ABSTRACT
Since the designation in the 1970's of a military satellite communications Ka-band (30-31 GHz uplink, 20.2-21.2 GHz downlink), these frequencies have held great potential to support U.S. forces and requirements. In 1995, the Ka band was chosen for the Global Broadcast Service (GBS) which will be operational on the UFO satellites beginning in 1998. However, only a small percentage of the allocated 1 GHz of bandwidth will be used by GBS. During the recent MILSATCOM architecture reviews, the Ka band was again considered for the Advanced Wideband System (AWS) and the Gapfiller satellites. This paper will discuss the potential uses of the Ka band for the AWS and Gapfiller satellites. Included will be a technical discussion of the potential applications for both tactical and fixed infrastructure requirements in the 2005-to-2010 timeframe.

Overview
Information is essential for successful military operations. This has become evident with the initiation of programs including the Navy's IT-21, the Army's digitization of the battlefield and other DoD information technology programs. By 2010, the DoD has projected a worldwide need to serve ~1.8 Gbps of traffic between fixed user sites that must be satisfied by DoD MILSATCOM. This level of traffic is more than 3 times the current fixed user traffic served by the DSCS III system. An even larger growth factor for tactical (transportable user) traffic is projected. Based on the highest levels of tactical user traffic which was carried by DSCS satellites during Desert Storm in 1992, a more than 50-fold increase, ~6.6 Gbps is currently projected by 2010 for the two major theater of war scenario (MTW).

The DoD is planning to accommodate these large growth factors by expanding the current X-band (DSCS) capabilities into a combined X and Ka-band system known as the Advanced Wideband System (AWS). Because the current DSCS III constellation will not last significantly beyond the 2004-2006 period, an interim system capability, known as the Gapfiller system, will be used to provide service during the phase out period of the DSCS III satellites until the AWS becomes available. One of the purposes of this paper is to explore options for the Gapfiller use of the Ka-band; i.e., which users, tactical, or fixed, (or both) are best served by Ka-band and by which types of terminals and satellite elements.

Tactical Use of Ka Band
To keep the cost of the Gapfiller within a limited budget, the likely solution will be a geostationary satellite system that complements any residual DSCS III satellite assets for tactical use. Fixed service may be complemented by packages on other systems. One option being considered is a package on the replenishment TDRS satellites planned for launch in the early 2000's.

Potential trade space for the Ka-band services include: (1) determine if onboard satellite processing is required or whether a simple transponder based system is adequate, (2) should AJ protected services be offered at Ka-band, (3) whether sufficient AJ protection is available through spread spectrum (frequency hopping, PN or hybrids) alone, or whether antenna spatial processing would be required.

The next-generation Army tactical wideband earth terminal, STAR-T, will be deployed in support of Echelons above Corps (EAC). The Army is considering the addition of the Ka band to the STAR-T terminals. STAR-T's are...
now in Limited Rate Initial Production (LRIP) with full production planned for the early 2000's. LRIP versions will be configured with C, X and Ku bands. The C-band would be removed and replaced with Ka, making the terminal an X, Ku, Ka capability. An obvious advantage is the extensive bandwidth (1 GHz) available at Ka. This potentially could help satisfy the 6.6 Gbps of tactical traffic. An analysis was conducted to examine the supportability of requirements at Ka band using a modified STAR-T terminal.

Assuming the STAR-T aperture size, the transmit HPA size (in watts), and the coverage area of the satellite remains the same (i.e., the same beamwidth for the satellite receive antenna), then moving to Ka-band increases the terminal antenna gain by $F^2$. The free space loss also increases by the same factor, i.e., the net power received by the satellite remains the same under clear sky conditions. However, the uplink margins that must be added due to rain absorption and scattering effects increases from approximately 2.5 dB at X-band, to more than 12.5 dB at Ka-band thereby requiring almost 10 dB more transmit HPA power at Ka-band. This 10 dB increase in terminal HPA power for Ka-band operation can be avoided by reducing the satellite coverage area by a factor of ~3.3 and thus achieving a 10 dB increase in satellite receive antenna gain. Thus, to base the required terminal HPA power simply on the uplink performance in thermal noise and rain, we can expect to need a ten times larger terminal HPA at Ka-band or we must be willing to sacrifice the satellite coverage to be less than 1/3 of the coverage at X-band.

**Payload Design**

Currently there is no specific design for the Wideband Gapfiller satellite. At this point in the process, the government has a Gapfiller concept to support trade studies and costing activities. The actual design will ultimately be determined by competing contractor proposals based upon government performance requirements. The following discussion contributes to the ongoing dialogue on potential design implementations. Subsequent analysis is based upon an unstressed design with no consideration of jamming effects. The first aspect to be examined is the design of the Ka payload. Currently, the Gapfiller concept is a transponder system. Commercial ventures such as Teledesic® and Spaceway® are considering a processed payload. These systems are investigating on-board processing to reduce the size and cost of customer earth terminals while providing user services in the 10’s of Mbps, and system throughput in the 10’s of Gbps. The current STAR-T has a single HPA for C, X, Ku band transmission and is approximately 10% of the earth terminal cost. To maintain the same link availability and achieve data rates in the range of 5 to 20 Mbps, the required Ka band HPA could be 30-50% of the earth terminal cost. Reductions in satellite coverage at Ka-band may be avoided by the use of onboard processing (demodulation/remodulation). Results of a technical trade between processed and transponder payload for the STAR-T requirements are shown in Figure 1.

![Figure 1](image)

As can be seen, the coverage area has a dramatic impact on the earth terminal HPA size for the transponder approach. Coverages larger than 1.5° require HPAs in excess of 200 watts which become increasingly expensive. The processed approach places more complexity in the payload, but permits a significantly smaller HPA for the same coverage area. Equivalent relatively low cost HPA's would require a 1.5° beam for transponder and a 3° beam for processed. Hence, broader coverage is permitted in the processed payload option. Since Gapfiller is cost and risk constrained and must be on-orbit by 2004, on-board processing is not considered likely. For this reason the use of 0.5-1.5° beams is being postulated for tactical Ka-band services on the Gapfiller satellites. It should be noted that a 0.5° beam corresponds to a subsatellite circular coverage of only 200 miles. Therefore to cover a large portion of the earth will require a large number of beams. As an example, the current DSCS III uplink antenna has a 61-port multiple beam antenna (MBA) that covers the earth field of view by using 61 2.2 degree beams. Use of 0.5 degree beams would require nominally 20 times this number of beams $(2.2/0.5)^2$ to provide full earth field of view at Ka-band, so the complexity and cost of such an
aperture could be a significant cost driver. A compromise between total coverage area, beam size, and number of beams is possible to develop a middle ground solution. Several such solutions have been postulated within the government's architecture working groups. Typical solutions have considered 7 to 37-beam apertures with beam sizes of 0.5 to 1.0 degrees with a total coverage ranging from 2.5 - 5.0 degrees diameter per antenna and up to two gimbaled 19-beam MBA’s (gimbaled to point the antenna anywhere within the earth field of view).

**Tactical Anti-jam Design**

Previously, the discussion was oriented toward an unstressed approach. The 1 GHz of bandwidth for that approach would be used for high throughput for tactical users. An alternative use of the Ka bandwidth would be for protection against jamming through the use of spread spectrum techniques. An analysis was conducted to determine the value of the Ka band in a stressed environment to support tactical users. Two different approaches were proposed and studied. The first employs a simple satellite uplink antenna which would not offer any discrimination against a jammer. In this approach the processing gain of the spread spectrum provides the sole means of protection against the interference. The second incorporates a nulling uplink antenna. Both approaches use a transponded channel and the Universal Modem (UM) operating in the orthogonal hopping mode.

**Nulling Design**

The following assumptions were used for the analysis:

- Army ACUS requirements (Network of 36 STAR-T modified terminals)
- Theater coverage (2 degree)
- 70 dBW (back off to 67 dBW), 30.5 G/T, UM (orthogonal hopping)
- 200 MHz saturated channel at Ka-band with 50 dBW satellite EIRP
- Single jammer either COTS (76 dBW) or Technology (84 dBW)
- Closest user either 100 or 200 mi. from jammer
- Average user either 200 or 300 mi. from jammer

With the user-jammer separation in the range of a few hundred miles, a satellite aperture size of 6 feet was selected. To cover a theater of 2°, a 37-beam MBA was postulated. Figure 2 displays the performance of the selected antenna design. With the closest user terminal approximately 100 miles from the jammer, the graph shows a minimal loss of 2 dB user gain while maintaining 28 dB of discrimination. The average distance user of 200 miles suffers no loss of gain and maintains 29 dB of discrimination. These values were then used to estimate the individual user terminal performance and the total throughput of the Ka transponder. Figure 3 depicts the results of the channel loading.

Results are displayed for the closest user, average user, and total throughput for the 200 MHz, 50 dBW channel. Link data rates decrease by 33% when a COTS jammer attacks the channel. With nulling applied against a COTS jammer, link rates are reduced by 17% for close-in users and virtually unchanged from benign rates for the average-distance user. The technology jammer has a significant effect on link rates and the total throughput without nulling. Reductions are a factor of 6 for both close-in and average-distance users. As with the COTS jammer results, nulling against the technology jammer is very effective.
Link rates for close-in users are reduced by 17% with no changes in link rates for the average-distance user.

**Tactical Ka Summary**
From a tactical user perspective, the Ka band has significant potential. It has been shown that to minimize earth terminal cost and expand theater coverage, a processing payload is advantageous and should be considered for the AWS. For transponded service, uplink antenna coverage should be designed to approximately 1.5° beams. This implies that multiple apertures or an MBA are required to cover a tactical theater. Nulling is very effective, but implies complexity and cost. For a reasonable cost-limited design offering some degree of protection, Ka transponders with spread spectrum is adequate for a COTS level jammer.

**Fixed Wideband Use of Ka**
DISN and other high data rate networks are essential for warfighter support. Primarily this provides reach-back to the sustaining bases, imagery, and intelligence data. These communities require 1.8 Gbps worldwide throughput. New fixed wideband Ka terminals would be required for this service. To provide for a transition capability, yet permit flexibility for future use of commercial wideband offerings, the number and size of any new Ka terminals should be kept to a minimum.

**Fixed Wideband Design**
As with the tactical design, similar payload and earth terminal trades are applicable to the fixed requirements. However, since the link rates are substantially higher, a processed payload will not be considered in this paper. To maintain the current availability to customers with a 30/20 GHz system, the uplink and downlink margins are in the range of 12.5 and 6.5 dB respectively. These and other key parameters were defined for an analysis to determine the effect of coverage area on required earth terminal HPA size. Again as with the tactical analysis, HPA size is a significant contributor to earth terminal cost.

Figure 4 shows the results of the investigation with 2° beams a reasonable solution. Earth terminal antenna size is also important in determining performance on the uplink and downlink. A limited industry survey concluded 30 GHz antennas larger than 8 meters may be cost prohibitive for a transition wideband system. For connectivities between 2 degree beams, a 400 W HPA will support approximately 45 Mbps during the worst case fade (12 dB fades), but the rates will be adapted using ATM multiplexer technology and adaptive modem technology to support at least 155 Mbps per HPA under clear sky conditions (a residual 7 dB uplink margin). Although power control of the terminal HPA will not be performed, the satellite will rely on limiters to maintain a constant downlink power level. The downlink can be power controlled or simply operated with a fixed margin and with reliance on the ATM and modulator rate adjustment to accommodate any downlink fades that exceed the available downlink margin.

**Fixed Ka Service Summary**
A 3° coverage area requires a 1KW HPA or larger depending upon the signal loss from the HPA to the antenna feed horn and required back-off for quasi-saturated operation. Cost of an HPA of this size could be extremely high. Therefore, a 2° coverage area is recommended. From a downlink perspective, a 45 Mbps link requires approximately 15 linear watts of satellite power in a 2° beam.
Ka Band Conclusion

A number of areas have been examined regarding the application of the Ka band for military wideband satellite communications. For tactical applications, processed payloads have significant advantages for reducing earth terminal cost. With transponded payloads, coverages must be in the order of 1.5° to minimize earth terminal HPA size; therefore, use of multiple apertures or an equivalent MBA coverage are required. Use of the Ka bandwidth with spread spectrum and no nulling can afford tactical users an adequate degree of protection against COTS jammers. For fixed wideband service, two-degree coverages are recommended and multiple uplink antennas will be required to supply sufficient coverage. Additional study is recommended to review these preliminary results and explore other system parameters to include the waveforms to be used with the Ka tactical and fixed services.