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A SYSTEM STUDY OF REQUIREMENTS FOR SHF/EHF-TERMINAL PHASED-ARRAY ANTENNAS

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E. Barry Felstead, Claude J. Bélisle and Gilbert A. Morin

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ABSTRACT

There is much current interest in the use of phased-array antennas for military satellite communications terminals. These antennas present definite advantages over conventional dish antennas, such as electronic steering capability, conformal surface potential, and graceful degradation. In view of the potential of phased arrays, CRAD initiated an R&D project, as part of the Military Information and Technology Infrastructure (MITI) thrust, to provide advice on issues such as performance benefits, potential technical improvements, implementation issues, and potential market niche areas. In this report, this process is initiated by generating a set of specifications for the development of such phased-array antennas. Five types of terminals are analyzed, namely: EHF manpack, EHF airborne, EHF land transportable, multi-band vehicle mounted, and multi-band shipboard. For the five strawman applications, performance specifications such as EIRP, G/T, etc. are provided.

RÉSUMÉ

Il y a beaucoup d'intérêt en ce moment dans les antennes réseaux à commande de phase pour les terminaux militaires de communications par satellites. Ces antennes offrent des avantages importants par rapport aux antennes paraboliques: contrôle électronique du pointage des faisceaux, surfaces conformales, et dégradation progressive. Etant donné le potentiel élevé des antennes réseaux, DRDD a mis en marche un projet de recherche à l'intérieur du vecteur de "Technologie de l'Infrastructure Militaire de l'Information (TIMI)" afin de développer l'expertise nécessaire non seulement dans les domaines techniques mais aussi dans l'identification des marchés à créneaux. Dans ce rapport, le processus est amorcé par l'élaboration de spécifications pour le développement d'antennes réseaux. Cinq types de terminaux ont été étudiés:

1. terminal portatif à onde millimétrique,
2. terminal aéroporté à onde millimétrique,
3. terminal transportable au sol à onde millimétrique,
4. terminal multi-bande pour véhicule,
5. et terminal multi-bande maritime.

Pour les cinq types, les performances habituelles au niveau système ont été fournies.

EXECUTIVE SUMMARY

For future DND satellite communications, a major stumbling block is in the antennas. There are antenna problems related to size, mass, location, utility, versatility, multi-band capability, and multi-beam capability. Each of the three services has its own set of problems.

For maritime applications there is a great competition for antenna space and considerable RF interference between the various radar, navigation, ESM, and communications systems. Also, there is a problem with the weight of some dish antennas since they have to be supported high on masts or suspended well out from the superstructure. Finally, multi-band and multi-beam capabilities are important.

For airborne applications, the problems relate to disturbance of the aerodynamics and the fact that it is undesirable to put holes in the skin of the aircraft. Furthermore, mass and volume are an obvious problem especially on high performance aircraft.

For land operation, some implementation problems arise from the need for multi-band and multi-beam operation. There are also problems with set up time for transportable terminals, and antenna size for manpacks. Communications "on-the-move" is made difficult because of antenna problems.

Phased-array antennas are thought to be a possible solution to some of these antenna problems. Considerable effort is being expended by Allies in phased-array antennas, especially in the US and the UK.

Because of the potential of phased-array antennas for satellite-communications earth terminals, it was decided to develop a capability within DND in this area. Before embarking on work on actual antenna components, it was decided to do a system study to determine the terminal types that should be considered and the associated performance specifications. The results are the subject of this report.

Five strawman terminal types were selected from relatively simple to very difficult to achieve. These five are listed in Table ES1. The first three applications are in the military EHF band and are listed in increasing order of complexity. The last two applications are set up so that there is a good level of commonality on the tri-band portion so that solutions on one contribute to the others.

For the five strawman applications, performance specifications such as EIRP, G/T, etc. are provided. The range of antenna applications is clearly far wider than could be covered by limited CRAD resources. Nonetheless, it was felt necessary to

present the range of possible applications for a subsequent architecture study. There, the scope of the work will be narrowed to focus on applications that a) have a highest priority in DND, b) can be solved with the resources available, c) fit best within the R&D capabilities of DREO/CRC, and d) have the best chance of making a contribution or establishing a niche area.

TABLE ES1. Phased-array antenna applications, bands supported and some features.

Application	Bands supported	Features
EHF manpack	Military EHF (44/20 GHz)	Low data rate, stationary mount
EHF airborne	Military EHF (44/20 GHz)	Low profile, perhaps conformal
EHF land transportable	Military EHF (44/20 GHz)	Wider band, fast set up, migration to "on-the-move"
Multi-band vehicle mounted	"Tri-band": Commercial C (6/4 GHz) Military X (8/7 GHz) Commercial Ku (14/12 GHz)	Wider band, simultaneous multi band and multi beam, fast set up, compact design, migration to "on-the-move"
Multi-band shipboard	"Five-band": Commercial C (6/4 GHz) Military X (8/7 GHz) Commercial Ku (14/12 GHz) Military EHF (44/20 GHz) Commercial Ka & military GBS (30/20 GHz)	Wide band, simultaneous multi-band and-multi beam, novel deployment

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1. INTRODUCTION

For future DND satellite communications, a major stumbling block is with the antennas. There are antenna problems related to size, mass, location, utility, versatility, multi-band capability, and multi-beam capability. Each of the three services has its own set of problems.

For maritime applications there is a great competition for antenna space, considerable RF interference between the various radar, navigation, ESM, and communications systems. Also, there is a problem with the weight of some dish antennas since they have to be supported high on masts or suspended well out from the superstructure. Finally, multi-band and multi-beam operation are important.

For airborne applications, the problems relate to disturbance of the aerodynamics and the fact that it is undesirable to put holes in the skin of the aircraft. Furthermore, mass and volume are an obvious problem especially on high performance aircraft.

For land operation, some implementation problems arise from the need for multi-band and multi-beam operation. There are also problems with set up time for transportable terminals, and antenna size for manpacks. Communications "on-the-move" is made difficult because of antenna problems.

Phased array antennas are thought to be a possible solution to some of these antenna problems. Considerable effort is being expended by allies in phased-array antennas, especially in the US and the UK.

In view of the potential of phased arrays, CRAD initiated an R&D project, as part of the Military Information and Technology Infrastructure (MITI) Thrust, to provide advice on issues such as performance benefits, potential technical improvements, implementation issues, and potential market niche areas. In this report, this process is initiated by generating a set of specifications for the development of phased array antennas for military satellite communications terminal applications in the SHF and EHF frequency bands. Five types of terminals are analyzed, namely: EHF manpack, EHF airborne, EHF Land transportable, multi-Band vehicle mounted, and multi-band shipboard.

In this report, the five strawman applications are presented and discussed. Then, the system-level requirements for each application will be given. Such requirements as, EIRP, G/T, scanning, and sidelobe levels will be determined.

2. STRAWMAN APPLICATIONS

In this Chapter, the five strawman applications are discussed in general. In subsequent Chapters, the specifications will be provided.

2.1 EHF MANPACK TERMINAL

This application of a phased array is to an EHF (20/44 GHz) manpack terminal. This terminal is designed to be carried by troops and is meant for low data-rate communications. Communications is to be established from a fixed position, but extension to operation on the move should be considered. Phased-array antennas are proposed here to perform the fine-steering operation, and thereby reduce the weight. Motor driven gimbaled steering over the narrow fine-steering range would be replaced by electronic steering. An extension to wider-angle steering would make communications on the move possible.

Manpack terminals in the EHF band already exist but they use dish antennas rather than phased arrays. The SCAMP and ASCAMP terminals, built for the US Armed Forces, are examples. These terminals must be set up on solid ground for operation as they use gimbaled dish antennas. In [1], a variation is proposed wherein the dish antenna of an ASCAMP terminal is replaced by a multi-faced phased array. In this configuration, the manpack would be mounted on a back pack and it would be possible for the operator to be walking or moving while communicating.

2.2 EHF AIRBORNE TERMINAL

There is a push to have satcom on *all* USAF air craft including fighters [2]. Clearly, dish antennas are not viable on a fighter. Phased arrays are particularly attractive for airborne applications because it is possible to make them with very low profile and thereby reduce the effects on the aerodynamics. It was decided that the airborne application of a phased array to be studied here would be to an EHF terminal.

The airborne application is particularly challenging because of some air-specific requirements. One is the need for a low profile antenna to minimize the aerodynamic effects. This becomes particularly important on fighter aircraft. Preferably, the antenna should also follow the contour of the aircraft skin (sometimes referred to as "conformal" antenna). Another is the need for as small a hole in the skin as possible through which to feed the antenna. The large scan angles [2], [3], and motion also make an airborne application a considerable technological challenge.

In past airborne satcom terminals, above UHF, radomes have been placed on the aircraft. The RAF Nimrod, for example, had a gimballed dish antenna placed in the tail wing. These are obviously not valid solutions for fighter aircraft. The use of phased arrays could eliminate the need for radomes, because of their conformal structure potential. At the same time the effects on the aerodynamics would be reduced. Fast electronic steering, without mechanical movement, could also provide a solution to the rapid steering needed by airborne applications.

In [3], EHF phased-array antennas are studied for airborne applications, and good progress is made on development. However, the estimated production costs are still high, in the order of $500 k (US) per 44/20-GHz pair. Nonetheless, there can be some over riding operational requirements that would justify such an expenditure. In [2], it is predicted that the combined cost of both 44 and 20 GHz arrays for aircraft should drop to less than $300 k (US). There are certainly areas in which cost reduction can be made as pointed out in [3]. Also, work at CRC has produced approaches that could result in cost savings. Therefore, in any subsequent architecture study, some effort should be made to propose approaches that will reduce cost.

2.3 Land-Transportable EHF Ground Terminal

The land-transportable application is a vehicle-mounted EHF terminal that will support multi-channel low data rate (LDR) and medium data rate (MDR) communications [4]. Such a terminal could be used for Army tactical applications as well as Canadian Forces (CF) strategic applications [5]. The standard dish antenna for such a terminal is to be replaced by a phased array.

Land-transportable terminals have and are being developed for the U.S. Army. Their SCOTT transportable terminals were capable of handling only LDR communications. Their newer Secure, Mobile, Anti-Jam, Reliable Tactical Terminal (SMART-T) terminals [6] support multi-channel LDR and MDR. Such terminals are typically transported on a HMMWV, and operated from a fixed position. They cannot be operated in a mobile mode.

Land-mobile Ka-band antennas have been demonstrated with the ACTS satellite [7]. Therefore, a mobile capability in bands close to military EHF have already been demonstrated. Finally, it is seen below for tri-band terminals, the US Army is pushing toward "on-the-move" vehicle mounted capability. Therefore, it is proposed that the initial application be to fixed operation with the potential to migration to on-the-move operation.

2.4 Multi-Band Vehicle-Mounted Ground Terminal

The need to take advantage of both military and commercial satellites has led to a proliferation of "tri-band" terminals. In [6], there are at least eleven tri-band terminals described of varying size and capability. They are listed under various names and forms including the "fly-away" form. The one thing in common is that they all support C-, X-, and Ku-band satcom. A case for such tri-band terminals is well made in [8] from both a US and a NATO perspective. Furthermore, the CF is obtaining 17 transportable long-range communications terminals (TLRCT) [5] for both strategic and tactical purposes along with two gateways. These are for mid-term goals. The terminals are designed for C, X and Ku band operation with at least half of them having the complete set of tri-band hardware.

There is effort being expended in the US on developing phased arrays for army applications. These are transportable and vehicle mounted such as on a HMMWV. One configuration uses a cube with phased arrays on five sides. Others use pyramid shapes. The US Army CECOM at Fort Monmouth has supported a number of such phased-array projects including JUNIPER and NOMAD. From [9] it is noted that NOMAD has "demonstrated 3-beam capability at S and C band" and that JUNIPER has "two full duplex beams at X band and extensibility to Ku." They both have "Rugged HMMWV mounted design for instantaneous communications." The difference between the two is primarily in the frequency range covered. NOMAD has an "instantaneous" bandwidth of 1.5 to 6.5 GHz (S and C bands), and JUNIPER has an "instantaneous" bandwidth of 7 to 10.5 GHz (X-band plus). It is not clear what "instantaneous" means in this instance. The overall objective is to have full hemispherical multi-mission coverage with multi-beam capability, and eventually have "on-the-move" capability. However, very little is known about the details of these antennas. In any event, it is clear that the US is pursuing phased arrays that operate as close to tri band as possible, and with multiple beams.

In view of the above considerations, it was decided to make this phased-array application to the tri-band at the C, X, and Ku bands. Since there would be little advantage in going to phased arrays if separate antennas were used for each of the three bands, it was decided to propose tri-band operation with one antenna. Furthermore, it is recommended that the antenna be capable of simultaneous multi-band and multi-beam operation. Finally, it is suggested that the antenna be capable of on-the-move operation. A benefit of such a capability is that it would contribute to the commonality with shipboard antennas to be discussed below.

2.5 MULTI-BAND SHIPBOARD TERMINAL

There is a considerable problem on navy ships in finding suitable locations for all the competing antenna systems [10]. For satcom, ship motion makes fast steering over a wide angle mandatory. In order to achieve such steering with the traditional dish antenna, a large volume away from other parts of the ship, and with a good line of sight to the satellite are needed. To get the line of sight, two or more antennas are usually required. A radome is usually necessary. Such requirements are usually difficult to meet. Also, more than one satcom band is often required. As discussed in [10], phased array antennas deployed on numerous flat surfaces available could ameliorate the severe real estate problems.

The issue now arises as to which bands to support. There are many competing needs for shipboard satcom. There is mid-term need for tri-band capability as evidenced by the purchase of such TLRCT terminals for the CF [5], some of which are destined for the Navy. There will be need for EHF milsatcom for both LDR and MDR [5]. There seems to be a lower priority assigned to Ka-band capability. However, there is considerable interest in the commercial world for numerous existing Ka band (e.g. ACTS) systems, as well as upcoming wideband data systems such as Teledesic and Astrolink that would have good military application. There is also much activity in the Ka band for the US and UK Navies for the Global Broadcast System (GBS). For example, from [11] it is stated "... will introduce operation of the broadcast system through a 20 GHz downlink, will initially be in place in April 1998 with the first launch of a US Navy UHF Follow On (UFO) satellite (flight 8) with a GBS payload package." Finally, there is already much activity within CRC on Ka-band satcom. Although they are developed for commercial satellite systems, they have been operated with the US military in two exercises to date (Global Yankee (96), and Global Apache (97).

In view of the above considerations, it was decided to make this phased-array application to five bands which are military EHF, tri-band (C, X, and Ku), and Ka band. The EHF antenna will have commonality with the land transportable EHF antenna but with more severe steering requirements. The tri-band antenna will have commonality with the multi-band vehicle-mounted antenna. The only thing that is completely new is the Ka band.

3. EHF MANPACK TERMINAL

3.1 GENERAL

In this Chapter, a set of specifications is provided for the EHF manpack terminals to be operated under the communication data link standard MILSTD 1582C. Therefore, only low data rate (LDR) communications, from 75 b/s up to 2.4 kb/s is required. The FEP or Milstar are examples of satellites that would support such a terminal. The specifications are drawn partly from information obtained from the SCAMP and FASSET ground terminals. A summary of the specifications is shown in Table 3.1. A discussion on the rationale for some of the specifications is also given.

3.2 POINTING, ACQUISITION AND TRACKING (PAT) CONSIDERATIONS

3.2.1 Downlink Spatial Acquisition and Tracking Considerations

For a MILSTD 1582 compatible terminal, the spatial acquisition and tracking is done with the aid of downlink sync hops. Usually, there are four stages in the process: initial pointing, coarse acquisition, fine acquisition, and tracking. The proposed acquisition and tracking approach is based partly upon the ASCAMP system. Since only limited information was available on the acquisition and tracking used in ASCAMP, this limited information was combined with information on the method used for the FASSET ground-terminal antenna [13], [14].

For ASCAMP, initial pointing uses mechanical steering based upon compass, level, geo-location, and ephemeris information. The uncertainty of such initial pointing is ±10° in azimuth, and only ±0.25° in elevation [12]. For FASSET [13], [14], after initial pointing, coarse acquisition is done with a spiral stepped scan using gimbals supporting the dish. The beam 3-dB contour is the basis of this scan. Then fine acquisition and tracking are done with a conical scan using a rotating sub reflector. Here, the beam 1-dB contour is the basis of this scan.

3.2.2 Transmit and Receive Sections Relationships

In contrast to dish antennas, with phased-array antennas, the transmit and receive parts will likely be separated, although likely on the same plane. In any event, it will be necessary to make sure that the uplink beam direction can be made the same as that of the downlink beam. The following specifications reflect these ideas.

The uplink beam pointing is based entirely upon the downlink pointing direction. With the usual dish antenna, the uplink beam is then automatically pointed in the correct direction. The downlink pointing must be accurate enough to point the uplink beam. With the traditional dish antenna, the receive and transmit beams are coincident and parallel. However, the receive beamwidth is over twice the transmit beamwidth in the ratio of 44/20. Therefore, the pointing accuracy of the receive beam, as a fraction of the beamwidth, must be better than that of the uplink by this ratio. Note that the pointing error of the *transmit* portion must include errors made on the acquisition and tracking on the *receive* side.

3.2.3 Scanning Specifications

The spatial acquisition and tracking pointing-error and step size specifications are given in terms of the reduction in antenna gain, in dB. In this way, step size can be specified independently of gain and beamwidth. From these values, the corresponding error and step angles can be determined by the system designer for a particular design. Scanning rates defines the minimum angular rate that the beam is scanned in order to perform various acquisition and tracking functions. Since the terminal is stationary, the only tracking function necessary is that to track the very slow motion of the satellite (slightly inclined orbits of existing military EHF satellites). The pointing-error loss is to be distinguished from "scan loss" which is a natural consequence of scanning a phased array and has an approximate value of

$$\text{scan loss} = 10 \log[\cos(\text{scan angle})] \text{ dB} \qquad (1)$$

3.3 EIRP and G/T Considerations

It was not possible to perform our own link budget analysis since FEP, Milstar, etc. numbers are not available to us. Therefore, the values given in Table 3.1 for EIRP and G/T are a composite of values taken from a variety of sources of information on *terminals*. The sources used are very approximate and do not always define which satellite beam (such as earth coverage, agile, narrow spot, wide spot), the number of channels, maximum data rate, etc. are supported by the particular EIRP or G/T, etc.

When it comes to design of the transmit part, it should be kept in mind that the gain and power can be traded off such as was done in [1], where a very large total transmit power of about 50 W was proposed so that a small phased array could be used. However, one would be limited to very low data rates and the power amplifiers at each antenna element would have to be designed so as to use no power whenever the terminal is not transmitting.

3.4 SPECIFICATION SUMMARY

The proposed specifications are summarized in Table 3.1. To justify most of them either a reference, a note, or both are given.

TABLE 3.1. Specifications for the EHF Manpack Terminal

Parameter	Value	[Ref.], (Note)
Communications link specs		
Data rate, Tx and Rx	2.4 kb/s	[15]
Transmit frequency hopping range	43.5 to 45.5 GHz	[6]
Transmit bandwidth	2 GHz	
Receive frequency hopping range	20.2 to 21.2 GHz	[6]
Receive bandwidth	1 GHz	
Tx and Rx hop rate	<20 khop/s	
Antenna: primary		
EIRP	49 dBW	(a), (b)
G/T	14 dB/K	(c), (b)
Max gain variation over operating band, Rx	±0.5 dB	[15], (d)
Max gain variation over operating band, Tx	±0.5 dB	[15], (d)
Transmit polarization	circular, right hand	(e)
Receive polarization	circular, right hand	(e)
Axial ratio	3 dB max	[14], (f)
Sidelobe level below main beam	≤ –20 dB	[14], (g)
Antenna: PAT		
Coarse acquisition total scan angle, azimuth	±10°	[12]
Coarse acquisition total scan angle, elevation	±0.25°	[12]
Fine-acq & track total scan angle, azimuth	±2°	
Fine-acq & track total scan angle, elevation	±0.2°	
Coarse acquisition beam contour/step size	3 dB	[13], [14]
Minimum scan rate, azimuth	10°/s	(h)
Minimum scan rate, elevation	0.5°/s	(h)
Fine-acq & track beam contour/step size	1 dB	[13], [14]
Pointing error loss, receive	<0.2 dB	
Pointing error loss, transmit	<0.3 dB	
Misalignment loss of Tx relative to Rx beam	< 0.1 dB	
Antenna: Other		
Antenna set-up time	< 5 minute	
Average DC antenna power consumption	< 17 W	(i)
Antenna mass	≤ 1.2 kg	(j)

Notes:
(a) A composite value taken various sources giving typical SCAMP like terminals as having power in the order of 2 W and dishes of about 24 inches [6], [16], [17]. Also used transmit gain from [15] of about 46 dB.
(b) The values given are at the *largest* scan angle, i.e., the scan loss of 10 log[cos(10°)] = –0.07 dB is incorporated.
(c) A composite of various sources giving typical SCAMP-like terminals as having total system noise temperatures in the order 600 K and dishes of about 24 inches [17]. Also used receive gain from [15] of about 39 dB.
(d) Based upon achieved performance on the Lincoln ASCAMP antenna in [15].
(e) Unclassified value from MILSTD 1582C.
(f) For the ASCAMP terminal of [15], measured maximum values over the band for the feed of 0.9 dB for TX and 0.7 dB for Rx were obtained. The specification from [14] of 3 dB max was used.
(g) The ASCAMP antenna of [15] had sidelobe levels at 44 GHz of only about –12 dB with the ones at 20 GHz only slightly better. Nonetheless, it was thought useful to attempt the better specification of –20 dB.
(h) The values for scan rate were arbitrarily chosen. Electronic scanning will likely be capable of much higher rates than specified above.
(i) The antenna DC power consumption includes that power needed to generate the specified RF transmit power and to perform all the phasing requirements. From [6], some typical SCAMP terminals transmit in the order of 1.5 to 5 W. It is assumed that an efficiency of about 30% can be achieved on a power amplifier. Therefore, a value of 5/0.3 = 16.7 W is used as a target maximum DC power consumption.
(j) This specification is based upon the existing ASCAMP terminal [15] which gives the mass as 2.6 pounds. Because of an ambiguity in [15], it is not clear if this value includes the feed. The goal here should be to have a mass no greater than the existing dish antenna. From [6], one SCAMP terminal had a total mass of 37 pounds = 16.7 kg; the antenna should have a mass somewhat less than this value.

4. EHF AIRBORNE TERMINAL

4.1 GENERAL

The application considered here is also for low data rate (LDR) EHF communications compatible with MILSTD 1582 operation but, for onboard airplanes. The specifications for this terminal antenna will be based on the work reported in [2] and [3]. The application in these references were for an unspecified type of aircraft. In these references, there is a *single* set of antennas consisting of one phased-array antenna at 44 GHz and another at 20 GHz. As illustrated in Fig. 4.1, the antenna set is mounted on top of the aircraft. It is specified as having elevation angles down to 20° for all azimuth angles. This specification requires scanning of 70° from the zenith, as well as rotating the beam 360° in azimuth, thereby making this antenna a difficult challenge. Although a large aircraft is depicted, the same antenna format would be used on all aircraft, large or small. A conceptual layout of the antenna set is shown in Fig. 4.2.

Issues of transmit and receive sections relationships, and down-link spatial acquisition and tracking are much the same as for the EHF manpack antenna. Therefore, the discussion in that Chapter is applicable here.

Specifications for DC power consumption, heat dissipation, and weight are not given here. The guideline should be to keep these values as small as possible, and no more than for traditional technologies. Also, these values should be consistent with operation on aircraft.

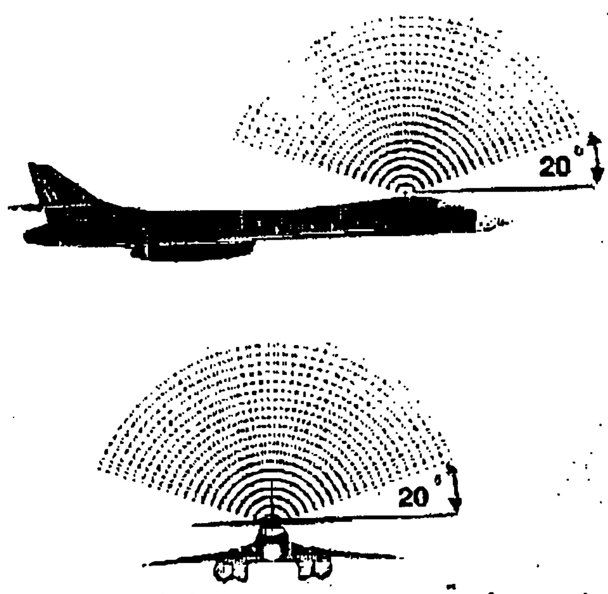

Fig. 4.1. Conceptual drawing of the antenna pattern for a single set of EHF arrays mounted on top of an aircraft. Based upon a Boeing concept presented in [2].

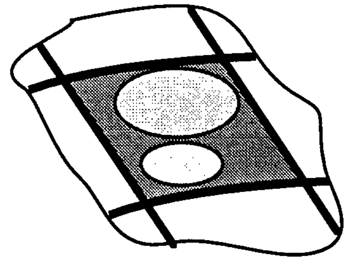

Fig. 4.2. Conceptual representation of a single set of conformal EHF arrays as seen mounted on top of an aircraft. Based upon a Boeing concept presented in [2].

4.2 POINTING, ACQUISITION AND TRACKING (PAT) CONSIDERATIONS

The spatial acquisition and tracking considerations are much the same as for the EHF manpack described earlier. The differences arise from the facts that the platform is moving and that all steering, both large angle and fine pointing, is done electronically.

The scanning specification of a 70° cone from zenith is seen from (1) to cause a significant scan loss of up to approximately 10 log[cos(70°)] = –4.7 dB

The scan rate must be sufficient to compensate for the change in direction of the satellite as the aircraft moves, and therefore will depend partly on the type of aircraft. Values for the scan rate for airborne phased arrays could not be found in the literature. For example, no values were specified in [3] for EHF nor in [18] for SHF. It was probably assumed that a fully electronically scanned beam would always be fast enough for the airborne application. Beam tracking keeps the beam pointing at the satellite as the aircraft moves and therefore depends upon the aircraft direction of travel, velocity, and rate of change of direction. The tracking can be divided into coarse and fine with the fine tracking likely involving some form of scanning in a small uncertainty region.

Issues of transmit and receive sections relationships, and down-link spatial acquisition and tracking are much the same as for the EHF manpack antenna. Therefore, the discussion in that Chapter is applicable here.

4.3 EIRP AND G/T CONSIDERATIONS

The values for EIRP and G/T are taken from [3], and [2]. Unfortunately, they do not provide any link budget to justify these values. Instead, in [3], a power budget internal to the phased array is done that leads to particular values of EIRP and G/T. We have assumed that these values are sufficient to meet the link budget requirements. In [11], it is stated that they take advantage of the fact that their EHF airborne terminals will work above most of the rain attenuation. Therefore, they omit from the link budgets, the rain fade margins of 12 dB for the 44 GHz uplink and 5 dB for the 21 GHz downlink. It is not stated in [3] or [2] whether rain fade margin was removed, but it appears to have been as seen by comparing values from these two references for the airborne application to those in the manpack application given earlier here. Thus, the manpack EIRP and G/T is actually larger than the airborne values, although not quite by the amount of the margin.

4.4 SPECIFICATION SUMMARY

The proposed specifications are summarized in Table 4.1. To justify most of them either a reference, a note, or both are given.

TABLE 4.1. Specifications for the EHF Airborne Terminal

Parameter	Value	[Ref.], (Note)
Communications link specs		
Data rate, Tx and Rx	2.4 kb/s	[15]
Transmit frequency hopping range	43.5 to 45.5 GHz	[6]
Transmit hopping bandwidth	2 GHz	
Receive frequency hopping range	20.2 to 21.2 GHz	[6]
Receive hopping bandwidth	1 GHz	
Tx and Rx hop rate	<20 khop/s	
Antenna: primary		
EIRP	44.0 dBW	(a), (b)
G/T	3 dB/K	(c), (b)
Max gain variation over operating band, Rx	±0.5 dB	
Max gain variation over operating band, Tx	±0.5 dB	
Transmit polarization	circular, right hand	(d)
Receive polarization	circular, right hand	(d)
Axial ratio, receive	2 dB	[3, p.13]
Axial ratio, transmit	2 dB	[3, p.15]
Sidelobe level below main beam	≤ –20 dB	[14]
Antenna: PAT		
Scan angle, azimuth	360°	[3], [2]
Scan angle, elevation	20° to 90°	[3], [2]
Coarse acquisition beam contour/step size	3 dB	[13], [14]
Fine-acq & track beam contour/step size	1 dB	[13], [14]
Minimum scan rate, azimuth	360°/s	(e)
Minimum scan rate, elevation	70°/s	(e)
Pointing error loss, receive	<0.2 dB	
Pointing error loss, transmit	<0.3 dB	
Misalignment loss of Tx relative to Rx beam	< 0.1 dB	

Notes:
(a) Ref. [3, p.15] gives 44.0 dBW and ref. [2] gives 45 dBW for a "first generation."
(b) The values given are total array system values and includes losses such as scan loss, radome loss, line loss, etc.
(c) Ref. [3, p.13] gives +3 dB/K and ref. [2] gives +5 dBi/K for a "first generation."
(d) Unclassified value from MILSTD 1582C.
(e) See discussion in Section 4.2 above. In the absence of published values, values for scan rate were arbitrarily chosen. Electronic scanning will likely be capable of much higher rates than specified above.

5. LAND-TRANSPORTABLE EHF GROUND TERMINAL

5.1 INTRODUCTION

In this Chapter, a set of specifications is provided for the land-transportable EHF ground terminal. The baseline terminal for which these specifications are drawn is the SMART-T terminal [6]. As specifically described in [4], the system is to support simultaneously 2 LDR and 2 MDR signals for an aggregate of 2.240 Mb/s. In comparison to the previous two applications, there is some increase in capability needed by the fact that MDR traffic needs to be supported, and a means of stowing and rapidly setting up will be needed.

For the airborne EHF application, there was a baseline configuration available from outside sources upon which to model our approach. However, for the EHF land-transportable application, no such outside source was available. It is envisaged that it will involve some combination of flat array antennas. Therefore, it is only possible to provide overall performance specifications rather than for a specific array as was done in the previous two EHF applications. Specific configurations would be provided in an architecture study. There is the potential to make an antenna design that has a good degree of commonality with the shipboard EHF array.

A summary of the specifications is given in Table 5.1. In the next Sections, a discussion on the critical specifications will be given. Issues of transmit and receive sections relationships, and down-link spatial acquisition and tracking are much the same as for the EHF manpack antenna. Therefore, the discussion in that Chapter is applicable here.

Specifications for DC power consumption, heat dissipation, and weight are not given here. The guideline should be to keep these values as small as possible, and no more than for traditional technologies. Also, these values should be consistent with operation of a land-transportable terminal.

5.2 EIRP AND G/T CONSIDERATIONS

Approximate values for EIRP and G/T can be obtained from the manpack or airborne EHF terminal values, given above, merely by adding the increase due to the increased data rate, i.e. by adding 10 log(1544/2.4) = 28.0 dB. However, this does not necessarily account for the way multiple channels are combined in the LDR and MDR data link standard which uses various forms of FDMA and TDMA. Values from a variety of sources were obtained and listed in Table 5.1. Reference [17] and [4] were for land transportable and therefore presumably had rain fade margin included. The value from [11] was for airborne which omitted 12 dB of uplink rain margin because it was assumed that operation was above the clouds. Therefore, for present purposes, the value given in [11] of 55 dB was increased by 12 dB to 67 dB.

For EIRP, there were two groupings of two values. Because, the values in [17] and [11] were sources most likely to have actual link budget values available for their calculations, it was decided to choose the 67 dBW value. The values for G/T had a discrepancy of 20 dB, which we could not explain. It was decided to go with the two that agreed at 22 dB/K.

TABLE 5.1. Values of EIRP and G/T for the EHF land transportable application.

Source→ Parameter↓	Manpack EHF + 28.0 dB	Reilander [17]	SED [4, p. 4-52]	Cook [11, Table 1]
EIRP, dBW	77	67.0	78	67
G/T, dBi/K	42	22.2	22	Not provided

5.3 STEERING CAPABILITY

The objective is to obtain hemispheric coverage from a stationary platform, with the possibility of extension to "on-the-move" capability. Therefore, the required steering is 360° in azimuth and from 0° to 90° in elevation.

5.4 SPECIFICATION SUMMARY

The proposed specifications are summarized in Table 5.2. To justify most of them either a reference, a note, or both are given.

TABLE 5.2. Specifications for the EHF Land-Transportable Terminal Phased Array Antenna

Parameter	Value	[Ref.], (Note)
Communications link specs		
Data rate, Tx and Rx	2.4 to 1544 kb/s	(a), [4]
Transmit frequency hopping range	43.5 to 45.5 GHz	[6]
Transmit bandwidth	2 GHz	
Receive frequency hopping range	20.2 to 21.2 GHz	[6]
Receive bandwidth	1 GHz	
Tx and Rx hop rate	<20 khop/s	
Antenna: primary		
EIRP	44.0 dBW	(b)
G/T	3 dB/K	(b)
Max gain variation over operating band, Rx	±0.5 dB	
Max gain variation over operating band, Tx	±0.5 dB	
Transmit polarization	circular, right hand	(c)
Receive polarization	circular, right hand	(c)
Axial ratio, receive	2 dB	[3, p.13]
Axial ratio, transmit	2 dB	[3, p.15]
Sidelobe level below main beam	≤ −20 dB	[14]
Antenna: PAT		
Scan angle, azimuth	360°	(d)
Scan angle, elevation	0° to 90°	(d)
Coarse acquisition beam contour/step size	3 dB	[13], [14]
Fine-acq & track beam contour/step size	1 dB	[13], [14]
Minimum scan rate, azimuth	360°/s	(e)
Minimum scan rate, elevation	70°/s	(e)
Pointing error loss, receive	<0.2 dB	
Pointing error loss, transmit	<0.3 dB	
Misalignment loss of Tx relative to Rx beam	< 0.1 dB	
Antenna: Other		
Antenna set-up time	< 5 minute	

Notes:
(a) Multi-channel LDR and MDR for an aggregate of 2.240 Mb/s [4].
(b) See discussion in Section 5.2 and Table 5.1.
(c) Unclassified value from MILSTD 1582C.
(d) A nominal hemispheric coverage is the objective which consists of a minimum elevation angle of 10° offset by a maximum tilt of the antenna platform of 10°. Platform tilt could arise due to the terrain on which it is mounted or, if "on-the-move" operation is ever needed, variable tilt could occur.
(e) The values for scan rate were arbitrarily chosen. Electronic scanning will likely be capable of much higher rates than specified above.

6. MULTI-BAND VEHICLE-MOUNTED GROUND TERMINAL

6.1 GENERAL

This application of phased arrays to tri-band (C, X, and Ku) terminals increases the complexity since there are multiple bands and multiple beams to support. However, the frequencies are lower than for EHF which should ease some of the difficulties. Initially, the objective is to obtain hemispheric coverage from a stationary platform. But consideration is to be taken of possible migration toward "on-the-move" operation, and possible commonalities with the tri-band portion of the shipboard version, which necessarily has motion.

Because of the uncertainty of how a tri-band phased array would be implemented, one must be careful not to give specifications that cannot be met. The difficulty arises primarily in the cross-band capabilities. Therefore, the specifications are given in two parts: band specific (Tables 6.1, 6.2 and 6.3) for which the specifications are straight forward ones for each band, and cross band (Table 6.4) for which the specifications must be carefully chosen and are subject to later revision depending upon subsequent study.

6.4 BANDWIDTH AND DATA RATE CONSIDERATIONS

For the EHF terminals discussed earlier, onboard processing and frequency hopping is used. The result is that bandwidth and data rate are decoupled. However, the tri-band terminal will likely operate with a bent pipe transponder. The result is that the signal transmitted or received may only be using a part of the available band. Nonetheless, the antenna must be capable of operating over the full band.

The data rates to be supported are a little difficult to provide. From [5] it is seen that the TLRCT tri-band terminals are aimed at rates up to T1. In [8, pp. 8-10] are given data rates and number of carriers for 5 tri-band terminals under active development. They range from a single carrier supporting 256 kbit/s on both transmit and receive to 5 carriers with an aggregate data rate of 9.4 Mbit/s on both transmit and receive. Some of these were unsymmetrical with the receive part having the higher capacity. In view of the fact that actual new CF terminals will be up to T1, that is the rate chosen here. In Table 3.1/3 of [4] is given the EIRP and G/T for a 2-channel 2 Mb/s tri-band terminal; it was decided to use those values here, while comparing to other sources (p. 363 of [6], and Tables 3 through 7 of [8]) to make sure that they were in reasonable agreement.

6.5 SPECIFICATION SUMMARY

6.5.1 Band-Specific Specification

The proposed specifications are summarized in Tables 6.1, 6.2, and 6.3 for each of the bands. There will necessarily be some repetition since some specifications apply to all three bands. To justify most of the specifications, either a reference, a note, or both are given.

TABLE 6.1. Specifications for the Multi-Band Vehicle-Mounted Ground Terminal Phased Array Antenna: C-Band

Parameter	Value	[Ref.], (Note)
Communications link specs		
Data rate, Tx and Rx	2 chan to 1544 kb/s	(a)
Transmit frequency	5.850 to 6.425 GHz	[8, p.4]
Transmit bandwidth	575 MHz	
Receive frequency	3.625 to 4.200 GHz	[8, p.4]
Receive bandwidth	575 MHz	
Antenna: primary		
EIRP	63.0 dBW	(b)
G/T	19 dB/K	(b)
Max gain variation over operating band, Rx	±0.5 dB	
Max gain variation over operating band, Tx	±0.5 dB	
Transmit polarization	CP and LP	(c)
Receive polarization	CP and LP	(c)
Axial ratio, receive	2 dB	(d)
Axial ratio, transmit	2 dB	(d)
Sidelobe level below main beam	≤ –20 dB	(e)
Antenna: PAT		
Scan angle, azimuth	360°	(f)
Scan angle, elevation	0° to 90°	(f)
Coarse acquisition beam contour/step size	3 dB	(g)
Fine-acq & track beam contour/step size	1 dB	(g)
Minimum scan rate, azimuth	360°/s	(h)
Minimum scan rate, elevation	45°/s	(h)
Pointing error loss, receive	<0.2 dB	
Pointing error loss, transmit	<0.3 dB	
Misalignment loss of Tx relative to Rx beam	< 0.1 dB	

Notes:
(a) As discussed in a previous section.
(b) Primarily from p. 3-6 of [4] with some reference to [6] and [8] to corroborate.
(c) Telesat uses linear polarization and Intelsat uses circular polarization.

(d) These values found by rounding off values found in a catalog for a particular tri-band terminal.
(e) This value is a reasonable objective but can be viewed as a flexible specification.
(f) A nominal hemispheric coverage is the objective which consists of a minimum elevation angle of 10° offset by a maximum tilt of the antenna platform of 10°. Platform tilt could arise due to the terrain on which it is mounted or, if "on-the-move" operation is ever needed, variable tilt could occur.
(g) These values are based upon discussions with personnel at DREO. The values should be viewed as approximate guidelines.
(h) The values for scan rate were arbitrarily chosen. It must be fast enough to compensate for vehicle motion when used in the "on-the-move" mode. Electronic scanning will likely be capable of much higher rates than specified above.

TABLE 6.2. Specifications for the Multi-Band Vehicle-Mounted Ground Terminal

Phased Array Antenna: X-Band

Parameter	Value	[Ref.], (Note)
Communications link specs		
Data rate, Tx and Rx	2 chan to 1544 kb/s	(a)
Transmit frequency	7.90 to 8.40 GHz	[8, p.4]
Transmit bandwidth	500 MHz	
Receive frequency	7.25 to 7.75 GHz	[8, p.4]
Receive bandwidth	500 MHz	
Antenna: primary		
EIRP	65.0 dBW	(b)
G/T	19 dB/K	(b)
Max gain variation over operating band, Rx	±0.5 dB	
Max gain variation over operating band, Tx	±0.5 dB	
Transmit polarization	RHCP	[20]
Receive polarization	LHCP	[20]
Axial ratio, receive, bore sight	<1.9 dB	[9]
Axial ratio, transmit bore sight	<1.9 dB	[9]
Sidelobe level below main beam	<-18 dB	[9]
Antenna: PAT		
Scan angle, azimuth	360°	(c)
Scan angle, elevation	0° to 90°	(c)
Coarse acquisition beam contour/step size	3 dB	(d)
Fine-acq & track beam contour/step size	1 dB	(d)
Minimum scan rate, azimuth	360°/s	(e)
Minimum scan rate, elevation	45°/s	(e)
Pointing error loss, receive	<0.2 dB	
Pointing error loss, transmit	<0.3 dB	
Misalignment loss of Tx relative to Rx beam	< 0.1 dB	

Notes:
(a) As discussed in a previous section.
(b) Primarily from p. 3-6 of [4] with some reference to [6] and [8] to corroborate.
(c) A nominal hemispheric coverage is the objective which consists of a minimum elevation angle of 10° offset by a maximum tilt of the antenna platform of 10°. Platform tilt could arise due to the terrain on which it is mounted or, if "on-the-move" operation is ever needed, variable tilt could occur.
(d) These values are based upon discussions with personnel at DREO. The values should be viewed as approximate guidelines.
(e) The values for scan rate were arbitrarily chosen. It must be fast enough to compensate for vehicle motion when used in the "on-the-move" mode. Electronic scanning will likely be capable of much higher rates than specified above.

TABLE 6.3. Specifications for the Multi-Band Vehicle-Mounted Ground Terminal Phased Array Antenna: Ku-Band

Parameter	Value	[Ref.], (Note)
Communications link specs		
Data rate, Tx and Rx	2.4 to 1544 kb/s	(a), [4]
Transmit frequency	14.00 to 14.50 GHz	[8, p.4]
Receive frequency	10.95 to 12.75 GHz	[8, p.4]
Antenna: primary		
EIRP	71 dBW	(b)
G/T	27 dB/K	(b)
Max gain variation over operating band, Rx	±0.5 dB	
Max gain variation over operating band, Tx	±0.5 dB	
Transmit polarization	LP	(c)
Receive polarization	LP	(c)
Cross polarization	–30dB within 1dB contour	
Sidelobe envelope	29-25*Log(θ) dBi	(d)
Antenna: PAT		
Scan angle, azimuth	360°	(e)
Scan angle, elevation	0° to 90°	(e)
Coarse acquisition beam contour/step size	3 dB	(f)
Fine-acq & track beam contour/step size	1 dB	(f)
Minimum scan rate, azimuth	360°/s	(g)
Minimum scan rate, elevation	45°/s	(g)
Pointing error loss, receive	<0.2 dB	
Pointing error loss, transmit	<0.3 dB	
Misalignment loss of Tx relative to Rx beam	< 0.1 dB	

Notes:
(a) As discussed in a previous section.
(b) Primarily from p. 3-6 of [4] with some reference to [6] and [8] to corroborate.
(c) From an SSE Telecom brochure.
(d) This value was taken from that for a dish antenna with 48 dB gain and 2.4 m diameter. It is not clear if this specification is exactly applicable here.
(e) A nominal hemispheric coverage is the objective which consists of a minimum elevation angle of 10° offset by a maximum tilt of the antenna platform of 10°. Platform tilt could arise due to the terrain on which it is mounted or, if "on-the-move" operation is ever needed, variable tilt could occur.
(f) These values are based upon discussions with personnel at DREO. The values should be viewed as approximate guidelines.
(g) The values for scan rate were arbitrarily chosen. It must be fast enough to compensate for vehicle motion when used in the "on-the-move" mode. Electronic scanning will likely be capable of much higher rates than specified above.

6.5.2 Coupled Specifications

The proposed specifications for multi-beam and multi-band operation are summarized in Table 6.4 for the multi-band vehicle-mounted antenna system. The switch-over times are just arbitrary values to alert the system designer that switch over must be substantially faster than the 10 to 30 minutes required for existing tri-band systems. The values of these specifications indicate that mechanical changing antenna parts is not sufficiently fast.

TABLE 6.4. Specifications for Multi-Beam and Multi-band Operation of the Multi-Band Vehicle-Mounted Ground Terminal Phased Array Antenna

Parameter	Value
Number simultaneous beams, any combination of bands	2
Number of satellites accessed simultaneously	2
Switch over time between bands	<1 s
Switch over time between satellites	<1 s

7. MULTI-BAND SHIPBOARD TERMINAL

7.1 INTRODUCTION

In the multi-band shipboard application, the highest level of complexity is found, and for a number of reasons. First, five frequency bands are needed and simultaneous operation is preferred. The data rates are at their highest, up to 1.544 Mb/s. Another increased difficulty arises from ship motion, which, along with the airborne application is the most severe. But what distinguishes this application from the other resides mostly in the implementation issues. The most problematic additional implementation factors are the real estate shortage, superstructure blockage, and electromagnetic interference between the communications and radar antennas.

7.2 SHIP MOTION AND STEERING CAPABILITY

A very important factor in mechanically steered antennas for shipboard use is the motion of the ship. Since the specifications for ship motion were available for the WSC-6 SHF antenna, and are probably representative, they are presented here as our specifications. From [6, p. 366], the ship motion specifications are given in Table 7.1. The objective is to obtain hemispheric coverage for all values of pitch and roll up to the maximum specified in Table 7.1.

In determining the steering range needed, it is necessary to know the maximum expected roll and pitch. Working numbers for now will be used of 30° for roll and 10° for pitch.

TABLE 7.1 Ship maximum motion specifications.

Motion	Sinusoidal amplitude/ period
Roll	35°/7 s
Pitch	12°/5 s
Yaw	8.5°/6 s
Heave	7.31 m/4.5 s

7.3 EIRP AND G/T CONSIDERATIONS

For EHF and tri-band, the values of EIRP and G/T, used in earlier Chapters are applied. The values for the Ka band are now considered.

For a value of Ka-band EIRP, numbers used in [19] for the suitcase terminal were used. For an uplink at 512 kb/s an EIRP of 39.1 dBW was used. It included an aggregate (up and down link) link margin of 4.7 dB. The data rate ratio between that and the present system is 10 log(512/256) = 3 dB, which is added to the 39.1 dBW for the total EIRP of 42 dBW. The set up in [19] was for a suitcase terminal sending to a hub which, therefore, is representative of a ship terminal sending to shore. Ship-to-ship transmission would need a larger EIRP.

For G/T, a value of 13.0 dB/K was obtained for the suitcase terminal in [19] for use at 1544 kb/s. There was an aggregate (up and down link) link margin of 14 dB. The data rate was the same as for the system here so that no correction is needed. The setup in [19] was for a hub sending to a suitcase terminal, which is representative of a shore to ship link. Ship-to-ship transmission would need a larger G/T. In [11], a value G/T of 16 dB/K, including a 5 dB fade margin, was given as that necessary to receive the UFO GBS data. Since such GBS service might eventually be chosen, it was decided to choose this higher value of G/T as the target.

7.4 SPECIFICATION SUMMARY

7.4.1 Band-Specific Specification

The proposed specifications are now summarized for each of the bands. This work has been set up so that the antenna for four of the five bands covered use the same antennas as used in previous terminal antennas. Therefore, for these four bands, refer to the previous specifications as follows:

- EHF: see Table 5.2 for the EHF Land Transportable
- C-band: see Table 6.2 for the Multi-Band Vehicle-Mounted: C-Band
- X-band: see Table 6.3 for the Multi-Band Vehicle-Mounted: X-Band
- Ku-band: see Table 6.4 for the Multi-Band Vehicle-Mounted: Ku-Band

The exception to these specifications is in the scan angles arising from ship motion. For these two values, use scan angles given in Table 7.2. The only new antenna is the one at Ka band. Its specifications are summarized in Table 7.2. To justify most of the specifications, a note is given.

TABLE 7.2. Specifications for the Multi-Band Ship-Borne Phased-Array Antenna: Ka-Band

Parameter	Value	[Ref.], (Note)
Communications link specs		
Data rate, Rx	1544 kb/s	(a)
Data rate, Tx	256 kb/s	(a)
Transmit frequency	29.5 to 30.0 GHz	
Receive frequency	19.7 to 20.2 GHz	
Antenna: primary		
EIRP	42 dBW	(b)
G/T	16 dB/K	(b)
Max gain variation over operating band, Rx	±0.5 dB	
Max gain variation over operating band, Tx	±0.5 dB	
Transmit polarization	dual LHCP/RHCP	(c)
Receive polarization	dual LHCP/RHCP	(d)
Axial ratio, receive	2 dB	(e)
Axial ratio, transmit	2 dB	(e)
Sidelobe level below main beam	≤ –20 dB	(e)
Antenna: PAT		
Scan angle, azimuth	360°	(g)
Scan angle, elevation	–20° to 90°	(g)
Coarse acquisition beam contour/step size	3 dB	(h)
Fine-acq & track beam contour/step size	1 dB	(h)
Minimum scan rate, azimuth	360°/s	(i)
Minimum scan rate, elevation	45°/s	(i)
Pointing error loss, receive	<0.2 dB	
Pointing error loss, transmit	<0.3 dB	
Misalignment loss of Tx relative to Rx beam	< 0.1 dB	

Notes:

(a) An attempt was made to find representative values of data rates between GBS and commercial Ka-band communications. In [11] is provided a list of numerous Ka-band commercial satcom systems that could be useful along with their various data rates to be supported.

(b) As discussed in previous sub section.

(c) We have not found guidance on this value, but is probably in the same class as in note (d) for the receive part. Therefore, the dual polarization was selected as a desired feature, but switchable could be acceptable.

(d) According to [11], their 20 GHz receive GBS antennas should be capable of being switched between LHC and RHC polarizations. Nonetheless, they go on to say "... but if the antenna design lends itself naturally to simultaneous dual polarization, this is more desirable. The dual polarization requirement is derived from the desire to be compatible with commercial ..."

(e) These values were selected in the absence of references.

(g) A nominal hemispheric coverage is the objective which consists of a minimum elevation angle of 10° offset by a maximum roll of the antenna platform of 30°.

(h) These values are based upon discussions with personnel at DREO. The values should be viewed as approximate guidelines.
(g) This value is a reasonable objective but can be viewed as a flexible specification.
(i) The values for scan rate were arbitrarily chosen. It must be fast enough to compensate for ship motion as defined in Table 7.1. Electronic scanning will likely be capable of much higher rates than those specified above.

7.4.2 Coupled Specifications

As discussed earlier, detailed specification of the parameters such as number of simultaneous beams and bands is better left to an architecture study which can indicate what is practical. Nonetheless, Table 7.3 gives some suggested target capabilities as a starting point.

TABLE 7.3. Specifications for Multi-Beam and Multi-Band Operation of the Multi-Band Shipboard Phased-Array Antenna

Parameter	Value
Number simultaneous beams, any combination of bands	2
Number of satellites accessed simultaneously	2
Switch over time between bands	<1 s
Switch over time between satellites	<1 s

8. CONCLUSION

The specifications for five different phased-array satcom terminal applications were presented. These values were based primarily upon finding the specifications of similar terminals without knowledge of the link-budget parameters of the corresponding satcom systems. Nonetheless, the terminal specifications given here should be sufficiently close to enable work to proceed to the next stage, that of developing the corresponding architectures.

Based upon the work here, it is possible to make a preliminary assessment as to the level of complexity and difficulty, and the utility of each of the five applications. Such an assessment is summarized in Table 8.1. For example, it is seen that the EHF manpack antenna is probably the easiest to implement, but it also has the least marginal benefit over existing dish antennas.

Table 8.1. A summary preliminary assessment of implementation difficulty and utility for each of the five strawman applications.

Application	Implementation difficulty	Value of application
EHF manpack	Relatively easy to implement fixed version. More technical challenge for an on-the-move version	Of slight improvement over existing dish antennas for fixed use. Makes on the move operation possible in advanced version.
EHF airborne	Very challenging and expensive.	Could be of sufficient benefit to justify cost
EHF land transportable	Less technologically challenging than the airborne EHF. Challenge is in making antenna cost effective.	Of marginal utility over existing dish antennas for fixed use. However, could benefit from commonalities with the multi-band shipboard antenna. Makes on-the-move operation possible in advanced version.
Multi-band vehicle mounted	Eases implementation difficulty since no EHF. However, multi-band makes implementation very challenging. Multi-beam operation compounds the difficulty.	Many tri-band systems exist and are under development. A system that provides simultaneous multi bands and multi beams could be valuable. Good potential for innovative solutions.
Multi-band shipboard	Very challenging.	Because of the unique deployment conditions on a ship, this application could be a very valuable addition and justify the expense. Very good potential for innovative solutions.

9. REFERENCES

[1] H. Paul, D.R. Ayers, and P. Shloss, "EHF phased array manpack terminal design," in Conf. Record IEEE MILCOM 91, pp. 1128-1132, Nov. 4-7 1991, McLean, Virginia.

[2] Dave Cobb (Wright Laboratory), "20 GHz Phased array antenna," in Minutes, vol. IIIB, TTCP STP-6 23rd Meeting, Malvern, UK, 23-27 October 95.

[3] D. McMeen, *et al*, "Integrated circuit active phased array antennas for millimeter wave airborne satcom applications," Boeing Contract, Rome Lab, Final Technical Report, RL-TR-94-143, August 94.

[4] R. Plemel, R. Herbert, and K. Schappert, "Ground Segment Options Report," SED Systems Inc. Report #8166-110, 9 May 94. DND File No. 2790-4 (DCEEM 5).

[5] LCol. D.R. Harris, "Canadian National Position Paper Military Satellite Communications," in Minutes of TTCP STP-6, 24th Meeting, NSC Dahlgren VA, Oct. 97.

[6] *Jane's Military Communications*, 18th Ed, 1997-98, J. Williamson ed., Jane's Sentinel House, Surrey UK, 1997.

[7] A.C. Densmore and V. Jamnejad, "A satellite-tracking K- and Ka-band mobile vehicle antenna system," IEEE Trans. Vehicular Tech, pp. 502-513, Nov. 1993.

[8] C. Barron, "A coming of age multiband satellite communications earth terminals," in Proc. of Sym. on Concepts for the Post-NATO IV Satcom System, paper IV.3, vol. 1(b), The Hague, 4-7 April 1995.

[9] Thom Nelson (CECOM), "JWID 95, Multi-beam/multi-mission phased array demonstrations," CN80 Camp Pendleton/Ft. Gordon, in Minutes, vol. IIIB, TTCP STP-6, 23rd Meeting, Malvern, UK, 23-27 October 95.

[10] G. Morin and L. Wagner, "Study of Future Antenna Technologies for Shipboard Satellite Communications" DREO Technical Note No. 97-007, Ottawa, May 1997.

[11] Bill Cook, "Low cost 'Wideband' SATCOM antennas for the near future, Rome Lab paper received at STP-6 mtg., Dahlgren VA, Oct. 96.

[12] Robert J. Figucia, "A time saving acquisition procedure using sidelobe detection," in Conference Record IEEE MILCOM 91, pp. 814-818, McLean, Virginia, Nov. 4-7 1991.

[13] MPR Teltech Team, "Ground Terminal Prime Item Development Specification," FASSET Document 108.2.00, pp. 50-51, 1 June 1992, Secret.

[14] MPR Teltech Team, "Ground Terminal Antenna Subsystem Development Specification," FASSET Document 217.0.00, pp. 10-13, 19 August 1994.

[15] Joseph C. Lee, "A compact EHF dual-frequency antenna for ASCAMP," in Conference Record IEEE MILCOM 91, pp. 1123-1127, McLean, Virginia, Nov. 4-7 1991.

[16] R.T. Reilander, "Potential future army tactical communications using lightweight EHF communication satellites," Milcom 91, classified sessions, Oct. 91.

[17] R.T. Reilander, "The technical feasibility of geosynchronous EHF lightsats," unpublished work, 1992.

[18] G.R. Diemond, R.M. Montgomery, and J.T. Gallo, "Optically Controlled SHF Satcom Array (OCSSA)," Rome Lab Final Technical Report, RL-TR-96-66, Harris Corp. contractor, May 96.
[19] Corey Pike, Pierre Tardif, Will Janssen, Elim Chan, and Gretchen Bivens, "Ka-band (29/19 GHz) suitcase satellite terminal," in Conf. Record, IEEE Milcom 96, pp. 341-346, McLean, VA, Oct. 21-24, 1996.
[20] Alan C. Smith, "A low profile vehicle mobile satcom antenna," in Conf. Record of the IEEE Milcom '93, pp. 705-709, Boston MA, October 1993.

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There is much current interest in the use of phased-array antennas for military satellite communications terminals. These antennas present definite advantages over conventional dish antennas, such as electronic steering capability, conformal surface potential, and graceful degradation. In view of the potential of phased arrays, CRAD initiated an R&D project, as part of the Military Information and Technology Infrastructure (MITI) thrust, to provide advice on issues such as performance benefits, potential technical improvements, implementation issues, and potential market niche areas. In this report, this process is initiated by generating a set of specifications for the development of such phased-array antennas. Five types of terminals are analyzed, namely: EHF manpack, EHF airborne, EHF land transportable, multi-band vehicle mounted, and multi-band shipboard. For the five strawman applications, performance specifications such as EIRP, G/T, etc. are provided.

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