure.

Introduction

A significant cost of AISR missions today is the leasing of bandwidth from commercial satellite (COMSAT) systems, including Ku-band. Going forward, DoD guidance recommends future AISR systems support both commercial Ku-band systems (legacy and future), as well as military Ka-band [1]. In this paper, we analyze and predict AISR performance on the Intelsat Epic satellite constellation, with comparisons to legacy Ku-band and Ka-band systems.

Epic is Intelsat's next generation satellite platform that delivers global high-throughput technology without sacrificing user control of service elements and hardware. The Epic platform utilizes C-, Ku- and Ka-bands, wide beams, spot beams, and frequency re-use technology to provide a host of customer-centric benefits.

Intelsat Epic

Architecture

Intelsat Epic is a series of multi-spot, high frequency re-use satellites [2]. The satellite beams are commonly referred to as User, Gateway, Wide or Spot beams. User and Wide beams utilize standard Ku-band frequencies. Gateway and Spot beams utilize C-band and alternative frequencies. Global Ka-band beams are also provided. The frequency diversity between User/Wide and Gateway/Spot beams maximizes beam coverages and bandwidth. The diversity allows placement of Gateway/Spot beams co-incident with User/Wide beams without impacting the bandwidth available in any of the beams.

Gateway/Spot beams do not have fixed connectivities to/from User/Wide beams. Via an on-board digital switch, any uplink beam, User, Wide, Gateway or Spot can be connected to any downlink beam, User, Wide, Gateway or Spot. All beam connectivity permutations are supported, including loopback. Gateway and Spot beams can be viewed as high capacity beams providing connectivity to any User or Wide beam as required.

User and Wide beams are primarily designed for use by remote terminals while Gateway beams are primarily designed for use by hub / teleport ground equipment. Although beams are tailored for expected usage, all terminal types – hub, controller, remote, etc. – can be operated in all beam types. Beam layouts for IS-33e are shown in Figures 1, 2, and 3.

Fig. 1: IS-33e Ku-band User & Gateway Beams

Fig. 2: IS-33e Ku-band Wide Beam

Fig. 3: IS-33e C-band Spot Beams

Beam to beam connectivities can be established in multiple sub-bands within the transponder's bandwidth. A beam may have multiple simultaneous connectivities. As an example, User beam #7 may have 26 MHz loopback, 26 MHz to/from Gateway #1, 13 MHz to/from Gateway #2, 13 MHz to/from another User beam, etc. Satellite operating procedures and tools are under development with the expectation that beam connectivities will change over the life of the satellite to match evolving demands.

User beam frequencies and polarizations are selected to maximize beam-to-beam isolation. Better beam isolation translates into improved received signal-to-noise ratio (SNR) and corresponding higher satellite efficiency in terms of megabits per second (Mbps) transmitted per megahertz (MHz) of satellite resource. Based upon known and expected demands, some User beams are allocated bandwidth different from nominal. To date, all beams on Intelsat Epic satellites are of fi xed location. Steerable beams have been, and will continue to be, considered.

Epic supports open architecture. Users can deploy ground platforms of their choosing, in their desired network topology (e.g. star, mesh, distributed star), across the beam connectivities already described. Open architecture also allows Users to select the data rates supported and whether their network capacity operates in a dedicated or shared manner. Ku-band was chosen for the User beams for multiple reasons:

- Large deployed base of Ku-band terminals requiring ongoing support and improved performance
- Compatibility with traditional, wide beam, Ku-band satellites to enable terminals to operate across multiple satellite platforms
- Better performance than Ka-band during rain
- Better performance than Ka-band when utilizing equal-sized spot beams [3]

Future Epic satellites may have Ka-band User beams if market demand demonstrates the need.

The multi-spot, high frequency re-use design provides inherent interference/jamming mitigation. An intentional or unintentional jammer must be within a beam to interfere. If outside the beam, the satellite's sharp beam roll-off design will provide isolation.

Additionally, beams operating in cross connect (e.g. User to Gateway) provide a lower probability of detection. Transmissions within a beam are not seen in the uplink beam but rather at the geographically distant cross connect beam. This split beam operation also enables transmissions into a User beam while adversaries are attempting to jam transmissions from the User beam.

The onboard digital switch provides another layer of interference protection. When interference is detected, the onboard switch can be configured to not propagate the interferer further. The interferer can be terminated in the satellite or it can be switched to a beam and frequencies specifically established for monitoring. As that is being done, the desired transmitter's carrier can be tuned to uplink in clear bandwidth and, via the switch, be downlinked at its original intended frequency.

Finally, in terms of protection, wider transponder bandwidths support a greater range of protected waveforms and provide greater protection performance. Epic User beam transponders are nominally wider than the 36, 54 or 72 MHz typical on legacy Ku-band satellites and the 32 MHz wide transponders on Inmarsat I-5 Global Service Beams [4].

Intelsat's Epic satellites are designed as a complementary overlay to Intelsat's existing fixed satellite network. They are not intended to replace wide beam satellites but rather augment where high capacity and high performance are needed. Epic will be fully integrated into Intelsat's existing satellite fleet and global IntelsatOne terrestrial network.

To date, commitments have been made for five Epic-class satellites and more are in planning stages. Intelsat continually evaluates and updates its fleet replenishment and enhancement strategy. Epic-class satellites are an integral tool in that process.

Legacy Ku-band Comparison

This section discusses the differences in satellite performance between Intelsat Epic and traditional, wide beam, Ku-band satellites. This section focuses on the Epic User beam performance metrics. Nominal beam edge EIRP for a User beam on an Epic-class satellite is 55 dBW. This compares to 53 dBW beam peak performance for legacy Ku-spot beams on IS-IX series satellites. Beam peak on Epic User beams is nominally 4 dB over beam edge, or 59 dBW. In other words, over the entire Epic User beam coverage area, satellite EIRP will match or exceed that provided at beam peak on legacy IS-IX Ku-band spot beams. Intelsat Epic G/T performance, similar to EIRP, compares to, or exceeds, beam peak performance of legacy satellites; across the entire User beam coverage area. Legacy IS-IX Ku-spot beams nominally provide 9dB/K G/T at beam peak. Epic User beams provide 8dB/K G/T at beam edge and 13dB/K at beam peak.

Application to AISR

AISR missions are often required to use smaller, so-called disadvantaged, satellite terminals. This need is driven by size, weight and power (SWaP) and other operational constraints. The high EIRP and G/T performance provided by Intelsat Epic satellites are very advantageous for these smaller terminals.

The higher G/T provided by Epic-class satellites, translates into higher transmission rates from existing terminals and/or less terminal EIRP per transmitted Mbps. An interesting phenomenon occurs due to Epic's high EIRP values. If a User beam transponder is operated at saturation with the power distributed evenly across the available bandwidth, typical inter-satellite coordination limits would be exceeded; i.e. Intelsat Epic's downlink power spectral density (PSD) would be excessive. Epic, of course, will not operate in such a manner.

Transponders will operate with sufficient output back off (OBO) to ensure that coordination limits are met. This has two significant implications. High downlink PSD, and its corresponding high bps/Hz throughput is provided without having to purchase extra MHz or power equivalent bandwidth (PEB). Secondly, this high downlink PSD is provided without operating the satellite transponder in a non-linear mode. This is particularly beneficial when the links employ higher efficiency, amplitude phase shift key (APSK) modulations.

AISR Systems and Technology

AISR satellite networks are typically characterized by high-throughput return links (remote to hub) and lower throughput forward links (hub to remote). This network architecture is opposite the more conventional Internet/surfi ng or video distribution models. Consequently, SATCOM engineering for AISR systems requires special considerations, especially for the return link. Return link data rates of interest range from 1 to 20 Mbps for most systems, with 10 Mbps being of particular interest as it allows transport of high-definition full motion video, HD 720p, along with other platform/mission traffic. AISR systems can be reasonably divided into manned and unmanned variants.

Manned AISR Systems

Manned AISR systems are typically commercial airframe systems with special equipment sets supporting the ISR collection and dissemination. The airframe often limits the antenna size. 30 to 45 cm diameter, reflector-based, antennas are common for smaller platforms such as Gulfstream and King Air. Larger airframe platforms can support up to 1m antennas and lowprofile, phased-array antennas are common. Manned systems often have larger forward link throughput requirements, as traffi c includes both ISR data as well as other IP-based services, including voice and data.

Unmanned AISR Systems

A variety of countries maintain fleets of unmanned AISR systems. For the US DoD inventory, satellite capabilities are common on Tier III and IV UAS [5] with 30cm up to 1.2m diameter antennas being common. Example terminals include the L-3 Communications Ku-band SATCOM data link Predator Reconnaissance System [6]. Return link data traffic is typically sensor data, including Full Motion Video (FMV), while forward traffic is primarily platform command/control. Future sensors and missions will demand more return link throughput, at lower costs. Migration to align with future COMSAT architectures is critical [5].

AISR Waveforms

A variety of AISR satcom waveforms are currently in use. For purposes of this paper, we focus on the DVB-S2 waveform specified in [7] for both forward and return link operations and in an SCPC network confi guration. US DoD is migrating to common waveforms [5] and DVB-S2 has been a high interest item [8, 9, 10] due to its capacity approach, performance and affordability considerations as a COTS technology.

AISR Performance Over Epic

Intelsat Epic Performance and Comparisons to Legacy Ku-band Satellites

To analyze Epic performance, link budget analyses (LBAs) were performed using expected performance for IS-33e, a satellite presently under construction. All links have a 7.3m hub antenna in a Gateway beam communicating with a remote terminal located in a User beam. Both forward carrier (to the remote terminal) and remote carrier (from the remote) are DVB-S2 [11].

Table I. Remote Terminal Parameters

Antenna Size (m)	Performance	
	Tx Gain (dB)	Rx G/T (dBi/K)
1.20	42.5	19.8
0.76	39.1	15.7
0.45	34.5	11.0
0.30	31.0	8.0

LBAs were completed for remote terminals ranging from 30 cm to 1.2m in diameter; located at beam center and beam edge. Performance parameters of the remote terminals are shown in Table I.

LBAs were done for sample carrier sizes with allocated bandwidth (BW) equal to power equivalent bandwidth (PEB) – which provides optimal satellite effi ciency - unless constrained by off-axis emission limits. For the confi guration analyzed, offaxis emissions limited transmissions for terminals smaller than 76cm. The LBA results can be scaled to a desired carrier size and/or a desired satellite resource allocation.

Typical AISR terminal antennas range from 30cm to 1.2m. Return link performance for those antenna sizes, at beam center, is detailed in Tables II below. Table II shows results for both (a) constant 10 Mbps transmission rate and (b) constant 4.1 MHz of satellite resources.

Table II. AISR Terminal Performance on Intelsat Epic

Resources for 10 Mbps Transmit on Epic			
Antenna Size (m)	Tx EIRP (dBW)	HPA (Watts)	Satellite Resources (MHz)
1.20	47.9	3.5	4.1
0.76	47.9	8.8	4.1
0.45	46.4	17.5	7.6
0.30	42.4	15.5	9.5

Transmit Rates with 4.1 MHz on Epic			
Antenna Size (m)	Tx EIRP (dBW)	HPA (dBW)	Terminal Transmit Rate (Mbps)
1.20	47.9	3.5	10.0
0.76	47.9	8.8	10.0
0.45	43.7	9.4	5.4
0.30	38.7	6.7	4.3

Table III details the DVB-S2 modulation and forward error correction (FEC) coding achieved in both sections of Table II. The corresponding satellite effi ciencies are also provided.

Table III. Intelsat Epic Efficiency With 7.3M Hub

Return Link Efficiency on Epic		
Antenna Size (m)	DVB-S2 Modulation, Coding Rate	Satellite Efficiency (bps/ Hz)
1.20	16APSK, 4/5	2.44
0.76	16APSK, 4/5	2.44
0.45	QPSK, 5/6	1.31
0.30	QPSK, 2/3	1.05

Note that the results in Table II are determined assuming operation at the maximum possible satellite efficiency, i.e. with highest aggregate Mbps per transponder. Higher throughputs are possible - for an individual terminal EIRP - by utilizing less satellite-efficient modulation and coding rates.

The transmit EIRP values in Table II are 1 dB over normal LBA results to compensate for an assumed 1 dB radome loss. HPA sizes in Table II assume a 0.5 dB loss between HPA output and antenna fl ange. If a terminal's Tx EIRP capability is different from that shown in Table II, the data rate and satellite resources can be scaled accordingly. The satellite effi ciency will remain the same.

The high G/T on Intelsat Epic satellites leads to multiple efficiency gains for AISR terminals. First off, the high G/T results in lower terminal EIRP and corresponding lower offaxis emissions. Due to this, carrier spreading is not required when transmitting from a 45cm or 30cm terminal on Epic. This differs radically from traditional Ku-band satellites which typically require 2 to 4 times spreading for, respectively, 45cm and 30cm antennas. The lack of spreading on Epic translates directly into bandwidth savings for the User. Additional savings are realized when more effi cient modulations and coding are utilized; e.g. QPSK, 5/6 listed in Table III instead of the QPSK, that is typical today.

A second efficiency gain derives from the fact that transmissions from 76cm terminals and larger can readily operate at maximum satellite effi ciency on Intelsat Epic i.e. operate with occupied MHz equaling PEB. This is due to their EIRP capabilities and off-axis isolation. With these effi ciencies, any 76cm or larger terminal, capable of 53 dBW EIRP, can uplink up to 40 Mbps on Epic at beam center and 8 Mbps at beam edge.

Table IV describes maximum return link capacities at beam center and beam edge on Intelsat Epic for a range of terminal EIRPs. As in Table II, the values in Table IV are achieved while operating at maximum satellite bps/ Hz efficiency. Also as before, for a given EIRP, higher throughputs are possible, up to transponder bandwidth limits, but at the cost of lower satellite efficiency.

Table IV. Intelsat Epic Efficiency With 7.3M Hub

Maximum Tx Rate on Epic		
Terminal EIRP (dBW)	Beam Center Tx Rate (Mbps)	Beam Edge Tx Rate (Mbps)
50	20	4
53	40	8
56	81	16
59	161	32
62	237	65
65	237 1	29

A common terminal size for airborne satellite communications is 45cm (18 inch) with maximum transmit EIRP of 44 dBW. On existing Ku-band satellites, this terminal typically achieves 1.0 to 1.5 Mbps transmission rates while occupying, respectively, 5 MHz and 7.5 MHz, due to spreading. These are nominal beam edge / beam center values. On Intelsat Epic, performance improves to 4 Mbps in 4 MHz at beam edge and 7.6 Mbps in 5.5 MHz at beam center. This is a fourfold increase in transmit bit rate with a simultaneous 20% decrease in satellite MHz.

Intelsat Epic Performance Comparisons to Ka-band Systems

From [1], future AISR systems will likely support commercial Ku- as well as military Ka-band satellites (i.e. WGS). In [7], analysis was performed showing link performance of WGS and legacy Eutelsat Ku-band, focused on the benefi ts of the DVB-S2 ACM properties. In this section, we update the analysis to include AISR terminals and the Intelsat Epic satellites. Link budgets parameters for the Ka-band system are taken from [12].

Table V compares Intelsat Epic and US DoD Wideband Global SATCOM (WGS) Ka-band performance for representative AISR systems. Link performance parameters, in terms of availability and bit error rate, are kept constant. As done earlier, two comparison scenarios are explored: one showing bandwidth resources required for a fi xed 10 Mbps data rate and a second showing the data rate possible with a fi xed 4.1 MHz of satellite resource. With higher G/T versus legacy Ku-band, Epic offers equal to superior performance to WGS Ka-band in all cases.

Table V. Epic Ku-band vs. WGS Ka-band Return Link

Resources for 10 Mbps Transmit on Epic and WGS Ka-band				
Antenna Size (m)	Ku-band Tx EIRP (dBW)	Epic Satellite Resources (MHz)	Ka-band Tx EIRP (dBW)	WGS Ka-band Satellite Resources (MHz)
1.20	47.9	4.1	53.7	7.7
0.76	47.9	4.1	53.7	7.7
0.45	46.4	7.6	53.7	7.7
0.30	42.4	9.5	51.6	25.1

Transmit Rates with 4.1 MHz on Epic and WGS Ka-band				
Antenna Size (m)	Ku-band Tx EIRP (dBW)	Epic Maximum Data Rate (Mbps)	Ka-band Tx EIRP (dBW)	WGS Maximum Data Rate (Mbps)
1.20	47.9	10	51.1	5.3
0.76	47.9	10	51.1	5.3
0.45	43.7	5.4	51.1	5.3
0.30	38.7	4.3	43.7	1.6

The results in Table V are for the following conditions:

- Ka-band terminal EIRP is the power-controlled value optimized for aggregate transponder capacity (1.2m, 0.76m, 0.45m) or as limited by off-axis energy constraints (0.30m)
- Ka-band Satellite performance from [12]
- Modem implementation loss assumed at 1 dB @ BER = 1e-8
- DVB-S2 with . = 0.25
- Availability = 99% ITU-Model 7 with terminal @ 30k feet altitude

Conclusions

UAS roadmap documents [1] identify commercial Ku-band SATCOM as an essential part of current and future AISR systems. In this paper, we extend the results from [3] to identify the opportunities with the Intelsat Epic satellites to improve UAS performance and AISR missions. We identified a 4x transmit data rate improvement for existing AISR terminals on Intelsat Epic compared to wide beam legacy Ku-band satellites. On Epic, existing small AISR terminals are enabled to 7.6 Mbps transmissions and large larger terminals up to 237 Mbps. A comparison was also made to WGS military Kaband capabilities, showing that Epic offers equal to better performance than WGS across a range of terminal sizes. Based on the analysis shown here, future AISR mission performance will be much improved using Epic and WGS Ka-band over legacy systems.

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About Intelsat General

Intelsat General Communications (IGC) is a wholly owned subsidiary of Intelsat, the foundational architects of satellite technology. IGC provides government customers with mission-critical mobility communications solutions that include managed services with flexible pricing plans. From remote military outposts and disaster-recovery sites to U.S. embassies and homeland-security agencies, IGC solutions support and enable some of the most complex government applications. As the only commercial satellite operator with an independent third-party Service Organization Control (SOC 3) cybersecurity accreditation, Intelsat is uniquely positioned to help its government customers build a secure, connected future.

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