

A System Architecture for an Advanced Canadian Wideband Mobile Satellite System

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ABSTRACT

In this paper, the system architecture for an advanced Canadian ka-band geostationary mobile satellite system is described, utilizing hopping spot beams to support a 256 kbps wideband service for both N-ISDN and packet-switched interconnectivity to small briefcase-size portable and mobile terminals.

An assessment is given of the technical feasibility of the satellite payload and terminal design in the post year 2000 timeframe. The satellite payload includes regeneration and on-board switching to permit single hop interconnectivity between mobile terminals. The mobile terminal requires antenna tracking and platform stabilization to ensure acquisition of the satellite signal.

The potential user applications targeted for this wideband service includes: home-office, multimedia, desk-top (PC) videoconferencing, digital audio broadcasting, single and multi-user personal communications.

INTRODUCTION

Both the development of experimental ka band satellite systems, such as Olympus and ACTS [1], and the conceptual studies of advanced future systems [2] has produced designs that offer satellite services to support a variety of user applications. These range from narrowband (handheld) personal communications to wideband B-ISDN trunking and supercomputer linkup. Coupled with this is the study of new payload and terminal technologies such as on-board processing, multiple spot beam antennas, and intelligent terminals to enhance the utilization of the ka-band.

The successful application of all this technology is however critically dependent on the market forces for the various different communications services that will, or perhaps more correctly, that are foreseen to exist in the post 2000 timeframe. Consideration must be given to the implementation, by that time, of both the LEO type narrowband personal systems, and the possible widespread deployment of the terrestrial B-ISDN fibre optic network. It is perceived that a commercial opportunity may exist, in between these two applications, for an advanced wideband mobile satellite communications service, although the expansion of cellular bandwidths cannot be dismissed. The use of the ka-band, however, is in any case an advantage to satellite systems for "above the clouds" applications such as an aeronautical service.

In this paper, one possible conceptual approach to the design of such a wideband mobile satellite system is presented. It begins with a discussion of the overall system architecture followed by sections on both payload and terminal design. Some aspects of these designs, in particular the mobile terminal are currently only at a preliminary stage. The concepts reported here are part of a continuing overall study effort for the Canadian Department of Communications, carried out by a Spar led team of Canadian aerospace industry to develop an advanced ka band satellite mission.

SYSTEM ARCHITECTURE

The overall architecture of the advanced mobile satcom system comprises ka band service links and a ku band backhaul and private business network. The services supported on the ka band system include the single-user land mobile, fixed or portable USAT, and an aeronautical service. The performance and key link parameters for these are given in Table 1. The ka band system utilizes a 0.5 degree and a 2.3 degree hopping spot beam coverage for the land mobile and

aeronautical services respectively, while the ku band backhaul/business network operates with four fixed beams. The land mobile and fixed services are constrained to Canadian coverage only, and the aeronautical service is extended to all of North America including Mexico for continuity of transborder service.

Table 1. Service Parameters

Services	Avail %	BER	Info Rates (kbps)	# DL TX	# Beams
Single-User Mobile	99	10 ⁶	16-256	7	84
Fixed/Portable USAT	99.5	10 ⁶	16-E1		
Aeronautical	99.9	10 ⁶	16-E1	1	12
Fixed ku VSAT	99.9	10 ⁷	E1	4	4

The payload is a baseband regenerative type, providing the advantages of signal regeneration and full single-hop interworking of services and interconnectivity of terminals. An MF-TDMA primary uplink access supports information rates in increments of 16 kbps upto to the maximum carrier transmission rates. In addition, a key objective of this on-board processing design is to permit the greatest flexibility of bandwidth usage approaching that of a bent-pipe transponder in some respects. As such, the system will allow operation of various terminal sizes with different transmission rates required to support narrow (16 kbps) to wideband (T1, E1) source traffic.

The sizing of the conceptual design presented here, is based on market studies for the post 2000 timeframe previously carried out by others. The terminal populations for each service is given in Table 2 below. The aeronautical population is by user, and essentially only considers Canadian air traffic. The trunk rate indicated represents the average information rate utilized by a terminal with a 5% grade of service and a traffic intensity of .01 Erlangs/user.

Table 2. Service Populations

Services	Trunk Rate (kbps)	#Trunks/hop (fix) beam	Pop./hop (fix) beam	Tot Pop.
Single-User Mobile	64	16	1154	8078
Fixed/Portable USAT				
Aeronautical	64	16	1154	1154
Fixed ku VSAT	E1	8	156	624

Single-User Mobile Service

This service, as its name indicates, is envisaged to support a single land mobile user with information rates upto 256 kbps. It also supports fixed/portable (but stationary during use) USAT applications that can operate at higher rates with larger terminals than is possible with mobiles which require antenna tracking and mobile power supplies.

The coverage for this service, comprising 84 spot beams which are organized in groups of 12 and served by 7 hopping TDM downlink carriers, is shown in Figure 1. The link budgets are given in Table 3 with notes regarding link parameters and assumptions. The budget also includes a 1 dB allowance for an adjacent satellite interference case produced by a "same satellite system" spaced about 8 degrees away. The system supports both mobile-to-base and mobile-to-mobile communications.

Table 3. Land Mobile Link Budget

Link Parameters		Forward: Base-to-Mobile		Return: Mobile-to-Base	
Description	Units	Uplink	Downlink	Uplink	Downlink
Frequency	GHz	14.0	20.0	30.0	12.0
TX Antenna Diameter	m	1.8	2.4	0.3x0.1	1.0
TX Antenna Gain ¹	dBi	46.2	43.3	34.0	29.5
Transmit Power	dBW	7.9	15.0	9.8	14.2
No. of Spots ²	Spots	4	84	84	4
EIRP	dBW	54.1	58.3	43.6	43.7
Space Loss (39500 km)	dB	207.3	210.4	213.9	206.0
RX Antenna Diameter	m	1.0	0.3x0.1	1.8	1.8
RX Antenna Gain	dBi	31.0	32.0	44.7	44.9
G/T	dB/K	2.2	6.2	16.6	20.7
Transmission Rate ³	kbps	1870.0	1500.0	364.0	13800.0
C/No Thermal	dB-Hz	77.6	81.2	74.9	84.9
Off-axis angle ⁴	deg.	2.0	8.0	8.0	2.0
Adjacent Sat Interference	dB	83.4	87.0	80.8	91.2
C/No Unfaded	dB-Hz	76.6	80.2	73.9	84.0
Sat Pointing Loss	dB	0.2	0.5	0.5	0.2
Atmos Loss	dB	0.2	1.0	0.8	0.2
Ground Pointing Loss	dB	0.2	1.0	1.0	0.2
Multipath Loss ⁵	dB	0.0	3.0	3.0	0.0
Availability	%	99.95	99.5	99.5	99.95
Ottawa Rain Fade ⁶	dB	5.1	3.1	3.0	3.8
Polarization Loss	dB	0.1	0.5	0.5	0.1
System Margin	dB	1.0	1.0	1.0	1.0
Faded C/No	dB-Hz	69.7	70.0	64.1	78.6
Faded Eb/No	dB-Hz	7.0	8.3	8.5	7.0
Demod Impl. Margin	dB	1.5	1.5	1.5	1.5
Non-linearity degrad ⁷	dB	0.0	0.0	0.2	0.0
Ideal Eb/No ⁸	dB-Hz	5.5	6.8	6.8	5.5
BER faded		8.8x10 ⁻⁶	8.4x10 ⁻⁶	6.4x10 ⁻⁶	8.8x10 ⁻⁶
Maximum BER faded		6.4 x 10 ⁻⁶		6.4x10 ⁻⁶	
Overall Availability	%	99.45		99.45	
		Two-way: Mobile-to-Mobile			
		6.4x10 ⁻⁶			
		99.0			

Notes:

- Mobile TX gain is reduced by 1.0 dB for radome and rotary coupler and satellite gain is reduced by 1.5 dB for RF filter/coupling. Mobile antenna is 30 x 10cm microstrip patch array. Ka band satellite antenna is focus fed reflector with single horn per spot beam.
- For ku band, 4 fixed beams and for ka band, 84 spots in hopping beam groups of 12.
- RF transmission rate for a four phase modulation with rate 1/2 FEC convolutional coding and overhead for burst synchronization, symbol timing, and routing headers.
- Off-axis angle is the adjacent satellite separation.
- Multipath loss includes fading and shadowing in a mobile environment.
- Rain fading for the Ottawa location, with a 3 dB uplink countermeasure gain using adaptive forward error correction (AFEC) and 1/2 information rate reduction.
- Non-linearity degradation for mobile uplink using an offset continuous phase modulation (OQPSK, MSK) operated with a class C saturated Impatt device.
- Ideal Eb/No includes Viterbi soft decision decoding and differential detection for mobile terminals, and coherent for fixed base station terminals.

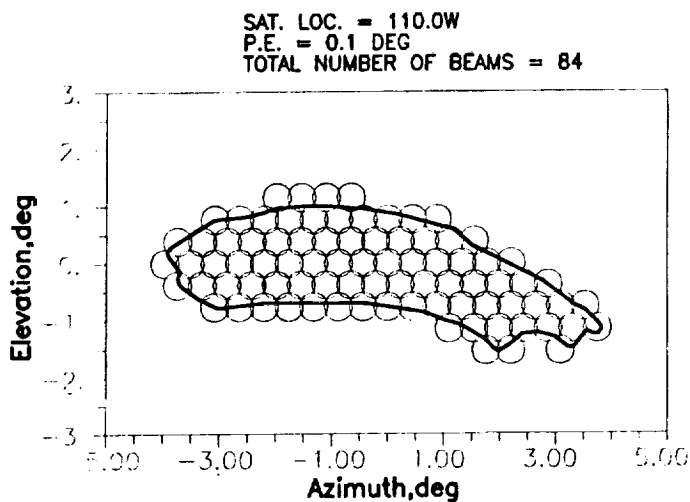


Figure 1. Land Mobile Coverage

The terminal is envisaged as essentially a vehicular unit that can either be directly used inside the vehicle or serve as a relay unit by being remotely accessed via a user to terminal air interface. The terminal consists of a 30 cm x 10 cm microstrip patch that mechanically tracks the satellite in azimuth, and transmits 10 w of RF power. Further details are discussed in the terminal design section below.

Aeronautical Service

The aeronautical service is essentially an airborne version of the land mobile service with some key differences as follows. The terminal requires doppler compensation due to aircraft motion and greater tracking capability in both elevation and azimuth. Since this service is offered to an inherently multi-user form of transportation, a higher time multiplied multi-user source information rate is expected.

The coverage for this service, comprising 12 spot beams, served as a group of 12 by one hopping TDM downlink carrier, is shown in Figure 2. As noted previously, an all North American coverage is assumed. The link budgets are given in Table 4 along with notes regarding additional or different items to the land mobile service. The key differences include no allowances for rain fade, multipath, or atmospheric losses. This effectively permits the use of an aeronautical terminal, similar in size to the land mobile, but operating with 12 larger spot beams compared to the 84 spots required to support land mobile.

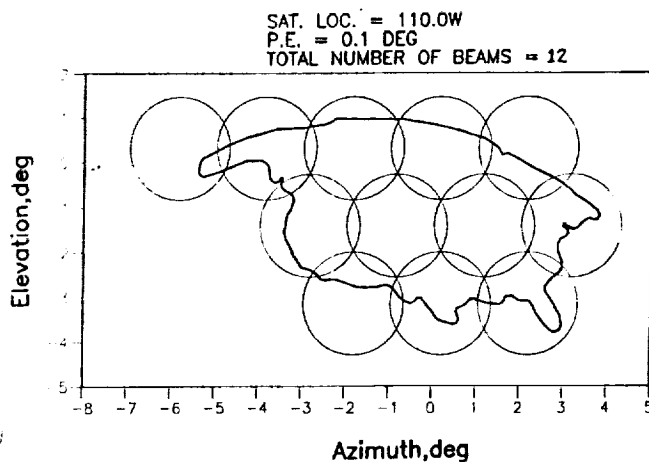


Figure 2. Aeronautical Coverage

Table 4. Aeronautical Link Budget

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Transmit Power	dBW	7.9	15.0	10.5	14.2
No. of Spots ²	Spots	4	12	12	4
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Space Loss (39500 km)	dB	207.3	210.4	213.9	206.0
RX Antenna Diameter	m	1.0	0.3	1.0	1.8
RX Antenna Gain	dBi	31.0	33.7	34.4	44.9
G/T	dB/K	2.2	7.8	5.6	20.7
Transmission Rate	kbps	1870.0	1500.0	364.0	13900.0
C/No Thermal	dB-Hz	77.6	74.0	68.1	84.9
Off-axis angle	deg.	2.0	8.0	8.0	2.0
Adjacent Sat Interference	dB	83.4	79.8	73.9	91.2
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Sat Pointing Loss	dB	0.2	0.2	0.2	0.2
Atmos Loss	dB	0.2	0.0	0.0	0.2
Ground Pointing Loss	dB	0.2	0.5	0.5	0.2
Multipath Loss ³	dB	0.0	0.0	0.0	0.0
Availability	%	99.95	100.0	100.0	99.95
Ottawa Rain Fade ⁴	dB	5.1	0.0	0.0	3.8
Polarization Loss	dB	0.1	0.5	0.5	0.1
System Margin	dB	1.0	1.0	1.0	1.0
Faded C/No	dB-Hz	69.7	70.8	64.9	78.5
Faded Eb/No	dB-Hz	7.0	9.0	9.0	7.0
Demod Impl. Margin	dB	1.5	1.5	1.5	1.5
Non-linearity degrad	dB	0.0	0.0	0.2	0.0
Ideal Eb/No	dB-Hz	5.5	7.5	7.6	5.5
BER faded		8.8x10 ⁻⁶	6.1x10 ⁻⁶	8.9x10 ⁻⁷	8.8x10 ⁻⁶
Maximum BER faded		8.8 x 10 ⁻⁹		8.9x10 ⁻⁷	
Overall Availability	%	99.95		99.95	
Notes:					
1. Mobile TX gain is reduced by 1.0 dB for radome and rotary coupler and satellite gain is reduced by 1.5 dB for RF filter/coupling. Mobile antenna is 30 cm microstrip patch array. Ka band satellite antenna is focus fed reflector with single horn per spot beam.					
2. For ku band, 4 fixed beams and for ka band, 12 spots in one hopping beam group of 12.					
3. Multipath loss is assumed zero for aeronautical service due to antenna directivity.					
4. Rain fading assumed zero for operation above clouds at cruising altitude.					

PAYLOAD DESIGN

The overall payload design consists of four main subsystems: the 84 and 12 beam ka band, the 4 beam ku band, and the On-Board Processing (OBP) systems. The OBP ties all subsystems together through a TST type of switch fabric that provides packet-switched interconnectivity of user traffic segmented into satellite data packets with self-routing headers.

As shown in the block diagram of the ka band payload in Figure 3, the other elements of the payload include single horn per spot beam antennas with a low noise receiver per horn. The uplink is, however, not hopped, so a filter/switch matrix maps the uplink carrier usage of a group of 12 spots corresponding to a hopping downlink group. In this way the uplink MF-TDMA bandwidth is shared over 12 spot beams to match the equivalent TDM downlink capacity which is hopped over 12 spot beam positions comprising the downlink group. The signal received from a group is bulk demultiplexed, demodulated and decoded by a Multi-Carrier Demodulator (MCD). This output enters the space switch through a T (Time or memory) stage port. The overall switch is a 6 x 6, which includes 2 ka band ports, one for each system, and four ku band ports.

The RF power subsystem approach selected for this conceptual design utilizes saturated TWTA's feeding dedicated downlink carriers per hopping beam group. An alternate approach, which is the subject of on-going studies, utilizes a hybrid matrix power system with linear SSPAs.

Table 5. Payload Mass and Power Estimate

Subsystem	Mass (kg)	Power (Watts)
84 Beam Ka Band	143	1250
12 Beam Ka Band	40	185
4 Beam Ku Band	75	130
OBP Switch	29	213
Total	287	1778

The key determining system-level factor in the evaluation of these two approaches is the degree of flexibility that is likely to be required in matching the satellite RF power to the instantaneous traffic distribution. The latter approach is inherently flexible in achieving this but currently has the significant technological disadvantage of the low DC power efficiency (10 %) of linear ka band SSPAs.

For the TWTA approach a DC power efficiency of about 40 % is achievable [3]. The critical aspect for this approach, however, is the selection of the spot beams comprising a hopping downlink group. The selection of the spots for a particular group are not necessarily physically contiguous, in fact the main criteria for spot selection is to ensure that the overall network traffic is as evenly distributed over the downlink TDM carriers, thereby maximizing the power utilization of the satellite. Mass and power estimates for this payload approach are given in Table 5 above. This payload size can be accommodated on a GE5000 bus for example.

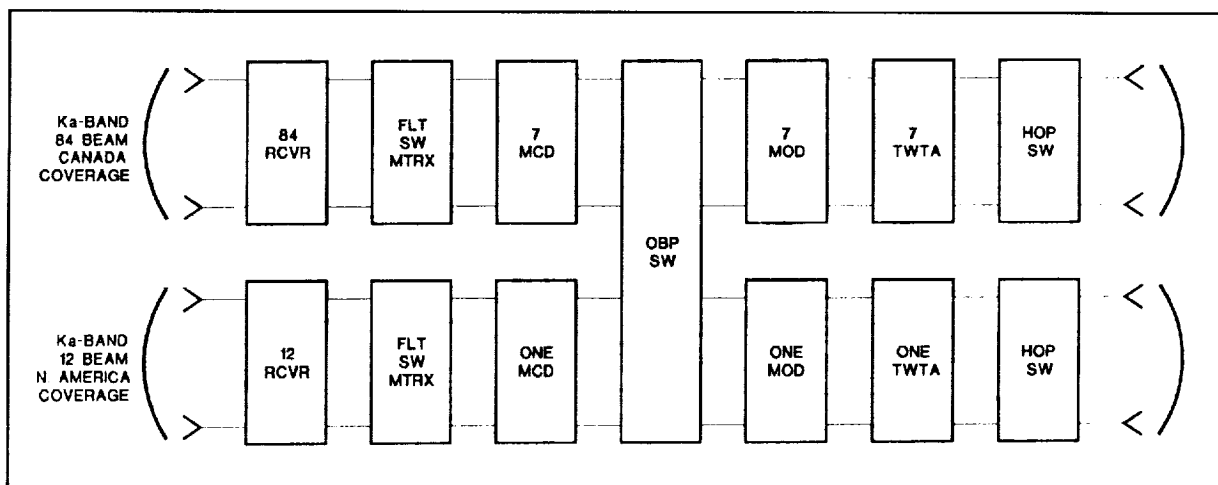


Figure 3. Ka-band OBP Payload

TERMINAL DESIGN

Earth Terminal Types

The focus of terminal design has been on mobile types, both vehicular and aeronautical. However the mobile satellite can support services to fixed terminals such as home office, multimedia and larger terminals for business applications. The former type are downgradable to the latter in terms of antenna tracking and acquisition capabilities and upgradable in terms of antenna size and terrestrial interface capabilities.

The key areas in the terminal design are:

- selection of antenna types
- selection of acquisition and tracking approach
- frequency control
- flexibility of terrestrial interface
- low cost approach

Antenna Design

The use of reflector type or microstrip patches are most attractive for mobile and small fixed terminals, although other approaches are possible - such as the use of dielectric lenses and slot arrays. Reflector types are compact and have high efficiency but have high cost. Microstrip arrays are adopted for the mobile application because of low cost and tolerable efficiency.

The best approach to signal acquisition and tracking is to employ patches with a relatively large beamwidth in elevation so that only the azimuth need be scanned and tracked [4].

A patch with dimensions 30 cm. by 10 cm. produces sufficient gain (about 34 dB) and elevation beamwidth (10 deg.) for the mobile application. A 10 deg. beamwidth in elevation is sufficient to allow for vehicle pitch, but a manually-adjustable elevation setting is used to adapt the antenna orientation to a particular geographical area. Separate patches are required for 30 GHz transmit and 20 GHz receive signals.

For azimuth signal acquisition a DC stepping motor is used to slowly scan until the FFT in the electronics package has detected a downlink signal. A dither approach to antenna tracking combined with vehicle motion sensors is then employed. In the probe approach to beam scanning, each spot is visited every 24 msec., equivalent to less than a meter distance travelled by the vehicle. The dither applied to the antenna moves it alternatively to either side of the estimated line of sight to the satellite and measures the signal strength of the probe signal, thus determining the pointing error's size and polarity. The 3.5 degree beamwidth at 20 GHz imposes a tight requirement for pointing accuracy and tracking which may limit the degree of motion instability which can be tolerated. This is being further studied. A completely electronic approach to scanning using phased arrays is judged to be cost ineffective - a complete transmit/receive array may cost up to \$4000.0 if the cost of phase shifters is included [5].

Terminal Architecture

The block diagram of the terminal is shown in Figure 4. This depicts the mobile version; for the fixed version the antenna controller and motion sensors are not present. The terrestrial interfaces are modular and

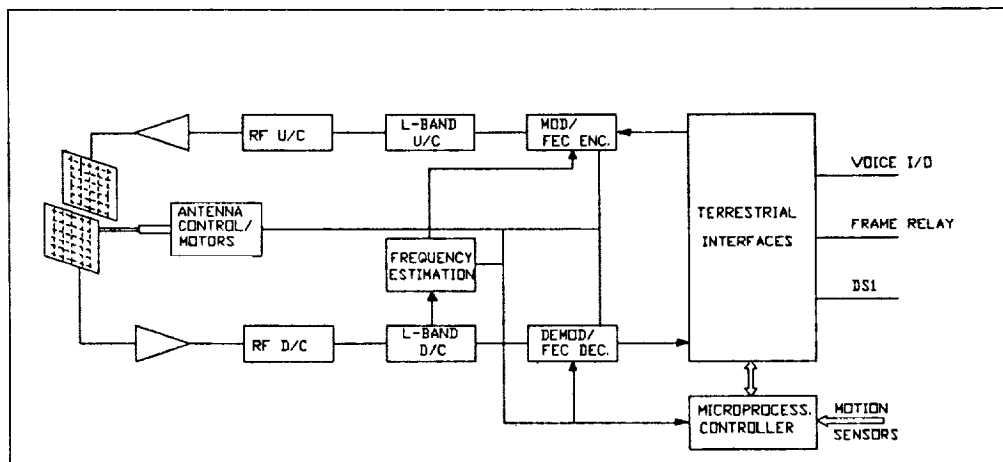


Figure 4. Terminal Architecture

adaptable to a variety of traffic types; voice and modest rate video for multimedia applications (up to 256 kbps), up to 2.048 Mbps for larger fixed antennas.

The transmit data stream is rate-1/2 encoded (this coding is removed in the satellite and the downlink is re-coded). A continuous phase modulation (MSK, OQPSK) is used to reduce sidelobe regeneration and distortion due to saturation non-linearities. The uplink is transported in a TDMA frame. The transmitter is a maximum 10 watt Impatt device operated as a class C amplifier to maximize the DC power efficiency.

Should the quality of the downlink signal degrade due to a rain fade which is larger than the allocated margin, the receiver can decide to signal the corresponding transmitter to reduce its data rate by a factor of 1/2, and add an extra level of coding. This level of coding passes through the regenerating transponder without processing.

The downlink signal is in TDM form and is received with a G/T of approximately 7.9 dB (in the absence of rain). A two stage downconverter is used to process the signal to the IF level. Since the downlink signal is not continuous, but may consist only of a probe that is brief in duration, a special frequency estimator is used to minimize acquisition time. This consists of a FFT spectral estimator package. The estimator continually acquires multipoint DFT representations of the signal. It includes software to assess the DFT data and to estimate frequency errors. Frequency changes are expected to occur at a slow rate compared to that of the software execution.

All elements of the terminal are expected to be amenable to year 2000 volume production techniques. For example 1 watt 30 GHz SSPAs (11% efficiency) were available 5 years ago and it is expected that low cost 10 watt units will be available in less than 10 years.

CONCLUSION

This paper has presented an overview description of conceptual studies focusing on a particular approach to the system architecture of an advanced ka band mobile satellite system. The motivation for this approach is to suggest an architecture that 1) might reasonably be achieved in the immediate post 2000 timeframe involving a minimum of new development items, and 2) provides a satellite service that could effectively handle user applications requiring wideband mobile services.

The utilization of a saturated TWTA power system onboard the satellite and mechanical tracking of the terminal antennas are considered less challenging and

costly, at least in the immediate future, than the hybrid matrix approach and electronic steering of the terminal antenna. Significant development items, including the OBP switch and antenna systems, however, do remain to be fully achieved and demonstrated.

The overall feasibility of such a system that provides a wideband mobile service, particularly land mobile, does in general critically depend on the technical requirements for the acquisition and tracking of a relatively high gain terminal antenna. Through experiments such as the ACTS land mobile terminal, the feasibility and development of these type of terminals in a ka band propagation environment can be tested and demonstrated.

However, in addition to the significant technical work that needs to be done, further effort is required to identify and estimate the market potential for one or a range of user applications that could be commercially successful using an advanced ka band satellite system.

ACKNOWLEDGEMENT

The conceptual design reported in this paper has been supported by the continuing study work to define an advanced ka/ku band satcom mission for the Canadian Government Department of Communications.

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