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Assessment of long-distance HF radio and satellite communication assets for RNLAF out-of-area operations

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Achtergrond

Eenheden van de Koninklijke Luchtmacht (KLu) kunnen worden uitgezonden voor "peace-keeping" en "peace-enforcing" in het kader van multinationale (NAVO, VN, WEU, etc.) "Out-Of-Area" (OOA) operaties. De bij deze OOA-operaties te gebruiken communicatiemiddelen en -infrastructuur moeten nog verder worden ingevuld.

Doel

Het project "HF versus SATCOM" heeft als doelstelling een duidelijk beeld te geven van de mate van geschiktheid van korte golf (HF) radio communicatie en satelliet communicatie (SATCOM) voor de inzet als lange afstand verbindingen tussen de "rear area" (Nederland) en het OOA-gebied.

Werkwijze

De toekomstige operationele concepten voor OOA-optreden door de Koninklijke Luchtmacht zijn nog niet geheel uitgekristalliseerd. De verschillende typen communicatiesystemen zijn daarom onderzocht op geschiktheid in relatie met algemene operationele aspecten en niet afgewogen tegen gedetailleerde operationele eisen.

De communicatiesystemen zijn onderzocht op de aspecten: geleverde netwerkdiensten, maximale capaciteit van verbindingen, dekkingsgebieden, beschikbaarheid en betrouwbaarheid, interoperabiliteit, mobiliteit, personeelsinzet, kosten, onderhoud, storingsgevoeligheid en informatiebeveiliging. Vier communicatiesystemen zijn onderling vergeleken op genoemde aspecten, aan de hand van de huidige mogelijkheden en kwaliteiten. Deze systemen zijn:

- Militaire HF communicatiesystemen;
- Militaire SATCOM systemen;
- Publieke SATCOM systemen;
- Civiele gesloten SATCOM systemen.

Conclusies

De beschouwde HF systemen zijn speciaal ontworpen voor militaire mobiele toepassingen. Ze bieden goede mogelijkheden voor de beveiliging van informatie en de koppeling aan andere netwerken en eindsystemen, terwijl de apparatuur gemakkelijk te bedienen en relatief goedkoop is en weinig onderhoud vereist. HF systemen hebben als nadeel dat de verbindingen afhankelijk zijn van de ionosferische condities. Het dekkingsgebied, de beschikbaarheid en betrouwbaarheid zijn hierdoor variabel en kunnen niet nauwkeurig voorspeld worden. Een ander nadeel is de beperkte transmissie capaciteit.

De militaire SATCOM systemen bieden een goede kwaliteit op het gebied van beschikbaarheid, betrouwbaarheid, informatiebeveiliging en storingsgevoeligheid. De Nederlandse Krijgsmacht, in casu de Koninklijke Luchtmacht, heeft echter geen nationale militaire satelliet tot haar beschikking en is daarom afhankelijk van andere naties of internationale organisaties, zoals de NAVO. Hierdoor kan de KLu geconfronteerd worden met een beperkt dekkingsgebied en een beperkte capaciteit. De meeste huidige militaire SATCOM systemen zijn niet speciaal ontworpen voor mobiele toepassingen, waardoor de apparatuur niet erg gebruiksvriendelijk is en niet zeer gemakkelijk te verplaatsen is.

Publieke SATCOM systemen mogen niet worden gebruikt voor de uitwisseling van echt militair operationeel verkeer. Deze systemen bieden echter een wereldwijde dekking met mobiele en gebruiksvriendelijke apparatuur. De aanschafkosten van de grondstations zijn laag, maar de gesprekskosten zijn hoog. De publieke SATCOM systemen bieden weinig mogelijkheden om storingen tegen te gaan en informatie te beveiligen. Het gebruik van cryptografische apparatuur is namelijk formeel niet toegestaan door de organisaties die de satellieten beheren. De beschikbaarheid van publieke SATCOM systemen kan sterk verminderen door overbelasting ten gevolge van een groot aantal gebruikers tegelijkertijd.

Civiele gesloten SATCOM systemen mogen ook niet gebruikt worden voor de overdracht van echt militair operationeel verkeer. Deze netwerken hebben het voordeel dat de gebruikers hun eigen netwerk kunnen configureren en beheren. Huidige gesloten netwerken zijn niet ontworpen voor militaire mobiele toepassingen, waardoor hun kwaliteiten op het gebied van mobiliteit, interoperabiliteit en informatiebeveiliging alleen redelijk zijn. Gesloten civiele SATCOM netwerken bieden wereldwijde dekking.

Toekomstige HF communicatiesystemen zullen waarschijnlijk niet veel verschillen van huidige systemen. Het gebruikersgemak en de maximale capaciteit zullen iets toenemen.
Op het gebied van SATCOM zijn echter grote veranderingen te verwachten. Militaire systemen zullen speciaal worden ontworpen voor mobiele toepassingen en het dekkingsgebied en de beschikbare capaciteit zullen worden vergroot. Voor de Nederlandse Krijgsmacht is, voor de ontwikkeling van toekomstige militaire SATCOM, het EUMILSATCOM programma van belang. De toepassingsmogelijkheden van gesloten civiele SATCOM systemen zullen toenemen. De grootste ontwikkelingen zijn echter te verwachten bij de publieke SATCOM systemen die zich zullen gaan richten op toepassingen in de sfeer van de persoonlijke communicatie.

Dit rapport geeft een globaal inzicht in de geschiktheid van de diverse communicatiesystemen voor de "rear area link" verbindingen van de Koninklijke Luchtmacht. Een nauwkeurige afweging kan echter pas worden gemaakt indien de gedetailleerde operationele concepten bekend zijn. Het verdient daarom de aanbeveling om eerst deze concepten en de daaruit voortvloeiende operationele en systeem eisen te bepalen, alvorens een definitieve keuze tussen de systemen wordt gemaakt. Verder zal de gehele communicatie infrastructuur moeten worden onderzocht, inclusief de lokale netwerken in Nederland en de OOA-gebieden. Ook de koppelingen tussen de verschillende netwerken moeten worden bestudeerd.

CONTENTS

LIST OF ACRONYMS

AFU	Assault Firing Unit
ALE	Automatic Link Establishment
ALIS	Automatic Link Set-up
ARQ	Automatic Repeat Request
ASCON	Automatic Switched Communication Network
BER	Bit Error Rate
BITE	Built-In Test Equipment
CDMA	Code Division Multiple Access
CNN	Cable News Network
COMSEC	Communications Security
DS-SS	Direct Sequence Spread Spectrum
DSP	Digital Signal Processing
ECM	Electronic Counter Measures
ECCM	Electronic Counter Counter Measures
EHF	Extremely High Frequency (30 - 300 GHz)
EIRP	Equivalent Isotropically Radiated Power
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulse
EPM	Electronic Protective Measures
ESA	European Space Agency
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FH	Frequency Hopping
GGW/DP	Groep Geleide Wapens / De Peel
HEO	Highly Elliptical Orbit
HF	High Frequency (3 - 30 MHz)
IBS	Intelsat Business Service
IDR	Intermediate Data Rate
IER	Information Exchange Requirements
ITU	International Telecommunication Union
LEO	Low Earth Orbit
LOTEX	Local Text Exchange
LPD	Low Probability of Detection
LPE	Low Probability of Exploitation
LPI	Low Probability of Interception
LTN	Local Telecommunications Network
LUF	Lowest Usable Frequency
MCC	Mobile Communications Container
MDF	Main Defense Forces
MDTN	Militair Dienst Telefoon Net
MEO	Medium Earth Orbit
MF	Multinational Forces

MIL-STD	Military Standard
MOB	Main Operating Base
MODEM	Modulator Demodulator
MOU	Memorandum Of Understanding
MTBF	Mean Time Between Failure
MUF	Maximum Usable Frequency
NAFIN	Netherlands Armed Forces Integrated Network
NATO	North Atlantic Treaty Organization
NICS	NATO Integrated Communications system
NL	Netherlands
OCKLu	Operatie Centrum Koninklijke Luchtmacht
OOA	Out-Of-Area
PCA	Polar Cap Absorption
PSTN	Public Switched Telephone Network
PTT	Post, Telegraph and Telephone Administration
RF	Reaction Forces / Radio Frequency
RNLA	Royal Netherlands Army
RNLAF	Royal Netherlands Airforce
RNLN	Royal Netherlands Navy
SAM	Surface to Air Missile
SATCOM	Satellite Communication
SHF	Super High Frequency (3 - 30 GHz)
SHORAD	Short Range Air Defense
SID	Sudden Ionospheric Disturbance
SSB	Single Sideband
SSTV	Slow Scan Television
STANAG	Standard NATO Agreement
SWF	Short Wave Fade
TDMA	Time Division Multiple Access
TRANSEC	Transmission Security
TRIAD	Triple Air Defense
TWTA	Travelling Wave Tube Amplifier
UHF	Ultra High Frequency (300 - 3000 MHz)
UK	United Kingdom
UN	United Nations
US	United States of America
VHF	Very High Frequency (30 - 300 MHz)
VOCODER	Voice Coder Decoder
VSAT	Very Small Aperture Terminal
WEU	West European Union

1 INTRODUCTION

1.1 Aim of the study

The Royal Netherlands Airforce (RNLAF) is reconsidering its operational concepts, due to changes in international political relations and the safety within and outside Europe.
Multinational operations under aegis of NATO, United Nations (UN) or an ad hoc coalition will become more important. Current and future RNLAF operations can be characterized by a flexible deployment of units, while the operational area is no longer restricted to the West European central region.

The changed operational concepts have led to an increasing need for the employment of long-distance communication assets. These assets will be used to exchange information between RNLAF units deployed in out-of-area (OOA) operations and The Netherlands. Currently, the RNLAF uses two different systems in order to fulfil this need for communications:

- High Frequency (HF) radio communication;
- INMARSAT satellite communication (SATCOM).

Both systems have their pros and cons and do not completely meet the operational requirements of the RNLAF. The RNLAF has therefore tasked TNO-FEL to assess the relative merits of the various long-haul communication systems with respect to the operational aspects. A number of currently available communication systems are compared in this report. These systems fall into two categories:

- HF radio communication systems;
- SATCOM systems.

The SATCOM systems can be divided into three types:

- Public access SATCOM systems (such as the INMARSAT system);
- Private SATCOM networks (very small aperture terminal (VSAT) networks);
- Military SATCOM systems.

1.2 Outline

The contents of this report are as follows.
The application of long-haul communications assets for RNLAF OOA operations is discussed in chapter 2. Chapter 3 presents an overview of current state-of-the-art HF communication systems. Especially, the applications and limitations of current HF system will be discussed. The characteristics of current state-of-the-art SATCOM systems are discussed in chapter 4. Subsequently, chapter 5 presents a qualitative comparison of the various long-haul communication systems with respect to the operational aspects of the RNLAF.

An outline of future developments in SATCOM and HF technology is given in chapter 6. This chapter will mainly discuss the effects of these developments on the relative comparison of the various communication systems. In this way, the RNLAF may carefully select a system which will also be able to meet future communication needs. Finally, the conclusions of this study are listed in chapter 7.

Appendix A gives an outline of architecture of the possible future RNLAF HF communication system. Appendix B gives an outline of the network and terminal architectures for the possible future RNLAF SATCOM system. Appendix C contains a glossary of terms.

2 LONG-HAUL COMMUNICATIONS FOR OOA OPERATIONS

2.1 Introduction

This chapter discusses the application of long-haul communication assets for out-of-area (OOA) operations on behalf of the RNLAF. First, the OOA deployment of forces of the RNLAF is discussed in order to provide some background information on the operational scenarios of the RNLAF. Hereafter the operational aspects concerning the long-haul communication assets are discussed.

2.2 Deployment of RNLAF forces

Forces of the Royal Netherlands Airforce (RNLAF) may be assigned to:

- **The Multinational Forces**
  Units of the RNLAF may be assigned to the multinational forces (MF) under aegis of the UN, WEU or an ad hoc coalition for peace keeping and peace enforcing operations. Forces of the RNLAF may be deployed world-wide, with the exception of polar areas.
- **NATO Forces**
  RNLAF forces may be deployed under aegis of NATO as part of the Main Defense Forces (MDF) and the Reaction Forces (RF). The NATO Reaction Forces consist of units which can respond to an attack on a short notice. These forces can be deployed in NATO territory and peripheral areas which do not include polar areas.

The following types of RNLAF units belonging to seven different operating bases in The Netherlands may be deployed in an OOA operation:

- **F-16 units:**
  - Main Operating base (MOB) Leeuwarden;
  - MOB Twenthe;
  - MOB Volkel.
- **Air defense units:**
  - Surface to Air Missile (SAM) Group De Peel ('Groep Geleide Wapens / De Peel' (GGW/DP)). The SAM-Group consists of four Triple Air Defense (TRIAD) weapon systems which can operate in two independent units;
  - Smaller air defense units (AFU, SHORAD including Stinger) added to other units.
- **Helicopter units:**
  - Gilze-Rijen (armed and light utility helicopter units);
  - Soesterberg (transport helicopter units primarily in support of operations of the Royal Netherlands Army (RNLA).
- **Transport units:**
  - Eindhoven (transport fixed wing transport aircraft and helicopters).

The F-16 units, air defense units and the helicopter units may be deployed in OOA operations.

For these types of units specific OOA communication assets are required. The extent to which specific communication assets are required will depend on the communication means that are already available in the area of operation. However, if there are no communication means already available, the OOA communication assets have to provide the required communication links.

2.3 OOA communication needs

The Royal Netherlands Armed Forces may be deployed in four different operational OOA scenarios at the same time at maximum. RNLAF forces in case of OOA operations in principle will operate from five different geographical locations at a maximum. The international organisation (NATO, UN or WEU) under which aegis the forces are deployed is responsible for the communications for *operational* command and control traffic.
In order to support national *logistic* command and control traffic, the RNLAF has to provide its own communication assets. For this type of traffic, each unit of the RNLAF will directly obtain support from its original operating base. Furthermore, the RNLAF centre of operations in The Hague ('Operatie Centrum KLu' (OCKLu)) also needs a rear area link, which will be used for political consultation, information and coordination purposes.

Long-haul communication assets will be used for the exchange of information between the rear area (The Netherlands) and the OOA area. These long-haul communication links are called the rear area links. The RNLAF also uses local communication networks, beside the rear area links. These local networks are used to exchange information between locally deployed RNLAF units and they may connect local end-users to the rear area links.
This scenario is depicted in figure 2.1, which schematically gives an outline of the RNLAF OOA communication architecture (as is foreseen in the future).

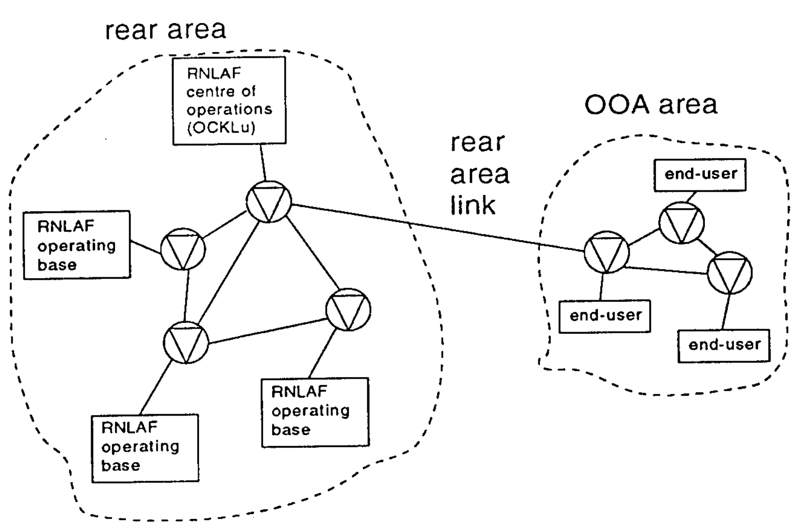


Figure 2.1: Outline of the RNLAF OOA communication architecture.

2.4 Local communication networks

This section discusses local communication networks which are used in The Netherlands or in the OOA area of operation. Both areas will be discussed separately.

2.4.1 Local networks in the rear area (The Netherlands)

Each RNLAF operating base in The Netherlands is equipped with the Local Telecommunications Network (LTN) to be used for communications within the base. The various RNLAF bases are currently interconnected by the following communication networks:

- **ASCON**
  The Automatic Switched Communication Network (ASCON) is a military owned national radio relay network which provides circuit-switched telephone communications between all RNLAF bases and a number of RNLA bases.
- **MDTN**
  The Armed Forces Telephone Network (Dutch abbreviation MDTN: 'Militair Dienst Telefoon Net') is a circuit-switched analogue telephone network. The Netherlands PTT is provider of the MDTN network.
- **PSTN**
  The RNLAF also utilizes the Public Switched Telephone Network (PSTN) to exchange information between the various bases, headquarters and operating centres of the Netherlands Armed Forces.
- **National Emergency Network**
  RNLAF bases are also interconnected via the National Emergency Network, which is controlled by the Netherlands PTT.
- **Packet switched data network**
  In the near future, the RNLAF will utilize the RNLA X.25 packet switched data network to provide the various bases with a message handling system.

In the future, the Netherlands Armed Forces Integrated Network (NAFIN) will replace ASCON and MDTN and serve as network for the transport of voice and data information between the various RNLAF operating bases. The first stage of NAFIN (the establishment of a transport layer) will be delivered into 1996. It is expected that from 1996 the NAFIN transport layer will be used for data communications and for the transport of voice traffic between RNLAF end-users.

2.4.2 Local networks in the OOA area

RNLAF forces deployed in an OOA operation will utilize various communication assets. If available, existing local communication networks will be used. Furthermore, for international operational traffic, communication assets will be utilized which will be provided by the international organisation (NATO, UN or WEU) under which aegis the forces are deployed.

Each type of RNLAF unit uses its own assets for local communications in the OOA area:

- **F-16 units**
  The F-16 units will use local communication assets, if available. Other communication systems such as fieldwire systems and handheld/mobile radio systems have still to be defined.
- **Air Defense Units**
  Units of the SAM-Group (GGW/DP) are equipped with the COMPATRIOT system, which provides communication links between the various employed SAM (HAWK and PATRIOT) systems. Besides COMPATRIOT these units also utilize mobile and handheld radio equipment for communications.
  AFU, SHORAD and Stinger-units are equipped with mobile and handheld radio equipment and also a fieldwire telephone system.
- **Helicopter units**
  The currently available communications systems for use by the helicopter units are HF - and VHF radio and a fieldwire telephone system.

2.5 Employment of long-haul communication assets

The operational aspects of the RNLAF for long-haul communication assets in order to set-up rear area links will be discussed in this section. Each RNLAF unit deployed in an OOA operation needs two different communication links:

- **Link to the RNLAF centre of operations in The Hague (OCKLu)**
  This link will be used for political consultation, information and coordination purposes.
- **Link to its original operating base in The Netherlands**
  This link will be used for the exchange of logistic and support (meteo, intelligence, etc.) information.

These links have to be nationally controlled, because the information to be transported is for NL eyes/ears only [1].
The long-haul communication assets need to be employed in such a way that the deployed RNLAF units have the same telecommunication functionalities at their disposal as they would have at their operating bases in The Netherlands. Existing telecommunications infrastructure (e.g. PSTN or NATO communication networks) will be used if available. However, RNLAF units deployed in OOA operations need always to be equipped with their national long-haul communication assets in order to be able to exchange information under all conditions.

The following operational aspects should be considered regarding the RNLAF long-haul communication networks [2-4]:

- **Multiple services**
  The network needs to support multiple services, such as voice, facsimile, data and telex. Military services such as priority management and pre-emption facilities also need to be supported.

- **Low probability of interception (LPI) and low probability of exploitation (LPE)**
  In order to perform operations in which unauthorized access to the links and transported information is unacceptable, it is required that the long-haul communication systems have a low LPI and LPE. The LPI/LPE performance can be improved by:
  - TRANSEC (Transmission security);
  - COMSEC (Communications security).

  COMSEC facilities are also required for the transmission of messages which are classified: the network needs to support all classifications from unclassified to NATO secret, which implies that encryption techniques need to be utilized.
- **Electronic protective measures (EPM)**
  The network has to be protected by electronic protective measures (EPM) in order to guarantee reliable communications under all conditions, including electronic counter measures (ECM) such as jamming.
- **Electromagnetic compatibility (EMC)**
  The long-haul communication system should not interfere with other electronic systems, such as radar systems and air defense weapon systems.
- **Availability and reliability**
  The system must be reliable and offer a high availability and low probability of blocking. The availability can be defined as the fraction of time within which the system is actually capable of transporting information between the transmitter and the receiver. The reliability can be defined as the ability of the system to perform a network service with the required quality.
- **Network connectivity**
  It is required that the long-haul communications network can be interconnected with current and future local networks used by the RNLAF.
- **Interoperability**
  The long-haul communication network needs to be interoperable with other (national and/or international) communication networks. Network interoperability problems can be minimized if the network applies to NATO interoperability standards (STANAGs).
- **Ease of operation**
  It is desired that communication links can be established automatically, without an operator. If an operator is necessary, it is required that relatively unskilled operators can set-up the communication equipment and establish reliable communication links.
- **Maintenance**
  It is required that the maintenance requirements for the communications equipment are limited. The communication assets must contain built-in test equipment in order to allow an easy detection of failures.

This report will compare the use of HF communication assets and SATCOM assets with respect to the operational aspects mentioned above.

3 CAPABILITIES OF CURRENT HF SYSTEMS

3.1 Introduction

This chapter describes the capabilities of current state-of-the-art HF communication systems. These capabilities are listed in order to enable a comparison between HF and SATCOM systems with respect to the general requirements and needs of the RNLAF concerning long-haul communications for OOA operations. This comparison will be made in chapter 5.

The contents of this chapter are as follows. First of all, the HF communications system currently used by the RNLAF is described in section 3.2. Subsequently, in section 3.3 an outline is given of a general state-of-the art HF system. This outline gives an impression of the specifications of current HF communication systems. The applications and limitations of state-of-the-art HF systems are presented in section 3.4. Finally, conclusions concerning the capabilities of current HF communication systems are presented in section 3.5.

3.2 The RNLAF HF system

The RNLAF HF system is a radio communication system which operates in the HF frequency band. Two HF stations are currently in use in The Netherlands. One station is located in Rhenen and the other station is located in Ried. Both stations are connected to the RNLAF centre of operations in The Hague through the ASCON network and the public switched telephone network (PSTN). This centre of operations remotely operates the two HF stations and serves as relay station between the various RNLAF operating bases and the two HF stations. This implies that the operating bases are not directly connected to the HF stations. Currently, ACP127 messages can be transmitted automatically by the RNLAF operating bases to the HF transceivers. Telefax messages and data file transfer are possible in a semi-automatic mode.

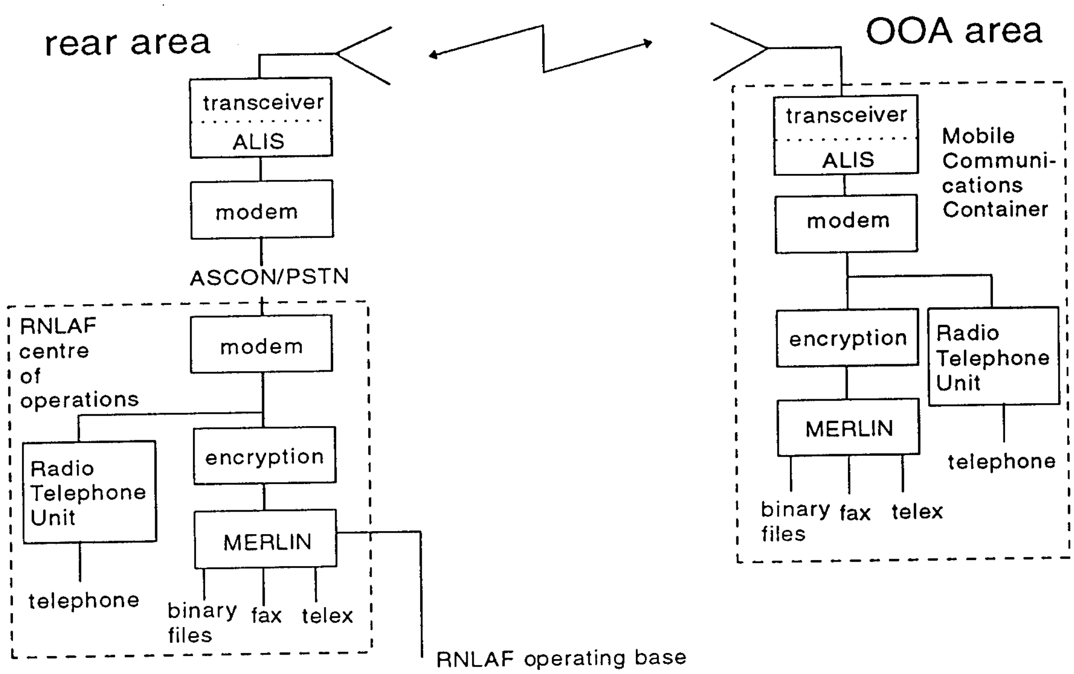
The HF transceivers contain an automatic link set-up (ALIS) unit which determines the optimum working frequency out of a pool of available frequencies. It also automatically establishes the communication links. The HF transceivers are connected to a computer system (MERLIN) which controls the transceivers and interfaces with the end-user equipment such as telefax and telex. The MERLIN computer applies data compression techniques, which means that all data and telex files are compressed up to 50% before they are released to the HF transmitters.

The HF transceivers placed in the OOA area are also connected to the same computer system which controls the HF transceiver. The transportable HF systems used in OOA operations are sheltered in a mobile communications container (MCC). These MCCs also contain the SATCOM assets used by the RNLAF. These SATCOM assets will be discussed in chapter 4. In the near future, the RNLAF will have five MCCs at its disposal [4].

The RNLAF HF system supports the following services:

- Unsecure voice;
- Secure voice (optional);
- (Secure) telex;
- (Secure) facsimile;
- (Secure) binary file transfer.

The RNLAF HF system is schematically depicted in the figure 3.1 [4]. The depicted Radio Telephone Unit is also called Phone Patch Facility.



Figuur 3.1: The RNLAF HF system.

The RNLAF radio communication system contains two modems: a high - and a low data rate modem. The effective data rate (throughput) of the high speed modem is 2400 bit/s; the effective data rate of the low speed modem is 360 bit/s. Adaptive control of the data rate can therefore be performed. The first modem is utilized under optimal atmospheric conditions, while the latter modem is used under non-optimal conditions. These modems are connected to the transceiver and amplifier which can be used with 100, 400 or 1000 W output power.

3.3 Description of state-of-the-art HF systems

This section gives a general description of state-of-the-art HF communication systems. First of all, an outline of a typical HF system will be given, in order to provide some background information. Hereafter the technical specifications of HF systems will be presented.

3.3.1 Outline

An HF communication system logically contains a number of modules: interface with the end-user equipment, modem, transceiver, power amplifier, antenna tuning unit, antenna, link control equipment and sometimes network control equipment. The logical block-diagram of a typical current state-of-the-art HF system is depicted in figure 3.2. The power amplifier, the modem and the link control equipment can be incorporated in the transceiver.

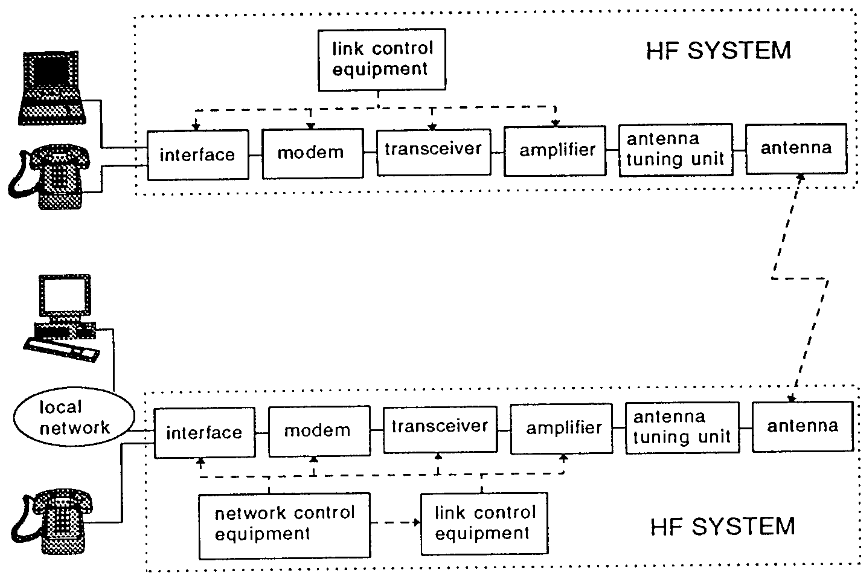


Figure 3.2: Block-diagram of a state-of-the-art HF system.

Each component of a HF system will be discussed in detail:

- **Interfaces**
  Modern HF communications systems contain standardized interfaces to which end-user equipment (such as telephones, telefaxes and data communication equipment) can be connected. The interfaces can also be connected to local networks in such a way that end-users connected to these networks can automatically establish HF communication links.
- **Modem**
  The modem modulates and demodulates the user data in such way that the transmitted signals are adapted to the properties of the transmission medium.
- **Transceiver**
  The transmitter and receiver convert the modem signals into signals with a frequency in the HF frequency range and vice versa.
- **Amplifier**
  The amplifier amplifies the transmitted HF signal.
- **Antenna tuning unit**
  The antenna tuning unit matches the antenna to the transceiver.

- **Antenna**
  The antenna radiates the HF energy in the form of electromagnetic waves. Antenna types that are commonly used in HF communication systems are: dipole antennas, whip antennas, longwire antennas and log-periodic antennas.
- **Link control equipment**
  Most HF systems contain an automatic link establishment (ALE) unit which establishes the links and performs channel quality control. Available channels between two stations are automatically analysed and ranked according to their availability and performance. Using this equipment, the user is secured against the cumbersome activities of checking frequencies and establishing links. The ALE unit can be integrated with the transceiver.
- **Network control equipment**
  Network control equipment is needed if multiple HF systems are used which mutually exchange information. This equipment must manage the complete HF network. This includes activities such as configuration management (the entrance or exit of terminals), frequency management, the formation of net groups and the management of security keys for security of communications and transmissions (COMSEC and TRANSEC). Most networks apply centralized control which means that only one network management system is needed.

3.3.2 Specifications

In this section some technical specifications of current HF communication systems will be discussed. The specifications of modems and transceivers will be discussed separately.

Modems
Modern modems employ intelligent forms of phase modulation or multiple frequency keying techniques in order to combat the notorious multipath effects which distort data transmissions. To reduce the bit error rate (BER), forward error correction (FEC) codes are added.
The raw data rate that can be achieved in a 3 kHz wide channel under fair conditions is about 2400 bit/s. If FEC is omitted it will rise to 4800 bit/s.

Transceivers and amplifiers
Most HF transceivers cover the frequency range from 1.6 MHz to 30 MHz, tuneable in 10 Hz steps. The transceivers are available in a wide range of radio frequency (RF) output powers, normally between 20 W and 150 W. Using separate solid state or valve amplifiers, this may be increased up to 1 kW or more. Modern transceivers can operate in different frequency modes:

- **Single-channel mode**
  One channel of 3 kHz available for data (through a modem), digital speech (through a vocoder) or analogue speech (SSB).
- **Multi-channel mode**
  In the multi-channel mode, some modern transceivers can provide up to four independent 3 kHz channels, one 6 kHz channel or two independent 6 kHz channels. The data throughput for each channel is equal to the data throughput in the single channel mode, except for the 6 kHz channels in which the capacity is doubled.

- **Frequency hopping mode**
  Some HF transceivers also provide a frequency hopping mode which increases the resistance against electronic counter measures (ECM), such as jamming. Most transceivers provide slow frequency hopping with a hop rate around 20 hop/s. (If the hop rate is equal or higher than the symbol rate of the RF signal, the mode is called fast hop, if more than one symbol is transmitted during one hop it is called slow hop [5].)
  The hopping bandwidth (the bandwidth in which frequency hopping takes place) can be tuned and may be programmable from 50 kHz up to 2 MHz. The maximum data throughput in the hopping mode is normally smaller than that in the fixed frequency mode.

3.4 Capabilities of state-of-the-art HF systems

This section discusses the capabilities of current state-of-the art HF communications systems. The following subjects will be discussed:

- Services;
- Coverage;
- Availability and reliability;
- Interoperability and network connectivity;
- Mobility;
- Personnel and economical aspects;
- Electronic protective measures (EPM) and security aspects.

3.4.1 Services

The question which user applications can be supported by an HF communication system can only be answered after an evaluation of the available link capacity. The available capacity in an HF channel is determined by:

- Modem;
- Channel bandwidth;
- Propagation conditions and noise.

The best available modems will adapt to the changing propagation conditions in order to reach the highest possible data throughput. In a 3 kHz channel and under fair propagation conditions one can reach 1200 to 2400 bit/s of data throughput. Under poor propagation circumstances (severe multipath) the throughput may drop to less than 300 bit/s.

The following services can be supported by an HF system:

- Analogue and narrowband digitized voice;
- Digital file transfer;
- Telefax;
- Telex;
- Slow scan video.

The information which has to be transmitted by the HF system may be encrypted. This applies to both analogue and digitized voice as well as data. Also, the digital data used for the ALE system can be encrypted in order to ensure that only legitimate users will have access to the system.
Some of these services (such as telefax) require the use of automatic repeat request (ARQ) protocols in order to guarantee a 100% error free data throughput. These services can therefore not be offered error free in the broadcast mode.

3.4.2 Coverage

Area coverage is heavily dependent on the availability of suitable frequencies, the geographical position, transmitter power, antenna and solar activity. Because of the large number of variables it is not possible to give a simple figure.
Generally spoken, most places on earth can be connected via HF through direct links. Nearly every distance can be reached using so called skywave propagation via the ionosphere, given the possibilities of using frequencies between 3 and 30 MHz. This can be accomplished with moderate power equipment and a suitable, efficient antenna (e.g. long wire or horizontal or vertical dipole).
Exceptions are links crossing the polar region which may encounter long spells of severe attenuation and distortion. This will be discussed in the next section.

The longer the distance ('longer' being more than about 5000 km) the greater the chance of encountering barriers which may be a temporary boundary for HF signals, unless large directional antennas can be employed which may reach those spots via detour.

Very short distances (up to about 100 km) can be reached via groundwave. This type of wave does not propagate via the ionosphere and is always present. Its range is limited to about 100 km. At HF, best groundwave performance is achieved using vertical polarization, i.e. vertically polarized antennas.

Whether the ionosphere will reflect radio signals, is dependent on frequency and the angle of incidence. For low frequencies that angle may be high, up to 90°. In that special case their is no so called 'skip zone'. In most cases however, the angle of incidence will be less than 90°, resulting in an area which can not be covered. This is illustrated in Figure 3.3.

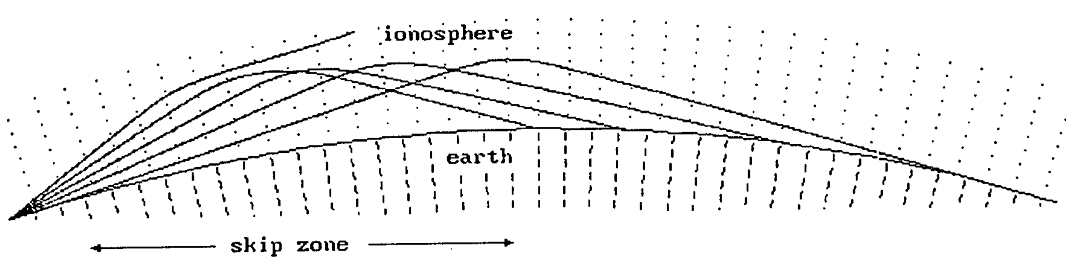


Figure 3.3 Coverage by HF: groundwave, skywave and skip zone.

The skip zone is the area closest to the transmitter for which there is no coverage. Longer distances can be covered, though may experience areas of poor reception.

3.4.3 Availability and reliability

The availability and reliability of an HF communication system is dependent on two aspects: the equipment and the transmission medium. These aspects will be discussed separately.

Equipment
Figures of equipment reliability are given by the manufacturers and are often expressed as MTBF (mean time between failure). MTBF figures of 6000 hours or more are obtainable.

Medium
High frequency skywave propagation takes place between the surface of the earth and the ionosphere which reflects the radio waves back to earth. Transmission over long distances takes place by successive reflections from the ionosphere to earth and back.
The ionosphere is a good reflector. HF signals may be reflected by the E- or F-layer, the F-layer being the most important reflecting layer. Reflection losses are mainly induced by the intermediate ionized layers, which must be passed before the reflecting layer can be reached. The signal needs to pass the D- and E-layer on its way to the F-layer. Mainly the D-layer causes attenuation of the signal. Both D- and E-layer are not or weakly present at night, resulting in an increase of signal strength during darkness.

The characteristics of the ionosphere layers vary with latitude, time of day, season and with solar activity. With increasing latitude, the ionosphere also becomes more sensitive to solar disturbances.

Solar activity may result in several ionospheric effects: short wave fade (SWF) (or sudden ionospheric disturbance (SID)) and polar cap absorption (PCA).
An SWF may wipe out all ionospheric propagation in the sun lit parts of the earth for several minutes, lasting sometimes up to a few hours. The effects are equal for all latitudes. Reason for the wipe out is the strong increase of ultra violet radiation of the sun during outbursts, which increases the ionization level of the D-layer. A strong increase in ultra violet radiation, caused by a solar irruption, will strongly increase the absorption and may wipe out HF communication up to 30 MHz. The higher frequencies are less effected and will also restore quicker than lower frequencies.
As a result of solar activity, the overall attenuation may increase dramatically for several days. This is mainly true for the polar region and is called a PCA event. Although a PCA does not block the communication paths completely, attenuation is increased and useful frequencies with little extra attenuation may not be found.

The total attenuation over the communications path varies and is the sum of attenuations due to absorption in the ionosphere, the losses due to ionosphere reflections and the losses due to earth reflections, together with the attenuation due to the normal expansion of the wavefront with the distance.

It can therefore be concluded that the availability of a link depends on the:

- Locations of the transmitting and receiving stations;
- Time of day;
- Season of the year;
- Solar activity.

The usable frequency band (i.e. the number of usable channels) also varies. If the operating frequency is above the maximum usable frequency (MUF), the wave will pass through the ionized region and out into space (see the upper ray in figure 3.3). If the operating frequency is below the lowest usable frequency (LUF), too much of the energy will be absorbed in the ionized layer and communication is not possible.
The MUF and LUF change with the state of ionization in the ionosphere. This means that the available band for communications varies.

It is therefore not possible to give general values for the availability and reliability of the HF communications medium. These values are largely dependent on the propagation conditions. (For the HF link between the Netherlands and Villafranca, Italy, the RNLAF has experienced a link availability of around 90%.)
Although computer programmes (e.g. IONCAP) can accurately predict the MUF, the LUF and the expected received signal strength, sudden changes in the solar activity can not be predicted.

3.4.4 Interoperability and network connectivity

On the subject of interoperability of HF equipment, voice coders for digitized voice and modems, the following STANAGs apply:

- **STANAG 4197**
  Modulation and coding characteristics that must be common to assure interoperability of 2400 bit/s linear predictive encoded digital speech transmitted over HF radio facilities.
- **STANAG 4198**
  Vocoder characteristics (2400 bit/s).
- **STANAG 4203**
  Technical standards for single channel HF radio equipment.
- **STANAG 4285**
  Characteristics of 1200/2400/3600 bit/s single tone modulators/demodulators for HF radio links.
- **STANAG 4444** (under development)
  This STANAG standardizes the operation of HF frequency hopping systems.
- **STANAG 4479** (under development)
  Characteristics of 800 bit/s digital speech encoder/decoder and associated error protection and interleaving schemes leading to the 2400 bit/s interface of the slow frequency hopping HF-ECCM system.
- **STANAG 5032**
  Single sideband.

HF communication systems also provide standardized data and remote operation interfaces to local end-systems and for remote operation (e.g. RS-232C, MIL-STD-188C).

HF equipment of different companies is only interoperable if the equipment applies to the appropriate STANAGs. If the equipment does not apply to the STANAGs, interoperability is only possible when the transceivers are operated in linear modes such as the single sideband mode or the amplitude modulation mode.

3.4.5 Mobility

Modern HF equipment is relatively lightweight, even in ruggedized military designs. Civil implementations may have a weight half of the military design.
The weight of military 125 W HF system - including transceiver, antenna tuner, power amplifier and power supply - might for example be 60 kg. For a military 1 kW HF system - including transceiver, antenna tuner, power amplifiers, power supplies and interface box - the weight might be around 330 kg.

Depending on the output power, an HF communication system (excluding power generators, shelters, etc.) physically contains 4 to 7 modules: antenna tuner, power amplifier(s), one or more power supplies, optional interface box and transceiver (including modem and ALE facilities). The modem may also be a separate unit. The complete transmitting system except for the antenna tuner will occupy less than 0.2 m^3 for a 125 W version and less than 0.4 m^3 for 1 kW. The antenna tuner antenna generally requires less than 0.025 for 125 W and less than 0.07 m^3 for a 1 kW HF system.

3.4.6 Personnel and economical aspects

First, the personnel aspects will be discussed and hereafter, the system costs.

Personnel
Three tasks have to be performed by personnel in order to establish reliable HF communication links:

- **Installation of the system**
  An HF communication system can easily be installed by a relatively unskilled person in half an hour or less. Only the set-up of the antenna may take some more time and personnel (this depends on the complexity of the antenna involved).
- **Operation of the system**
  Most state-of-the-art HF communication systems contain an automatic link establishment feature. This feature greatly simplifies the operation of the HF systems.
  Reliable communication links can be established automatically. No specific operation skills are needed to send and receive radio messages. After installing the HF system, it can be operated in remote control or stand-alone mode.
- **Maintenance**
  Most HF systems contain built-in test equipment (BITE) which enables a relatively unskilled operator to monitor any equipment malfunction. Most HF systems contain a display which lists fault messages including the faulty module and a specific code that describes the detected fault. The modular design of the system will make it possible to change defective parts within half an hour.

System costs

Costs of HF communication systems largely depend on the system configuration and incorporated features. It is very hard to list general figures. However, in order to get an impression, the costs of an HF system of 100 to 1 kW RF output power, incorporating facilities like ALE, frequency hopping (FH), information encryption and an antenna tuner can be estimated to lay between Hfl 80,000.- and Hfl 200,000.-.

The system costs largely are unique; once the system is bought, the operation costs are relatively low.

3.4.7 Electronic protective measures (EPM) and security aspects

EPM covers the electronic aspects of protection and counter measures:

- Electromagnetic compatibility (EMC);
- Electromagnetic interference (EMI);
- Electronic counter counter measures (ECCM);
- Electromagnetic pulse (EMP).

Security aspects (COMSEC and TRANSEC) will be separately discussed in this section.

EMC/EMI

Peripheral equipment, like telefaxes and computers may cause severe interference to the receive equipment. Noise levels may increase by tens of decibels over normal, causing disruption of the link.

On the other hand, high field strength levels from a nearby antenna may cause malfunction of computers and other data equipment. HF transmissions may cause interference on VHF and UHF links. This may be caused either by harmonics from the HF equipment, or by overloading of the VHF/UHF input circuitry. The RF part of radar like equipment is not likely to be sensitive to the HF transmissions. The radar processing part might be and should be properly shielded.

In general: equipment should be electromagnetic compatible and interconnecting cables should be properly shielded. Filtering of receiver inputs and transmitter outputs may reduce or eliminate interference.

HF antennas are large. A nearby thunderstorm may charge the antenna to several thousand volts, which may cause permanent damage to the input circuitry of the receiver. Nearby lightning strikes will induce large currents which in turn may cause damage. Protection with diodes and clamping devices at the input circuitry may prevent damage.

Proper grounding and shielding of interconnecting cables will prevent or reduce damage caused by nearby lightning strikes.

ECCM

Jamming on HF is more difficult than on VHF. The changing nature of the ionosphere will nearly always permit some of the desired signal to come through. Counter measures against jamming can be taken for example by changing the frequency in such a way that the jammer is in the skip zone. Other possibilities are frequency hopping and short burst transmissions.

EMP

An electromagnetic pulse (EMP) may cause a very high voltage in conductors and causes a very strong ionization of the D-layer and an unset of the E- and F-layer, resulting in a complete black out of all shortwave communication. This may last for a considerable time (hours).

Security aspects

Transmission security (TRANSEC) measures reduce the ability to detect transmissions (also called LPD; low probability of detection). Communication security (COMSEC) measures reduce the possibility to decode a message (LPI; low probability of intercept).

TRANSEC can be obtained by using transmission techniques like frequency hopping (FH) or (short) burst transmissions. The special propagation effects which causes skip zones, the use of sufficiently low frequencies which enhances losses on long distances or the use of antennas with special radiation patterns, may increase the TRANSEC abilities of an HF system.
COMSEC can be provided by using cryptographic techniques to encrypt the data.

3.5 Conclusions

It can be concluded that the capabilities of state-of-the-art HF communication systems are greatly improved during the last years. The capabilities of current HF systems can be summarized as follows:

- **Services**
  A typical HF system is capable of providing a reliable data throughput of 2400 bit/s in a 3 kHz channel during good to fair propagation conditions and up to 300 bit/s during poor propagation circumstances.
  HF systems can provide the following services: both analogue and digitized voice, telefax, telex, slow scan TV and digital file transfer.
- **Coverage**
  World-wide coverage may be provided, but the usability of a long-haul HF communication link is not constant and is dependent on time of day, frequency and sunspot number.
- **Availability and reliability**
  The availability and reliability of an HF communication system varies and is largely dependent on the following factors:
  - Locations of the transmitting and receiving stations;
  - Time of day;
  - Season of the year;
  - Solar activity.

  It is therefore difficult to give general figures for the availability and reliability.
- **Interoperability and network connectivity**
  HF communication systems are interoperable with each other if they apply to the appropriate STANAGs. However, most HF system do not simply apply to these STANAGs.

- **Mobility**
  The mobility of modern HF systems is high. The equipment is relatively lightweight, low volume and can easily be installed in a short period of time.
- **Personnel and economical aspects**
  Relatively unskilled operators are able to install and operate the HF system. The maintenance of the system can also be performed by relatively unskilled operators. Most HF systems contain built-in test equipment (BITE). Once the system is installed, it may be operated in remote control or stand-alone mode.
  Costs of HF systems largely depend on the system configuration and the incorporated features. Most costs are a one time feature and, once the system is bought, the operational costs are relatively low.
- **Electronic protective measures (EPM) and security aspects**
  EMC/EMI problems may arise because of the relative large antenna structures. Because of this, the susceptibility to external electromagnetic effects can be fairly large. Noise sources may also deteriorate reception. With proper protective measures and carefully chosen sites, however, these effects can be diminished.
  HF transmissions may cause problems to nearby receiving and data processing equipment, but with proper shielding and filtering these can be eliminated.
  TRANSEC and COMSEC can be provided by using propagation effects, frequency hopping, burstlike transmission techniques and encryption of the data.

4 CAPABILITIES OF CURRENT SATCOM SYSTEMS

4.1 Introduction

The capabilities of current state-of-the-art SATCOM systems are described in this chapter. The structure of this chapter differs somewhat from the structure of chapter 3. Chapter 3 discussed only one type of communications system, as opposed to this chapter which treats three different types of SATCOM systems. These three systems are the following:

- Public access SATCOM (e.g. INMARSAT);
- Private SATCOM networks (e.g. VSAT networks);
- Military SATCOM.

This chapter contains the same sections as chapter 3, but where applicable each section consists of three subsections in which the different types of SATCOM systems are separately discussed with respect to the relevant subject.
The contents of this chapter are as follows. The SATCOM system currently used by the RNLAF is described in section 4.2. Subsequently, general outlines of the three SATCOM systems are given in section 4.3. The applications and limitations of the various systems are discussed in section 4.4. And finally, conclusions concerning the capabilities of the current state-of-the-art SATCOM systems are presented in section 4.5.

4.2 The INMARSAT systems used by the RNLAF

INMARSAT is a civil international organisation which offers telecommunication and navigation related services to mobile users [6]. The INMARSAT space segment consists of four operational geostationary satellites, which provide a world-wide coverage (with the exception of the polar areas). Using these satellites, communication links may be established between the operating bases in The Netherlands and the various RNLAF units. The operating bases in The Netherlands primarily utilize the large fixed PTT satellite earth station in Burum for their communications with the deployed RNLAF forces. This satellite earth station is connected via the PSTN network to the operating bases. The deployed RNLAF forces utilize both INMARSAT-A and -C terminals:

- **INMARSAT-A**
  INMARSAT-A terminals are equipped with a directional antenna which has a diameter of 0.8 - 1.2 m. The antenna must be pointed manually to the satellite. The INMARSAT-A terminals offer both voice and telefax services. The RNLAF utilizes the Saturn CompacT terminals.
- **INMARSAT-C**
  INMARSAT-C terminals are equipped with very small omnidirectional antennas (diameter approximately 0.2 m). These antennas do not have to be pointed towards the satellite. The INMARSAT-C system utilizes digital transmission techniques with a data rate of 600 bit/s. This INMARSAT system only operates on a store-and-forward basis and

can therefore not support voice services. The RNLAF uses INMARSAT-C Capsat terminals to support telex and data communications.

Figure 4.1 depicts the use of INMARSAT SATCOM assets by the RNLAF.

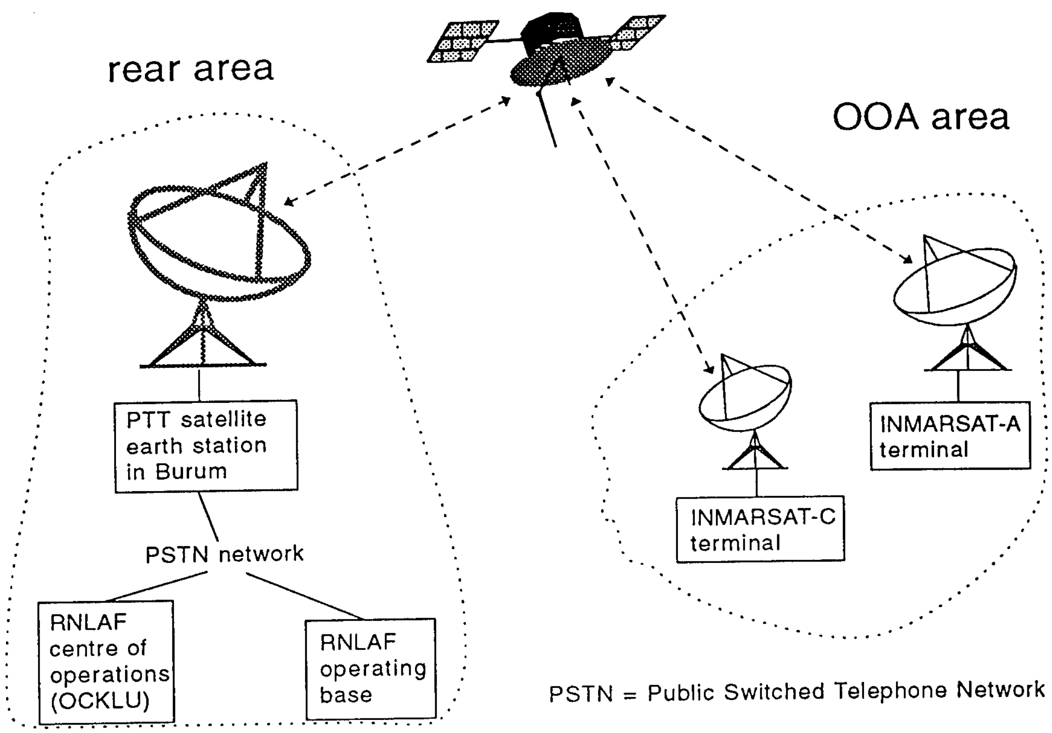


Figure 4.1: *The use of INMARSAT SATCOM assets by the RNLAF.*

4.3 Description of state-of-the-art SATCOM systems

This section gives a general description of the three considered SATCOM systems in order to provide some background information. Furthermore, the components needed for a SATCOM system will be listed. The specifications of the various systems will also be discussed.

The three different systems are:

Public access SATCOM
With public access systems, it is not possible for customers to configure their own networks. Public access systems consist of a small number of large fixed earth stations connected to the public switched networks and a very large number of small remote terminals. In most cases the large earth stations are exploited by the national PTTs. The characteristics of the small remote terminals are specified by the organization which provides the satellite capacity. Also the SATCOM link parameters (such as modulation techniques, multiple access methods, etc.) are specified by the capacity provider.

The exchange of military command and control information via public access SATCOM systems is prohibited by the regulations of the satellite organizations. The following international organizations provide public access satellite capacity [6]:

- INTELSAT;
- EUTELSAT;
- INMARSAT.

Many more organizations providing satellite capacity exist, but these are regional or even sub-regional. Most of these organizations either do not provide capacity or do not have coverage beyond their own target area.

INTELSAT
The current INTELSAT satellite constellation consists of 19 satellites. These satellites utilize both the C-band (4/6 GHz) and the Ku-band (11/14). For INTELSAT, the C-band offers the largest amount of satellite capacity and global coverage, while the Ku-band offers limited capacity and no world-wide coverage (only Europe and the eastern part of North and South America). The C-band has the drawback that mobile satellite services are not allowed, according to the Radio Regulations of the International Telecommunication Union (ITU).

EUTELSAT
The interim EUTELSAT organization was founded by the PTTs of 17 European countries in 1977. The EUTELSAT organization currently exploits 8 satellites which provide capacity in the Ku frequency band. These satellites provide a coverage area which includes Europe (up to the Ural Mountains) and the Mediterranean area.
EUTELSAT also offers land mobile services. For example, the EUTELTRACS positioning systems enables the mobile user to measure its position within 300 metres, using only two satellites. Messages can also be send to and from a mobile user [7].

INMARSAT
The INMARSAT organization provides satellite services to mobile terminals (as well maritime terminals, as land-based and aero-based terminals). INMARSAT currently exploits four satellites which provide a global coverage. The INMARSAT satellites provide capacity in the L frequency band (1.5/1.6 GHz), which is exclusively allocated to mobile satellite services. The following INMARSAT terminals are currently available:

- **INMARSAT-A**
  This system is currently used by the RNLAF and described in section 4.2.
- **INMARSAT-B**
  The INMARSAT-B system is comparable to the INMARSAT-A system, but utilizes digital transmission techniques, as opposed to the INMARSAT-A system. INMARSAT-B terminals are comparable qua volume and weight to the INMARSAT-A terminals.
- **INMARSAT-C**
  The INMARSAT-C system is also currently used by the RNLAF and is therefore described in section 4.2.

- **INMARSAT-M**
  The INMARSAT-M system enables the use of very small man-portable terminals and provides telefax and data services with a bit rate of 2400 bit/s and a voice service with a data rate of 4800 bit/s.

Private SATCOM networks
As opposed to public access systems, private systems may be closed networks. This means that these networks are not connected to public communication networks or networks belonging to other organizations. There are also no restrictions concerning terminal types, size of antennas, used modulation techniques, etc. This makes the private networks very suitable for the application of very small aperture terminals (VSATs).
Organizations providing capacity for private SATCOM networks also prohibit the use of their systems for the exchange of military command and control traffic.
With these networks, the customer is being enabled to configure its own dedicated network. Each customer can procure and exploit the complete ground segment, but satellite capacity has to be leased. Capacity can be leased from a large number of organizations which each provide world-wide, regional or national coverage. The most interesting satellite capacity providers for the RNLAF are:

- The INTELSAT organization which provides global coverage;
- The EUTELSAT organization which provides European coverage.

For both organizations, satellite capacity has to be rented via national PTTs on a fixed price basis. This means that a fixed amount of capacity will be leased and paid for, independent of the actual use of capacity.

Military SATCOM
Currently, a large number of military satellites are operational. The following NATO nations have military satellite capacity at their disposal: the United States, the United Kingdom, France, Italy, Spain, Canada and of course NATO itself. All satellites, except the NATO satellites, are used for national military purposes. Other nations may only use the satellites if a Memorandum Of Understanding (MOU) is signed by the using and providing nations. The NATO satellites currently provides capacity for the NATO Integrated Communications System (NICS), other NATO networks and some national maritime networks (e.g. the RNLN; for which also an MOU has been signed).

4.3.1 Outline

A SATCOM system is a transmit and receive system which is capable of establishing a link to another user via a satellite.
The main blocks of such a system are: an antenna, a transmitter (up-converter and power amplifier), a receiver (low noise amplifier and down-converter) and a modem (modulator demodulator).
Whether the antennas deployed will be large or small is virtually independent of the type of satellite system. Generally speaking the 'public access' systems will tend to be relatively small. Antenna diameters are between 0.2 and 2 m in general. The antenna diameters of military

terminals and the private networks vary between 0.3 and > 5 m.

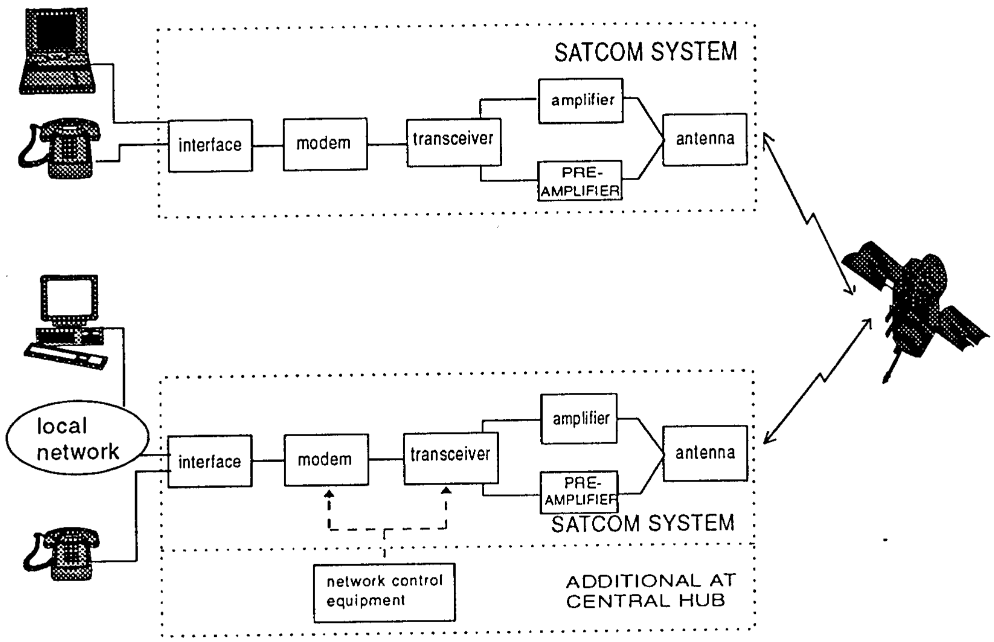


Figure 4.2: *Universal block-diagram of a state-of-the-art SATCOM system.*

Each block component will be discussed in the next paragraphs:

- **Interfaces**
  Interfaces providing connectivity to PSTN and other local networks are mostly provided by VSAT and INMARSAT systems. In case of a military system the user may define the interface to its own special purposes. In some cases the interface supplied on the modem may already be suitable.
- **Modem**
  The modem modulates and demodulates the data according to SATCOM standards. Civil standards are for instance IBS (Intelsat Business Service) and IDR (Intermediate Data Rate), which ensure interoperability between modems of different manufacturers.
  If required, most modems can be adapted to specific user requirements, however, interoperability will then be lost.
- **Transceiver**
  Unlike HF and VHF equipment, a satellite transceiver often consists of two separate units. A power amplifier is always needed, besides an up- and down-converter. Because most satellites are in fact linear transponders, frequency conversion takes place. The satellite will receive on the higher frequency and retransmit on the lower frequency. Consequently, up- and down-converters will use different frequencies and can work simultaneously (full-duplex).

- **Amplifier**
  The RF power delivered by an up-converter is in the order of a few mW. Depending on the satellite system used, several watt to hundreds of watt of RF power are needed. Up to about 40 watt of RF can be delivered using solid state amplifiers. Beyond this power level TWTAs (Travelling Wave Tube Amplifiers; up to about 600 W) or Clystrons become inevitable.
- **Pre-amplifier**
  The objective of a pre-amplifier is to amplify the received signal and add as little noise as possible to the incoming signal. In satellite communication signal levels are extremely low and so is the noise received from the sky and out of the galaxy. Much can be gained by employing a low noise pre-amplifier close to the antenna.
- **Antenna**
  The antenna radiates the RF energy in the form of electromagnetic waves. High gain antennas are needed to cover the enormous free space path losses involved.
- **Network control equipment**
  Most SATCOM networks apply centralized control, which means that the network control equipment is located at one place, which mostly is a network anchor station or a central hub station. Public access systems like INMARSAT have a network management centre near the central hub, where all traffic is routed to. Private and military SATCOM systems also apply a centralized concept. Only networks consisting of a very small number of fixed point-to-point links do not need a network control unit and therefore do not apply centralized control.

4.3.2 Specifications

This section discusses technical specifications of the different types of current SATCOM systems. SATCOM terminals and modems will be discussed separately.

Terminals

Military SATCOM

The overview presented here is based on the present capabilities of military satellites. In the advent of new satellites higher data throughputs may be realized.

Most military terminals operate in the SHF band (7.25 - 8.4 GHz). Some operate in the UHF band, but have a limited capacity of about 32 kbit/s. Because of the limited availability of UHF SATCOM capacity, interference problems in the UHF band and limited suitability for the RNLAF application, these terminals will not be discussed further.

In the overview in table 4.1 only an example for SHF band terminals is presented, because EHF terminals are still in an experimental stage. Off-the-shelf availability is expected before the year 2000.

Table 4.1: Overview of military SHF band terminals.

Band	Antenna diameter	RF pwr. EIRP	Weight	Data throughput
X*	0.6 m (manpack)	> 38 dBW	< 20 kg	2.4 - 4.8 kbit/s
X*	0.9 - 1.3 m (small)	> 57 dBW	120 - 500 kg	up to 256 kbit/s
X*	> 2.7 m (medium)	> 64 dBW	> 1000 kg	up to 2048 kbit/s

* X-band: 7/8 GHz

Public access SATCOM

The most important public access SATCOM system is the system provided by INMARSAT. The example of terminal specifications given in table 4.2 therefore applies to INMARSAT terminals. Public access satellite terminals can be purchased from various manufacturers. These terminals enable the user to link into the satellite network in the same way as they would link into a PSTN. In fact, the satellite network is connected to the PSTN, so a satellite terminal user can be connected to any subscriber in the PSTN world-wide. Also other 'mobile' SATCOM users can be addressed. This might either be by using the same satellite or via the PSTN - and another ground station - to another satellite.

Size, weight and cost are important issues for the customer, because he will often use the terminal in remote places with only light transport possibilities. It will be shown that a great deal of effort has mainly been put into the restriction of the ground terminals.

Table 4.2: Overview of INMARSAT terminals.

Band	Antenna	Size	RF pwr. EIRP	Weight	Data throughput
L*	0.9 m ∅	0.13 m^3	25 - 33 dBW	abt. 35 kg	64 kbit/s (INM.-A)
L*	0.9 m ∅	0.13 m^3	25 - 33 dBW	abt. 30 kg	64 kbit/s (INM.-B)
L*	0.12 m^2	0.025 m^3	19 - 27 dBW	abt. 9 kg	2.4 kbit/s (INM.-M)
L*	0.2 m ∅	0.012 m^3	12 dBW	abt. 7 kg	600 bit/s (INM.-C)

* L-band: 1.5/1.6 GHz

Private SATCOM networks

Private networks enable the customer to configure a dedicated network. For example connecting several plants to the main office for video conferencing, or data links to car dealers. Although often referred to as very small aperture terminals (VSAT), their actual size may be considerable. In fact terminals providing the 'VSAT' services with really small antennas (diameter < 1 m) are not available (yet). Table 4.3 gives an example of VSAT terminal specifications.

Table 4.3: Overview of VSAT terminals.

Band	Antenna diameter	Size	RF pwr. EIRP	Data throughput
C*	2.4 - 4.5 m	0.2 - 0.5 m^3	48 - 71 dBW	48 - 8500 kbit/s
Ku**	1.8 - 3.7 m	0.2 - 0.5 m^3	49 - 76 dBW	48 - 8500 kbit/s

* C-band: 4/6 GHz

** Ku-band: 11/14 GHz

Modems
In general, modems are the interface between data and RF. A modem provides modulation and demodulation of the RF carrier. Added may be features like coding for error correction and data buffers. The channel access schemes may be TDMA (time division multiple access), FDMA (frequency division multiple access) or CDMA (code division multiple access).
Military SATCOM systems have been using CDMA mainly for reasons of TRANSEC and ECCM. However TDMA and FDMA are also widely used.
INMARSAT uses FDMA on its A-, B- and M-terminals. The C-terminal (data only) uses a kind of packet switching.
VSAT networks may use either TDMA or FDMA transmit schemes. In case of FDMA systems an IBS or IDR type of modem is often employed. These types of modems use standardized protocols and data overheads, so they can interoperate with other modems as long as data rate, error correction code and modem type (IBS or IDR) are the same.

4.4 Capabilities of state-of-the-art SATCOM systems

The capabilities of current state-of-the-art SATCOM systems will be described in this section. The following subjects will be discussed:

- Services;
- Coverage;
- Availability and reliability;
- Interoperability and network connectivity;
- Mobility;
- Personnel and economical aspects;
- Electronic protective measures (EPM) and security aspects.

4.4.1 Services

Military SATCOM
The facilities in military SATCOM systems are merely defined by the available channel capacity and type of modem. The channel capacity may be that small that the possibility of speech is restricted (e.g. in case of a small manpack terminal). If the proper equipment is used data file transfer as well as telefax, still/moving video and speech can be supported by military SATCOM.

Public access SATCOM
INMARSAT offers medium speed transmission possibilities. The maximum data rate that can be supported by INMARSAT is 64 kbit/s (INMARSAT-A and -B). This may be enough for low quality moving video and still picture video. Also telefax and speech are supported, though not by all available terminals:

- INMARSAT-A: analogue speech, telefax, data (max. 64 kbit/s);
- INMARSAT-B: digital speech, telefax, data (max. 64 kbit/s);
- INMARSAT-C: data (max. 600 bit/s);
- INMARSAT-M: digital speech (4800 bit/s), telefax, data (max. 2400 bit/s).

Private SATCOM networks
The availability of transponder bandwidth and a large number of powerful commercial satellites enable private (VSAT) network suppliers to offer a large amount of facilities, such as:

- Video conferencing;
- Videotext;
- Telex;
- Telefax;
- (Selective) broadcasting;
- Public or private telephony.

Terrestrial interfaces which are supplied enable the user to connect to multiplexers, peripheral equipment, private networks or the PSTN.

4.4.2 Coverage

Military SATCOM
At present, coverage by NATO IV satellites only ranges from about 85° west to 85° east, excluding the polar regions. The antennas used for this 'world-wide' coverage are low gain, so large terminals are required. Some of the NATO IV antennas however are directed to Europe and provide higher gain, enabling small terminals to be incorporated.
National military SATCOM systems like Skynet (UK) and Syracuse (France) don't have world-wide coverage, except for DSCS (US).

Public access SATCOM
The INMARSAT satellites cover the whole earth, excluding the polar regions, but including the pacific ocean.

Private SATCOM networks
Coverage of private SATCOM systems depends on the availability of suitable satellites, but can be similar to that of INMARSAT (i.e. world-wide, excluding the polar regions). However, the coverage offered by these systems to mobile terminals is limited to Europe and Northern America, due to the frequencies these satellites operate on. Only private SATCOM networks operating in the Ku-band are allowed to provide services to mobile terminals. Current satellites operating in this band only provide coverage to Europe and America.

4.4.3 Availability and reliability

The availability and reliability of SATCOM systems dependents on the equipment and the transmission medium. These aspects will be discussed separately.

Equipment
The reliability of SATCOM systems is rather high. Sensitive parts are the power amplifier - specially when TWTs are involved - the local oscillator and the antenna. TWTs are more sensitive to mechanical and temperature shock than solid state amplifiers.
The antenna is vulnerable in two ways:

- Large (mobile) terminals which are subject to high winds may lose track (causing total or partial loss of signal). Mobile terminals (Highly Transportable Terminals) may fail to point within 1° when winds reach more than 70 km/h;
- Mechanical damage to the antenna will result in a loss of efficiency, i.e. a lower gain. This may have a strong impact on data throughput.

Small terminals (less than 1 metre antenna diameter) are less vulnerable to both aspects. High winds can be tackled by using firm underground and accurate positioning systems.

Medium
The influence of the transmission medium on the availability and reliability of SATCOM is limited.

Certain atmospheric conditions may influence the availability though. Precipitation is the main cause of increased path loss. With increasing frequency the attenuation caused by precipitation increases as well. Below about 4 GHz their is no substantial additional loss due to rain. Even with heavy rainfall rates of 64 mm/h, the extra loss amounts less than 1 dB. For higher frequencies this figure increases dramatically.
The increased path loss caused by rain may be compensated by employing power control or, less sophisticated, a margin in the link budget. The availability can be estimated from local statistical annual rainfall figures and converted into a link margin. By applying power control or an appropriate link margin, the availability can be made virtually independent of the weather situation [8].

Strong disturbances in the ionosphere, caused by solar activity, may lead to a change of polarization. This may be a problem when linear polarization is used (horizontal/vertical) and is less a problem when using circular polarization.
Attenuation may also be caused by obstacles. It is vital that the path to the satellite is clear. Trees will cause a substantial increase in path loss (several dBs) at frequencies above 5 GHz. This increase in path loss may be large enough to prevent reliable communications. On lower frequencies, very light vegetation is allowed if no other option is possible. Other structures of concrete or metal must be out of the line-of-sight between antenna and satellite, in order to enable communication.
A phenomenon happening during the equinoxes (March and September) is the outage caused by solar eclipses. This phenomenon appears during 5 days per year. The duration and number of occasions are dependent on antenna beamwidth (smaller beamwidths gives shorter outage periods on fewer occasions) [8].

If a reasonable link margin is included, the availability of the satellite is considered to be more than 99.99% [9]. However, for public access SATCOM systems, the availability may dramatically decrease due to the probability of call blocking. In times of semi-international conflicts broadcasting organizations may consume a large part of the available commercial satellite capacity. For private SATCOM networks, this may lead to the unavailibility of bandwidth which can be leased on satellites.

It can be concluded that the influence of the transmission medium on the availability and reliability of SATCOM is limited. Hardware reliability is high, but the TWTA and local oscillator should be carefully considered. An improvement is the use of solid state amplifiers.
Above about 10 GHz the medium is the dominant factor influencing the availability of the link, because of increased precipitation losses. Depending on the level of power control, or margin incorporated in the link budget, availability factors of more than 99.99% can be achieved with SATCOM.
Due to the probability of call blocking, the availability may decrease considerably. Commercial satellite organizations may have more interest selling to non-military organizations, thereby limiting access of military organizations.

4.4.4 Interoperability and network connectivity

Military SATCOM
At present their is virtually no standardization on military SATCOM. Existing networks and networks under development are designed according to user demands, without alignment to other systems. Code division multiple access (CDMA), time division multiple access (TDMA) and frequency division multiple access (FDMA) transmission techniques are used; often for similar kinds of applications.
STANAGs are under development, but very few are 'stable'. Existing STANAGs are:

- **STANAG 4231** (under development)
  UHF SATCOM.
- **STANAG 4484** (under development, old STANAG: 4232)
  SHF SATCOM.
- **STANAG 4376**
  SHF SATCOM EPM 'Universal Modem'
- **STANAG 4485** (under development)
  SHF SATCOM non-EPM small terminal modem.
- **STANAG 4486** (under development)
  SHF SATCOM non-EPM high data rate modem.
- **STANAG 4233** (under development)
  EHF SATCOM, based on US MIL-STD-1582c).

Standardized data interfaces for modems are for instance: MIL-188/449, V.35, G.703, AMI EUROCOM and T1/DS1 type of interfaces. Remote control interfaces are RS-232 and RS-485.

Public access SATCOM
The only public access network at present, INMARSAT, prescribes the manufacturers of INMARSAT equipment the standard they have to comply with. Facilities available on INMARSAT terminals are interoperable with terminals from other manufacturers as long as the types compare (INMARSAT-A with INMARSAT-A, INMARSAT-M with INMARSAT-M, etc.).
Interfaces used are: A/B line interface G3 standard for telefax, RS-242, Hayes AT compatible for data, 2 wire (RJ11) for telephone/telefax connection to the PSTN and V.24/28 computer interface.

Private SATCOM networks

For FDMA type of transmission systems two kinds of open network standards are operational: Intelsat Business Service (IBS) and Intermediate Data Rate (IDR). The IBS standard supports data rates from 9.6 to at least 2048 kbit/s and the IDR standard supports data rates in multiples of 64 kbit/s, up to at least 45 Mbit/s. Modems from different suppliers that comply to the IBS or IDR standards are interoperable.

4.4.5 Mobility

Military SATCOM and private SATCOM networks

Mobility of the military SATCOM and private SATCOM networks is comparable, because the sizes of terminals are comparable. In both cases, except for the military manpack terminals, a van or car will be needed to transport the equipment. The actual weight of the transmit and receive equipment depends on the size of the antenna, the required power of the power amplifier and the necessity of additional equipment like a tracking system and a de-icing facility. Other non-transmitting peripheral equipment, like multiplexers, may also add considerable weight.

A very rough estimate for the weight of a system (excluding power generators, shelters, etc.) is 2 kg per watt transmit power (for systems with transmit power > 10 watt). This was deduced from the weight of modern (mobile) satellite equipment.

Public access SATCOM

The mobility of the public access system (INMARSAT) is very high. Most types of terminals are offered as suitcases, weighing about 9 kg (INMARSAT-C and -M) up to about 35 kg for INMARSAT-A terminals. Most types of INMARSAT terminals can be operational within 5 minutes.

4.4.6 Personnel and economical aspects

Personnel

Military SATCOM

Military SATCOM requires attention and personnel which installs and controls the terminal and peripheral equipment. Because site break up may occur frequent, the benefits of automatic operation will be small. Depending on the network configuration to be chosen, personnel and equipment must also be available at the central hub.

Public access SATCOM

A public access system (INMARSAT) terminal may be controlled by a single person (operation and installation), so the personnel requirements are relatively small. The investments in the central hub and controlling personnel are done by the exploiting companies (INMARSAT and the local PTTs in this case).

Private SATCOM networks

When leasing a VSAT network the personnel requirements may be low, because part of it may be incorporated in the lease contract. Installation can be done by qualified personal of the lease company. During operation, depending on the requirements, the equipment may be used as 'stand alone' or under supervision of an engineer of the leasing company. However, military personnel may also be trained to operate the equipment. In this case, the private SATCOM systems require the same amount of personnel as the military SATCOM systems require for a reliable operation.

System costs

Military SATCOM

Military SATCOM systems require high initial investments in equipment such as terminals (including antennas, modems, etc.) and the central hub station (power, buildings, etc.). Also skilled personal (for maintenance and operation) must be available.

No dial costs or subscription costs are involved, but to be allowed to get substantial access to the satellite an investment in the development of the satellite is required or a Memorandum Of Understanding (MOU) must be signed with a nation providing the satellite capacity.

Public access SATCOM

When utilizing a public access system, the subscriber needs to buy a number of remote terminals. The costs involved are small compared to the military satellite equipment. Terminal costs vary between about Hfl 5,000.- (INMARSAT-C) and Hfl 30,000.- (INMARSAT-A).

The subscriber pays for the investments, done by INMARSAT and the local PTTs, through his subscription rate and dial costs, which are high. Because some competition exists between the various PTT organizations concerning the dial rates, it may be beneficial to investigate the possibilities of linking through foreign PTTs. Costs may also be saved by using a multiplexer on high data rate links such as INMARSAT-A (4 instead of 1 speech channel can be supported). This may even be increased further by using efficient vocoders.

Private SATCOM networks

For VSAT networks, depending on the kind of network that is configured (point-to-point or via a hub), extra costs may be involved because of capacity requirements needed from the central hub terminal.

Costs involved in leasing equipment and satellite capacity are fixed. Satellite capacity has to be leased, independent of the actual use.

4.4.7 Electronic protective measures (EPM) and security aspects

The following EPM aspects will be considered:

- Electromagnetic compatibility (EMC);
- Electromagnetic interference (EMI);
- Electronic counter counter measures (ECCM);
- Electromagnetic pulse (EMP).

The aspects on security will be addressed separately in this section.

EMC/EMI

The risk of interference to and from other equipment, which is not using the same frequency band, is small. Typical values of sensitivity of the antenna to other directions than the main lobe is more than 40 dB below the sensitivity in the main lobe. However, cases are known in which

cars caused interference to the reception via reflections from nearby buildings. These cars caused an increase in noise level which resulted in frequent outages. It is therefore recommended that in high density populated and industrialized areas terminals should be placed in such a position that potential radiating objects are avoided.
In order to prevent overloading of the receivers, equipment using the same frequency band or nearby frequencies should not be placed in the main lobe of the subsequent antennas. Radio systems using frequencies in the VHF and HF bands, are not likely to suffer interference from SATCOM transmissions.

Radiation produced by a terminal might be substantial and of levels that may damage biological tissues. This is specially true for large terminals (> 1 m). Safe power density values are 10 mW/cm^2. Power densities within the main lobe of a high gain terminal, at a distance of 10 metre, may be as high as 1 W/cm^2. Fortunately, the main lobe of such high gain terminals will be narrow. Measures should be taken however, to prevent any personnel entering the main lobe, while transmitting.

ECCM

SATCOM systems are susceptible to jamming of the uplink and in a lesser extent of the downlink.
Most military SATCOM systems are designed to counter electronic counter measures (ECM). If jamming is detected, they are able to switch from a normal mode of operation to a low capacity spread spectrum mode of operation, as opposed to private SATCOM systems and public access systems which are not able to counter threats. Private SATCOM systems may be designed in such a way that they are able to counter minor levels of threats.
In some cases military SATCOM use CDMA (code division multiple access), which reduces the possibility of jamming.

EMP

An EMP originates from an upper atmospheric nuclear detonation. The electrical field strength can be in the order of 50000 V/m during a few nanoseconds. Unprotected solid state equipment is very vulnerable to damage because of the high induced currents and voltages. Valves are less susceptible. The relatively small size of a SATCOM system (compared to HF antennas) makes it a little less susceptible to damage, because the induced voltage will be less. Still, protective measures should be taken to avoid damage.
Another effect related to the detonation is the increased ionisation in the ionosphere. This causes a severe decline of the useful bandwidth, down to several tens of kilohertz (compared to hundreds of megahertz under normal conditions). These effects may last several minutes (depending on frequency: the effect will last shorter for higher frequencies).

Security aspects

Interception of a transmission is heavily dependent on signal strength. Of the three SATCOM systems, interception of the RF signal will be easiest on the public access system. This system, using the INMARSAT satellites, needs very small terminals. In other words, high field strengths must be presented in order to establish reliable links. VSAT and military SATCOM systems need much larger terminals, in other words, require less signal strength than INMARSAT terminals.

Direct sequence spread spectrum (DS-SS) modulation is a useful way to diminish the signal strength level per hertz bandwidth. Furthermore, like also frequency hopping (FH), it provides COMSEC because of the incorporated encryption. DS-SS and FH are techniques that may be used with military satellites.
Only in rare cases DS-SS seems to be allowed on VSAT networks, yet. The public access systems do not support any of these techniques.
COMSEC can be provided by using cryptographic techniques to encrypt the data. This may be applied in military and private SATCOM systems, but not in public access systems which do not allow the use of cryptographic equipment.

4.5 Conclusions

The capabilities of current SATCOM systems can be summarized as follows:

- **Services**
  Public access SATCOM systems support data rates up to 64 kbit/s. Military SATCOM and private SATCOM networks can be designed to support at least 2 Mbit/s.
  Public access SATCOM systems support services like digital speech, facsimile and data. Additionally to these services, the other two SATCOM systems may also supply a service like video conferencing.
  Both public access and private SATCOM systems can not be used for the exchange of real command and control traffic. This is prohibited by the regulations of the organizations providing the satellite capacity.
- **Coverage**
  Coverage is world-wide (including the Pacific) for the public access systems and private SATCOM networks. However, private SATCOM networks offering services to mobile terminals, provide European and American coverage. NATO military satellites to date, cover parts of North- and South America, Europe and parts of western Asia.
  The polar regions can not be covered by geostationary satellites (which are utilized by all three systems).
- **Availability and reliability**
  During times of crisis, access to commercial satellites may be limited due to the leasing of bandwidth by non-military users (such as CNN) or due to call blocking. A military system does not allow civil users, should be designed to cope with crisis situations and will therefore be available.
- **Interoperability and network connectivity**
  At present their is virtually no standardization on military SATCOM. Facilities available on INMARSAT terminals are interoperable with terminals from other manufacturers. There are some modem standards for use with private network systems.
- **Mobility**
  The public access system terminals are small, lightweight and can be operated by one person. This is not true for the other two systems, which are often large, and may require more than one person to set-up the terminal.

- **Personnel and economical aspects**

  Public access terminals do not require qualified personnel to operate the terminals, as opposed to private and military SATCOM systems.

  For operations on short notice, public access systems, like INMARSAT, have proven to be quickly deployable and reliable. Costs are very high though, especially when the systems are often used (high call rates). Private SATCOM terminals have a fixed price for the leasing of terminals and capacity (independent of the actual use). The costs for a private SATCOM terminal may be high, but decrease for intensive use, compared to public access systems (due to lower call rates). The costs of military SATCOM systems can considered to be high, but may be comparable to the costs of the other systems if they are designed to provide the same coverage areas.

- **Electronic protective measures (EPM) and security aspects**

  SATCOM systems do not present a great threat or suffer concerning EMC and EMI. The employed antennas are highly directional, which limits the possibility of EMC an EMI and also the possibility of interception. Common sense should be used concerning health hazards while operating these systems (i.e.: Never enter the main lobe).

  Military SATCOM offers the best possibilities to ensure communications security (COMSEC) and transmission security (TRANSEC). This can be accomplished by using FH and DS-SS techniques. Additional communications security can be provided by using cryptographic techniques to encrypt the data.

  Encryption is not allowed on INMARSAT (public access system).

5 COMPARISON OF CURRENT HF AND SATCOM SYSTEMS

5.1 Introduction

This chapter presents a comparison of the HF and SATCOM systems, currently available. This comparison will be performed in a qualitative way, based on the information listed in chapters 3 and 4. The actual comparison of the various long-haul communication systems is described in section 5.2, while section 5.3 presents the conclusions.

5.2 Comparison of both systems

This section presents the comparison of four different state-of-the-art long-haul communication systems:

- HF systems;
- Military SATCOM systems;
- Public access SATCOM systems;
- Private SATCOM networks.

In table 5.1, each system has been assessed on a number of aspects. These aspects are also discussed in the chapters 3 and 4 (respectively for HF systems and for SATCOM systems). All aspects obtain a qualitative mark. The following marks are applied in table 5.1:

++	:	very good;
+	:	good;
0	:	reasonable;
-	:	bad;
--	:	very bad.

These ratings are based on a qualitative comparison of the capabilities of the long-haul communication systems with respect to the operational aspects of the RNLAF.

Subsequently, in separate sections a rationale will be given for each aspect on which the communication systems are assessed.

Table 5.1: Qualification table of current HF and SATCOM systems.

	HF systems	Military SATCOM	Public access SATCOM	Private SATCOM
Services	+	+	+	+
Link capacity	-	+	0	++
Coverage	0	0	++	0
Availability and reliability	-	++	0	++
Interoperability and network connectivity	+	0	++	0
Mobility	+	0	++	0
Ease of operation	+	0	++	0
Maintenance	+	0	+	0
Costs	+	-	-	-
EMC/EMI	0	+	+	+
ECCM	+	+	-	-
EMP	0	+	-	0
Security	+	++	--	0

Note that the ratings in table 5.1 are relative to the desired use of the communication systems by the RNLAF.

The explanation of the assessments for each aspect will be presented in the following sections.

5.2.1 Services

Services
All the communication systems are capable of offering the services required by the RNLAF. Both the HF systems and the various SATCOM systems offer voice, data, telex and facsimile services.

Link capacity

The capacity of HF communication links is low. An HF link offers a maximum capacity 2400 bit/s in a 3 kHz channel.

Military SATCOM systems may offer very high capacity links, when seen from a technical point of view. However, the procurement of capacity on current military satellites is difficult. The Netherlands Armed Forces do not have their own satellite, which means that they are dependent on other nations or on NATO for the provision of satellite capacity.

Public access SATCOM systems have a reasonable capacity (at maximum 64 kbit/s for INMARSAT).

Private SATCOM networks can offer very high capacity links.

5.2.2 Coverage

The coverage provided by HF systems is reasonable, but depends heavily on the ionospheric conditions. It may happen that some areas can not be reached, because of propagation limitations.

The coverage provided by military SATCOM systems is also reasonable, because only a third of the Earth surface may be reached, using one geostationary satellite. The provision of world-wide coverage requires the use of three satellites. It will however be difficult for the RNLAF to acquire capacity on multiple military satellites. NATO has two military satellites at its disposal with approximately the same coverage, which can therefore not be used for world-wide satellite communications. Satellite capacity has therefore to be provided by nationally owned satellites, such as Skynet (UK) or DSCS (US). This requires however the signing of a Memorandum Of Understanding (MOU) between the nation that provides the satellite capacity and the RNLAF.

Public access SATCOM systems provide very good coverage (world-wide with the exception of polar areas).

Private SATCOM systems provide only reasonable coverage. They do not provide world-wide coverage for mobile terminals, because only the satellites providing European and American coverage operate in the Ku-band which is assigned by the ITU to mobile terminals.

5.2.3 Availability and reliability

The availability and reliability of HF communication systems varies and is largely dependent on the propagation conditions.

As opposed to SATCOM systems which can be designed to offer a high availability (up to 99.999%) and reliability.

However, the availability and reliability of public access SATCOM systems may not be as high as expected, due to possible high probabilities of blocking. Especially in the case of international peace keeping and peace enforcing operations, international press agencies (like CNN) will also use satellite capacity provided by the public access SATCOM systems.

The same situation may apply for private SATCOM networks, if satellite capacity will be leased just in time for the operations. However, if military organizations lease capacity a considerable time before the actual start of the operations, the private SATCOM networks can provide the exact required amount of satellite capacity.

5.2.4 Interoperability and network connectivity

The interoperability of HF systems is good, because a number of STANAGS is developed which provide interoperability between systems applying to the STANAGS. Furthermore, the HF systems also provide standardized data and remote operation interfaces to local end-systems.
The interoperability of current military SATCOM systems is only moderate, because there are only few STANAGs available yet, as a result of which each nation designs its own SATCOM networks which are hardly interoperable. This situation also applies to the network connectivity. Presently, there is no standardization on the subject of interoperability between military SATCOM networks and terrestrial networks.
The interoperability of public access SATCOM systems is very good. All terminals belonging to a network are interoperable and there exists some interoperability between terminals belonging to different public networks. INMARSAT-A terminals are for instance interoperable with INMARSAT-M terminals. Furthermore, all public access SATCOM terminals provide standardized interfaces to civil end-systems. However, the terminals can not simple be connected to military end-systems.
Private SATCOM networks mostly provide only moderate interoperability. Each private SATCOM network is optimized for its specific user requirements, which do not incorporate requirements concerning international interoperability. Furthermore, also the civil private SATCOM networks can not simple be connected to military end-systems. For most applications, this requires the development of extra interfacing equipment.

5.2.5 Mobility

The mobility of HF systems is good. The equipment is relatively lightweight and can be installed in half an hour or less. For high power (> 1 kW) HF systems the mobility of the equipment will be less.
Military SATCOM systems are less mobile (except the manpack terminals), because they are heavier and a larger amount of time is needed to set-up the equipment.
Public access SATCOM systems are lightweight and have low volume (especially the INMARSAT-M terminals) and the set-up time also is very short.
Private SATCOM systems are normally not designed for mobile applications, which implies that most terminals are not constructed to transport them frequently.

5.2.6 Personnel and economical aspects

Ease of operation
The set-up and use of HF systems requires relatively unskilled personnel, as opposed to military SATCOM systems which requires skilled personnel in order to install and control the SATCOM terminals. Public access SATCOM terminals are very ease to use and can be set-up in less than five minutes. The utilization of private SATCOM systems requires skilled personnel (which has to be provided by the leasing company or military personnel has to be trained).

Maintenance
HF systems offer a good performance on the maintenance aspects. The equipment is very reliable and is mostly fitted with built-in test equipment (BITE). Military and private SATCOM

systems contain more modules which are more complex and more sensitive for failures. Public access SATCOM systems, however, are in general smaller and are especially designed for low maintenance.

Costs
HF systems are reasonably inexpensive, compared to the costs of SATCOM systems. The mutual costs of the various SATCOM systems are difficult to compare. The total system costs consist of procuring costs, calling charges, personnel costs, etc.
The procurement costs of HF systems are moderate, while the use of the transmission medium ('ether') is - still - free (except for licensing fees). Military SATCOM systems require high investments in facilities (both terminals and satellites), but there are no calling charges. Public access SATCOM systems require low investments in equipment, but the calling charges are high. Private SATCOM networks require quite high investments in equipment if the terminals are bought, however, terminals may also be leased which provides less initial investment, but high monthly rates. Furthermore, the leasing costs of satellite capacity are moderate, but there has to be paid for the leased satellite capacity, independent of the actual use.

5.2.7 Electronic protective measures (EPM) and security aspects

EMC/EMI
HF equipment has a reasonable EMC/EMI performance. Peripheral equipment (such as facsimiles and computers) may cause severe interference to the receive equipment. Furthermore, HF transmissions may also cause interference on VHF and UHF links.
SATCOM systems offer a good EMC/EMI performance. The risk of interference to and from other systems which are not using the same frequency band is small. However, radiation produced by SATCOM terminals might be substantial (especially for large terminals). Measures should therefore be taken in order to prevent any personnel entering the main lobe of the antenna, while transmitting.

ECCM
HF systems can provide anti-jamming capabilities, such as frequency hopping.
Military SATCOM systems also can provide good ECCM measures, such as the use of spread spectrum techniques.
Public access SATCOM systems do not incorporate anti-jamming capabilities.
Most private SATCOM systems are not designed to provide ECCM capabilities. Spread spectrum techniques are not applied, because they require the provision of large transponder bandwidths, which are very expensive.

EMP
HF systems provide a reasonable protection against electromagnetic pulses. However, the equipment may be damaged by EMPs. As a second effect of such an explosion a strong ionization of the D layer, and onset of the E and F layers in the ionosphere takes place, which results in a complete black out of all communications. SATCOM systems are less troubled by this ionospheric phenomenon, although they may be troubled by scintillation effects. Military SATCOM equipment may be well protected against EMPs, as opposed to public access SATCOM equipment which is not designed to be protected against EMPs. Private SATCOM

systems may be designed in such a manner that they give a moderate protection against EMPs.

Security aspects
The term security means in this context the provision of transmission security (TRANSEC) and communications security (COMSEC).
HF communication systems provide a fairly good protection of the information flow. Certain interception can only be performed in the direct environment of the transmitter and receiver. Due to the properties of ionospheric propagation, for instance the existence of skip zones can be utilized to decrease the possibility of eavesdropping. HF systems can provide COMSEC facilities and incorporated anti-jamming capabilities, such as frequency hopping.
Military SATCOM systems provide very good COMSEC and TRANSEC facilities. The use of directional antennas greatly reduces the probability of interception. Furthermore, military cryptographic equipment can easily be connected to military SATCOM systems.
Public access SATCOM systems provide very bad security facilities. Organizations such as INMARSAT prohibit the use of cryptographic end-equipment.
Private SATCOM networks provide reasonable security. The COMSEC capabilities are good, because the use of cryptographic equipment is permitted. However, most private SATCOM systems are not designed to provide good TRANSEC capabilities.

5.3 Conclusions

The pros and cons of the four communication systems, based on table 5.1 in section 5.2, will be listed in this section.

HF systems
The discussed HF communication systems are especially designed for military applications. These systems offer therefore good performance on interoperability, security and mobility aspects. The equipment is also ruggedized, relatively inexpensive, easy to operate and requires little maintenance.
However, the drawbacks of the HF systems are caused by the medium in which the electromagnetic waves are propagating: the ionosphere. The availability and reliability of HF systems varies and can not exactly be predicted. This is also true for the coverage area: in principle, each area can be reached, however, there may exist areas which can not be reached at all for certain periods of time, or only in a limited number of frequency bands.
Most HF systems offer a link capacity which is 2400 bit/s at maximum.

Military SATCOM
These SATCOM systems are especially designed for military use. The capabilities concerning security, availability and reliability are very good. However, the Netherlands Armed Forces do not posses their own satellite, which means that capacity has to be provided by other nations or international organizations such as NATO. This situation may limit the coverage area and link capacity offered to the RNLAF by these SATCOM systems. Furthermore, current military SATCOM systems are not especially designed for mobile applications which limits the performance concerning mobility and ease of operation. The interoperability of military SATCOM systems is also moderate, because only few STANAGs are available yet.

Public access SATCOM

Public access SATCOM systems can not be used for the exchange of real military command and control traffic, since this is prohibited by the regulations of the satellite organizations. However, the systems offer the advantages of a world-wide coverage and a link capacity up to 64 kbit/s, while the equipment is low cost, very mobile and easy to operate.

The drawbacks of public access systems are its very limited security capabilities, a potential high probability of call blocking, and its calling charges.

Private SATCOM networks

Private SATCOM systems have the drawback (just as public access systems) that it is not allowed to use these systems for the exchange of real military command and control traffic. This is prohibited by the regulations of the organizations providing the satellite capacity. These networks offer the advantage that its users are able to configure and operate their own dedicated network. However, the capabilities of the private systems concerning interoperability, security and mobility are only moderate, because most private networks are not designed for mobile military use.

Also, the coverage provided by these systems can considered to be moderate, because capacity to mobile terminals is only provided by satellites covering Europe and America.

6 FUTURE TECHNICAL DEVELOPMENTS

6.1 Introduction

This chapter gives an outline of the future developments in SATCOM and HF technology. Furthermore, the effects of these developments on the relative comparison of the long-haul communication systems (listed in chapter 5) are described. First, an overview is given of the developments in HF technology and systems. Hereafter, the developments in related satellite communication areas are discussed. Finally, the consequences of these developments for the system comparison are given.

6.2 Developments in HF systems

The main developments on HF systems have taken place the last decade. The introduction of fast data modems probably being the most important one. The trend for the next years is expected to be an evolutionary one. Existing new technologies, like digital signal processing (DSP), will mature and improve existing features. Some new features will be added, using DSP technology on baseband.
Analogue modulation techniques like SSB are likely to remain operational for quite some time. One of the main reasons being the interoperability aspects of military and civilian systems which are not completely resolved yet.
The trend however will be for more digitized information flows (either data or speech).

6.2.1 Technical developments

HF communication is slowly evolving to digital transmissions, new RF processing techniques are introduced and equipment is becoming smaller. The following topics will be described:

- Modems;
- Digital signal processing (DSP);
- Automation of link set-up;
- Physical aspects;
- Frequency hopping (FH);
- Voice coders decoders (Vocoders);
- Multi-channel transmitters;
- Antennas.

Modems
Only ten years ago a data rate of 100 bit per second in a 3 kHz channel was close to the limit. Modern modems are, at least partially, able to combat the multipath effects and attain data throughputs in the order of 2400 bit/s (in a 3 kHz channel).
Severe multipath remains a problem, limiting even the best modems to about 600 bit/s under these conditions. The advent of digital signal processing (DSP) technology may improve the ability to combat severe multipath, which will lead to a rise in data throughput. A doubling of the

present throughput under poor propagation conditions seems attainable. Under normal ('fair') propagation conditions however little improvement is to be expected.

Digital signal processing

Digital signal processing (DSP) will also play an important role in receiver technology. Traditional receivers utilized crystal filters with fixed bandwidth for bandwidth limiting and filter purposes. Fast DSPs are able to digitize the RF signal and create filters using a software algorithm. Furthermore demodulation can also be performed by a DSP, further limiting the number of components.

On baseband level smart DSP algorithms may cancel interference. Other DSP algorithms are able to improve the signal-to-noise ratio of e.g. analogue speech signals.

With increasing speed of DSP chips, more complex algorithms will be used, adding new features.

Automation of link set-up

The introduction of microprocessors, some 15 years ago, has given the designers of communication equipment the possibility of implementing propagation- and link analysis software. Establishing and maintaining an HF link requires several functions to be monitored and controlled in parallel. A microprocessor is capable of performing several tasks sequentially at high speed, so results may be output or input virtually at the same time.

The automatic link set-up features (ALE), already available in some present HF systems, is likely to become available on more equipment. Some enhancement may be expected in processing speed and better algorithms concerning propagation effects and changeover during frequency shifts.

Physical aspects

DSP technology will replace parts of the baseband and intermediate frequency sections of receiver and transmitter. Ultimately this will lead to a reduction in size and weight.

Frequency hopping

Frequency hopping (FH) has been under investigation the last decade and is now becoming available on some military HF equipment. It is expected to become more of a standard feature in the future.

FH is a measure against jamming, and will insure integrity. The present ('slow') hop speed of around 20 hop/s is not likely to increase a lot (perhaps to 100 hop/s), because of the time delays and multipath effects involved in HF communication.

Vocoders

Another aspect of digital communication is the use of digitized voice. Unlike VHF and UHF, the available bandwidth on HF rarely exceeds 3 kHz. Given the number of bits that can be transmitted under fair HF conditions, this limits the voice data rate to 2400 bit/s.

Some voice coders decoders (Vocoder) have been designed to use as little as 600 bit/s to transmit digitized speech. The recognizability of such low data rate signals is low though. Here an improvement may be expected in the next few years.

Multi-channel transmitters
The MIL-STD-188-141A standard foresees the development of independent multi-channel transmitters. Up to four neighbouring 3 kHz wide channels are expected to be realizable in future in HF equipment.
From a data communication point of view, this gives opportunities to quadruple the data throughput from 2.4 to 9.6 kbit/s. There is one serious problem however. Narrow channels of 3 kHz bandwidth are relatively easy to find. Up to 9 kHz wide channels may also be found, because broadcast stations employ 9 kHz wide channels. Wider channels, like 12 kHz as suggested by MIL-188-141A, are not likely to be obtained. Interference will certainly be an issue. Moreover, the International Telecommunication Union (ITU) assigns in most parts of the HF spectrum 3 kHz (or narrower) channels to users. In theory several channels next to each other may be obtained, but in practice this will be hard to realize.
If four controlled channels, independent of frequency, could be provided by the HF equipment, then it would be much easier to obtain clear frequencies. However, this would imply much more complicated equipment and restrictions of the total bandwidth because of the limited antenna bandwidth.

Antennas
Self adapting and adjusting antennas have been developed and are becoming available as light weight pieces of equipment. The incorporation of fast solid state switching devices makes some of them also suitable for frequency hopping purposes.

6.2.2 Service development

At present virtually all communication services, unless limited by speed, can be offered by HF systems. Some development is taking place however which will be addressed below:

Telefax
It is expected that services like telefax will be consolidated in the next few years. The time required to send a telefax will be reduced.

Pictures
Still video can already be transmitted using slow scan television (SSTV). This is an analogue kind of system, with low picture quality. Digitized pictures (high quality) may also be transmitted using HF, but take, because of the vast amount of data, a long time to be transmitted. In this respect two aspects will see improvement: picture data reduction techniques (compression) and modems with higher average throughputs (see 'Modems' of the previous section). This will lead to a considerable reduction in the required transmission time.
High quality moving picture (real time) transmission seems very unlikely to be possible via HF in the future, because of the low data throughput on an HF channel.

6.3 Developments in SATCOM systems

Developments in SATCOM technology will result in enhanced SATCOM systems in the post 2000 era. First the technical developments will be discussed and subsequently the resulting system concepts. Both military and commercial SATCOM programmes will be presented. The most promising military SATCOM programme is the EUMILSATCOM programme in which a number of European nations are investigating the possibilities of a joint military SATCOM system for the post 2000 era.

6.3.1 Technical developments

Future satellites will considerably differ from present-day satellites, due to a number of technical and technological developments. These developments will result in the possible incorporation of a number of new features in future satellites. These new features are the following [10]:

- Use of EHF frequencies;
- Phased array and multibeam antennas;
- On-board processing of information;
- Inter-satellite links;
- Civil systems containing satellites in alternative orbits (other than the geostationary orbit).

The incorporation of these features will result in enhanced facilities for the end-users of the SATCOM networks: the coverage area will be enlarged, the survivability will be increased and small and mobile terminals may easily be employed.
Furthermore, the interoperability between the SATCOM terminals and networks operative in the various NATO nations will be increased. NATO currently develops various STANAGs for UHF, SHF and EHF SATCOM communications.
Each feature will now be discussed separately.

EHF frequencies
The EHF frequency band is the frequency band between 30 and 300 GHz. The most important EHF bands for military satellite communications are the 44 GHz band and the 21 GHz (which in fact is still SHF). The 44 GHz band has a bandwidth of 2 GHz and will be used for the uplink communications. The 21 GHz band has a bandwidth of 1 GHz and will be used for the downlink communications. The use of EHF frequencies offers the following advantages [10]:

- The bandwidth available for spread spectrum ECCM techniques is very large at EHF frequencies. This increases the anti-jamming capability of the SATCOM systems, as compared to SATCOM systems using for instance the SHF frequency band.
- The bandwidth available for the provision of mobile services is increased.
  The 44 GHz band and the 21 GHz band are completely reserved for mobile applications, as opposed to only 125 MHz in the military SHF band.
- The LPI performance is improved.
  The narrow antenna beamwidth and the relatively high atmospheric absorption reduce the range at which a ground terminal can be detected.

- The resistance to nuclear effects is improved.
  Exo-atmospheric nuclear detonations seriously affect earth-space communications over a wide region. The appearing physical effects (an initial period of large attenuation followed by a period of scintillation) disrupts EHF communications momentarily, as opposed to UHF and SHF communications which are disrupted for much longer periods of time.

The use of EHF frequencies also has some drawbacks. The most important drawback is the greatly increased attenuation at EHF frequencies, compared to SHF frequencies. Especially the attenuation due to rain increases sharply at low elevations. A practical EHF SATCOM system might include link margins of 10 - 15 dB in order to encounter bad weather conditions and provide a high availability.
It can therefore be concluded that the EHF frequency band offers especially advantages for secure and highly survivable communications and for communications with mobile terminals. The EHF band is less attractive for high capacity SATCOM links, due to the increased attenuation and link margins. This implies that a smaller data rate can be obtained for a given satellite equivalent isotropically radiated power (EIRP).

Phased array and multibeam antennas
Space born adaptive antennas such as phased array and multibeam antennas provide the possibility of customising the coverage area. These antennas are steerable and may provide a very small coverage area. Replacing a global antenna with an adaptive antenna provides an additional gain of 10 - 20 dB [10]. This extra gain may for instance be used for the provision of direct links between two small terminals with only moderate terminal power. The extra antenna gain may also be used to decrease the EIRP of the SATCOM terminals.

On-board processing of information
Processing of information on-board the satellite can consist of the following features [10]:

- **Switching of data**
  Data can be switched between the various antennas if the satellite contains multiple spotbeams and/or global beams.
- **Conversion of frequency bands**
  Future satellites may convert SHF signals in EHF signals and vice versa. In this way, SATCOM terminals may use different frequency bands on the uplink and downlink. The terminals may for instance transmit in the EHF band (with a good EMC and LPI performance) and receive in the SHF band.
- **Despreading of signals**
  Spread spectrum signals may be despreaded (or 'de-hopped') on-board the satellite. Spread spectrum techniques need only to be applied on the uplink, because downlink jamming is considered to be less likely [11]. Non spread spectrum techniques which utilize satellite capacity more efficiently may therefore be applied on the downlink.
- **Demodulation and remodulation of signals**
  Demodulation of signals to baseband level on-board the satellite offers the advantage that noise and jammer power are removed from the uplink signals. This leads to an increased overall link budget and therefore to an increased survivability of the communications. Furthermore, uplinks and downlinks may operate at different transmission rates with

different multiple access techniques. This results in an increased flexibility: transmission rates and multiple access techniques used in the up- and downlinks may be adapted to the terminal requirements.

Inter-satellite links

Inter-satellite links provide direct communication facilities between satellites. The most important advantage offered by inter-satellite links is the in-orbit connectivity. Terminals located on opposite sides of the earth may directly communicate with each other without the need for multiple hops between satellites and ground relay stations.

Civil systems consisting of multiple satellites in alternative orbits

A number of future civil SATCOM systems will consist of satellites placed in alternative orbits, such as highly elliptical orbits (HEO), medium earth orbits (MEO) or low earth orbits (LEO), besides the use of satellites in geostationary orbits. The following paragraphs outline the characteristics of each orbit.

Geostationary orbits

Satellites in geostationary orbits are stationary relative to a point on earth. This offers the advantage that ground terminals do not need a tracking mechanism. The geostationary orbit lies in the equatorial plane at a distance of 42,164 km from the earth's centre. Only three satellites are needed to provide nearly world-wide coverage. However, the satellites do not offer communication services to regions with high latitudes such as northern Europe and northern America. Ground terminals in these regions require a very low elevation angle ($< 5^\circ$) in order to be able to see the satellite. This low elevation angle is impractical because the terminal has to be in line-of-sight with the satellite (which is very difficult in urban districts). Furthermore, the attenuation is very high at EHF, because of the long distances the electromagnetic waves have to traverse through the atmosphere. Most SATCOM systems do not incorporate the high link margins which are required for reliable communications at low elevation angles.
Furthermore, large fixed ground stations ('anchor stations') with high transmitter powers are needed in order to overcome the encountered attenuation caused by the large distance between the ground stations and the satellites. The links also have a large propagation delay which is annoying for voice services.

Highly Elliptical Orbits

Satellites in HEO are at apogee typically around the geostationary altitude, whereas at perigee the altitude may be only a few hundred kilometres. The movement of the satellite near apogee keeps pace with the rotation of the earth for several hours. The satellite can therefore be used for communications during this period. This implies however that a small number of satellites (typically 3 to 6) are needed to provide continuous coverage.
These satellites offer the advantage that they do not need an apogee boost motor which counts mostly half the mass of the satellite at launch. The most important advantage of HEO systems is their ability to provide communication services to regions with very high latitudes (even polar latitudes), while the terminals do not require low elevation angles.

Medium Earth Orbits
Satellites in MEO have circular inclined orbits with a typical altitude of 10,000 km. A moderate number of satellites (typical 10 - 15) is needed to provide world-wide continuous coverage.

Low Earth Orbits
LEO satellite systems consist of a constellation of many satellites (typically 50 - 100) in circular orbits at altitudes ranging from 500 to 1500 km. These systems have the advantage that the satellites are small and low-cost, while they may provide global coverage with short delays and small ground terminal transmitter powers. LEO systems are therefore well suited for the provision of personal communication services (handheld satellite telephones). The system costs are however high because a very large number of satellites is needed to provide global coverage.

It can be concluded that satellites in geostationary orbits are advantageous because they are stationary relative to the earths surface and only three satellites are needed to provide nearly world-wide coverage. However, the distance between the satellites and the ground stations is very large. The ground terminals need therefore high transmitter power and the communication signals experience very high propagation delays.
Systems consisting of satellites in alternative orbits do not have these disadvantages. The coverage area can be shaped in such a way that the satellites offer really world-wide communication services (also at high latitudes), while the distance between the satellites and the ground terminals can considerable be decreased. However, the number of required satellites in order to provide continuous coverage can be very high (up to 70) and the system complexity may be high. Communication links have often to be transferred from one satellite to another, because the satellites are only shortly visible (in case of LEO systems even only 5 - 10 minutes).
It is expected that a large number of different satellite systems will emerge. Each system will contain a satellite constellation which is optimized to meet the specific system requirements. A number of systems will even contain satellites in both geostationary and alternative orbits.

6.3.2 The EUMILSATCOM programme

As mentioned before, the currently most important future military SATCOM programme for the Netherlands Armed Forces is the EUMILSATCOM programme. In this programme, a number of European nations are investigating the possibilities of a joint military satellite system for the post 2000 era. The United Kingdom and France started the programme which currently includes seven nations. Spain, Italy, The Netherlands, Belgium and Germany and possibly Canada are also participating in the programme, besides the UK and France. The national military satellites of these countries (and the NATO IV satellite) all reach their end of life in the same timeframe (2002 -2006). The programme has been started because it is expected that this joint programme will offer some major advantages considering system costs (economics of scale policy) and interoperability.
The system specifications and developments are in an early stage, but some trends and characteristics can be recognized. The concepts of operations and the operational requirements are defined and each nation has defined its traffic needs in the information exchange requirements (IER) (NL IER: [12]).
The complete EUMILSATCOM system will contain four to five geostationary satellites, while the first satellite will be launched in 2003 [13]. The satellites will probably provide a coverage

area of 100° W to 120° E and 81° N to 81° S (SHF frequency band). Communications in the EHF band will also be provided. The satellites will incorporate multiple beam and phased array antennas which will be used to provide steerable spotbeams. Also, facilities will be incorporated which are capable of processing information on-board the satellite. However, the design of the satellites is not yet crystallized and depends on the relative costs of the various features.

6.3.3 Future commercial SATCOM systems

Developments in commercial SATCOM systems are immense. The use of satellites for commercial communication purposes is growing rapidly and will continue to do so in the near future. Mobile cellular networks show large grow rates and will play a significant role in the future telecommunication infrastructure. Commercial mobile satellite systems will be used to interconnect these networks and to extend their services to rural areas and developing countries.
There is a large number of proposals for the launch of commercial satellite systems. These satellite system will utilize the L frequency band (1.5/1.6 GHz), the Ku-band (11/14 GHz) and in the near future also the Ka-band (20/30 GHz).
The most important current proposals with respect to the RNLAF operational aspects will be discussed in this section. Satellite systems which offer a large coverage area and both voice and data services will be described. The following systems will be discussed [14]:

- IRIDIUM;
- INMARSAT;
- ARCHIMEDES;
- GLOBALSTAR;
- ELLIPSO;
- ODYSSEY;
- ARIES;
- TELEDESIC.

IRIDIUM
IRIDIUM is a commercial satellite system (mainly funded by Motorola) which consists of 66 satellites in Low Earth Orbits (LEO; altitude 780 km). The satellites are connected to each other using inter-satellite links. The system will provide world-wide continuous coverage in completion to cellular earth communication networks. Initially, the system will try to make a connection using cellular networks or public switched telephone networks. If this is not possible, the connection will be made via the LEO satellites. The terminals are therefore able to operate in a dual mode, both a terrestrial mode and a satellite mode. IRIDIUM will provide voice (4800 bit/s), data, facsimile and paging services with handheld terminals. The first satellite is planned to be launched in 1996, while the system is expected to be operational in 1998.

INMARSAT
INMARSAT will extend its services in the next ten years. The mini-M terminal standard will be introduced in 1995. This standard will offer world-wide voice, telex, facsimile and data services to its users using small, compact and low-cost terminals. INMARSAT has also plans for the development of a SATCOM system offering services with handheld terminals. This project is called PROJECT 21 and will offer communication services from the year 2000. The terminals

are called the INMARSAT-P terminals. The space segment will consist of 12 - 15 MEO (medium earth orbit) satellites or 4 geostationary satellites.

ARCHIMEDES

The ARCHIMEDES project is started on the initiative of the European Space Agency (ESA) and will provide mobile communication services to small and portable terminals. ARCHIMEDES will provide coverage to the northern hemisphere. The space segment will consist of 6 satellites in highly elliptical orbits (HEO). The first satellite will probably be launched in 1998.

GLOBALSTAR

GLOBALSTAR is a commercial project (funded by Loral, Qualcomm and other companies) which will provide world-wide communication services from 1998. The space segment will consist of 48 satellites in LEO. GLOBALSTAR will also rely on existing long-distance communication networks (such as PSTNs) to reach the end-user. The network will offer voice, data, facsimile and paging services.

ELLIPSO

The ELLIPSO system which is funded by the Ellipsat Corporation will consist of two complementary subsystems: ELLIPSO BOREALIS serving the northern hemisphere and ELLIPSO CONCORDIA serving tropical and southern countries.
The BOREALIS network will consist out of 18 satellites in HEO, while the CONCORDIA system will consist out of 6 satellites, with orbit type yet unknown.
The ELLIPSO system complements and expands existing cellular communication systems and will mainly provide voice services. ELLIPSAT plans to deliver its services from 1997.

ODYSSEY

ODYSSEY (developed by TRW) will provide voice, data and paging services to handheld terminals in Europe, North America and the Pacific rim. The coverage area will be extended in a later stage to North Africa and South America. The space segment will contain 12 MEO or LEO satellites and the system will be operational in 1998.

ARIES

The ARIES system (funding organization: Constellation Communications) will provide world-wide voice, data and facsimile services. The space segment will consist of 48 LEO satellites and will be operational from 1997.

TELEDESIC

The TELEDESIC system (funded by AT&T, McCAW Cellular Communications Inc. and Bill Gates) will provide rural telephony services for developing nations and remote parts of industrialized nations. The terminals will be very compact (handheld). The space segment will consist of 840 satellites and the system will be operational in 2001. The satellites have on-board processing features and are interconnected by inter-satellite links.

It can be concluded that there are many projects and initiatives for the launch of commercial satellite systems in the next decade. Five systems will provide global coverage (PROJECT 21, IRIDIUM, GLOBALSTAR, ARIES and TELEDESIC) and the other systems will provide regional coverage. It can be expected that a large competition will be developed, if all systems are launched and become operational. As a result of this competition, the service costs will probably be low which will be advantageous for the end-users. However, despite of this large number of proposed systems it remains doubtful how many of them will in effect be launched.

Besides the rise of these commercial 'public' satellite networks, the possibilities and capabilities of 'private' VSAT networks will also be increased. These networks will also benefit from all technical and regulatory developments. Most probable, it will be possible in the near future to establish a private VSAT network which can completely be designed to the requirements of its users. It can be expected that future VSAT networks are also able to provide nearly world-wide coverage. Furthermore, the system costs will be moderate for the end-users, due to the global competition which can be expected to emerge for SATCOM systems in the near future.

6.4 Conclusions and consequences

Changes concerning HF communications will be moderate, but will result in smarter systems, which will require less human support (automated operation) and somewhat higher data rates than the present systems.

Satellite communication, in particular civil SATCOM, is expected to see a kind of revolution with the introduction of several new systems operating from various types of orbits. One may expect that call charges will drop considerably when the first competing systems become operational. These systems are however designed for civil use, with civil applications. Security and availability are not guaranteed. The situation listed above concerning number of systems and costs may also apply for private networks, because private SATCOM systems are mainly provided by the same satellite organizations.
The military systems, which will become available after 2003 (e.g. EUMILSATCOM), are able to fulfil the requirements of the military forces concerning availability, security and capacity. These satellites will offer an increased coverage with both global beams and high gain antennas (steerable spotbeams). They will also offer an increased protection against threats (by incorporation of on-board processing facilities, use of EHF frequencies, etc.). Furthermore, these systems will especially be designed for the application of small mobile terminals, as opposed to the current military satellites.

Concerning the qualification table (table 5.1 in section 5.2) the main changes will be found on:

- **Link capacity**: slight increase for HF systems, considerable increase for military SATCOM.
- **Coverage**: likely to be really world-wide for public access SATCOM (LEO and MEO satellites will cover polar regions as well). The coverage area provided by private and military SATCOM systems will also considerably be increased.
- **Availability and reliability**: availability of capacity likely to improve for public access SATCOM and military SATCOM (more satellites and more suppliers).

- **Mobility**: improvement for military SATCOM (introduction of more high gain spotbeams, EHF and on-board processing facilities).
- **Costs**: considerable reduction for public access SATCOM and possibly for private SATCOM networks.

If security, availability and capacity are important issues, then only military SATCOM systems are able to offer these features. HF systems offer a fairly reliable and cheap alternative, if availability and capacity are not of prime concern.
The expected dramatic increase in public access SATCOM systems and the resulting expected drop in call charges make these systems an interesting alternative for peace keeping missions, mainly for the transfer of information concerning logistic and personnel aspects.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

1) RNLAF forces may at maximum be deployed to five geographical locations at the same time. Five different rear area links are therefore needed in order to support national logistic and control traffic between the rear area (The Netherlands) and the area of deployment. Each RNLAF unit deployed in an OOA operation needs two communication links:
   a) A link to its original operating base in The Netherlands;
   b) A link to the RNLAF centre of operations in The Hague (OCKLu).

2) Current HF communication systems can well be used for military applications. They offer good performance on interoperability, security and mobility aspects. The equipment is also ruggedized, relatively inexpensive, easy to operate and requires little maintenance. HF systems have the drawback that they generally offer a limited link capacity of 2400 bit/s at maximum and their availability, reliability and the offered coverage area varies with time and can not exactly be predicted.

3) Military SATCOM systems offer a high performance on security, availability and reliability aspects. However, currently, satellite capacity has to be provided by other nations or international organizations such as NATO. This may limit the coverage area and link capacity provided to the RNLAF. Furthermore, current military systems have a moderate performance concerning mobility, ease of operation and interoperability aspects.

4) Public access SATCOM systems are especially designed for civil applications and can not be used for the exchange of real military command and control traffic, which is prohibited by the regulations of the satellite organizations. Furthermore, these systems have bad security capabilities, high calling charges and a potential high probability of call blocking. Encryption of information is not allowed. Public access SATCOM systems offer the advantages of a world-wide coverage and link capacity up to 64 kbit/s, while the equipment is low cost, very mobile and easy to operate.

5) Private SATCOM networks have also the drawback that they can not be used for the exchange of real military command and control traffic. However, these networks offer the advantage that its users are able to configure and operate their own dedicated network. The disadvantages of these networks are their moderate capabilities concerning interoperability, security, mobility and coverage area.

6) Future HF systems will differ only slightly from current HF systems. The systems will be more autonomous and will therefore require less human support. The offered user data rates will also be increased somewhat.

7) Future SATCOM systems will differ considerably from current SATCOM systems. Future military SATCOM systems will especially be designed for mobile applications and will provide an increased coverage. The maximum capacity will be increased and they will offer an increased protection against electronic counter measures. Civil SATCOM systems will probably be subject to some kind of revolution. There is a large number of proposals for civil public access systems offering world-wide coverage for personal communication facilities, such as handheld telephones and small telefax and data terminals. As a result of the increased competition, the service costs will probably be low. However, despite of the large number of proposed systems, it remains doubtful how many of them will become operational. The capabilities of private SATCOM systems will also be increased. Future private SATCOM networks will be able to provide world-wide coverage with moderate system costs.

7.2 Recommendations

1) A detailed assessment of the communications systems and consequently a well-founded system choice can only be performed if the operational concept and requirements are further defined. It is therefore recommended to define first the operational and system requirements to a detailed level, before final decisions are made.

2) The complete communications infrastructure should be considered in the process of rear area link system definition. This includes the local communication networks in the rear area and the areas in which the OOA operations will be carried out.
Also, network connectivity and sizing should be investigated in future studies.

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APPENDIX A: GENERAL HF SYSTEM CONCEPT

A.1 Introduction

This appendix outlines a future RNLAF HF communication system. This HF system will interconnect the various RNLAF operating bases and the RNLAF centre of operations (OCKLu) with the RNLAF units deployed in OOA operations.
First, the architecture of the future RNLAF HF network will be discussed, and subsequently the architecture of the HF stations will be presented.

A.2 Network architecture

It can be expected that one HF station will be operative in The Netherlands. This HF station will serve as entry point to the rear area. Furthermore, chapter 2 states that at maximum five RNLAF units may simultaneously be deployed in OOA operations. This means that five separate HF links may be needed at maximum at the same time. The HF station in the Netherlands will therefore consist of five HF systems. Each deployed RNLAF unit needs only to communicate with its operating base in The Netherlands and with the RNLAF centre of operations (OCKLu) and not with other deployed RNLAF units. It is therefore advantageous to apply an HF network with a physical star topology. The centre of the star will be the HF station which serves as point of entry in The Netherlands (rear area). This proposed HF network can also be seen as a collection of separate links which have a common point of entry in the rear area. The resulting network is depicted in figure A.1.

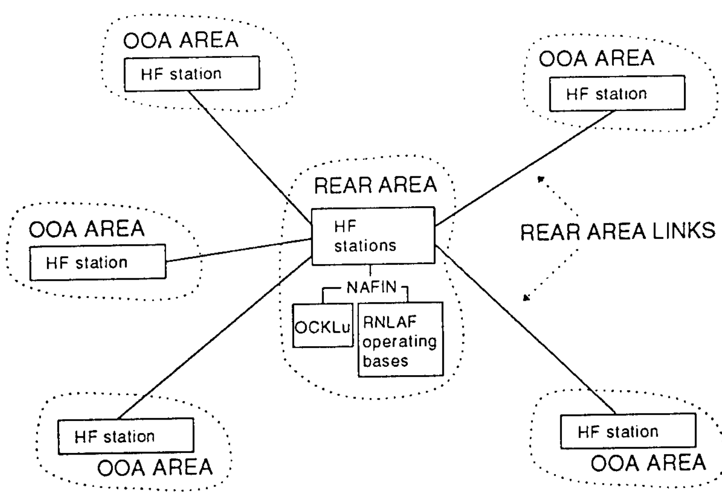

Figure A.1: Outline of the future RNLAF HF network.

An option is to distribute the five HF systems of the HF station in the rear area over a number of HF stations at different locations in the Netherlands (five at maximum) which are all connected to NAFIN.

A.3 HF station architecture

The architecture of the HF stations is discussed in this section. Each station will be constructed modularly and will contain the same modules. Only the gateway and connected local networks will differ. A general architecture of the HF stations is depicted in figure A.2.

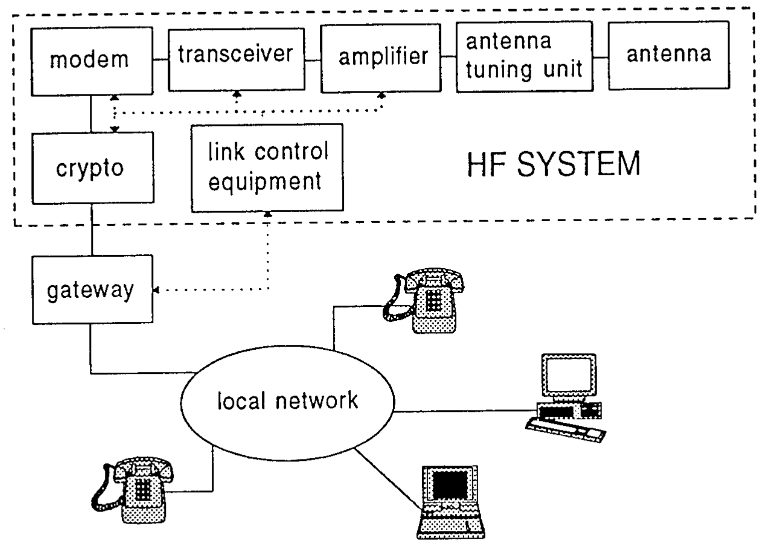

Figure A.2: Architecture of the HF stations.

In The Netherlands, the HF station contains five HF systems as depicted in figure A.2. This HF station is connected via a gateway to NAFIN which provides the interconnection to the various RNLAF operating bases and the RNLAF centre of operations. In the OOA areas, the HF stations are also via a gateway connected to the local communications infrastructure. This gateway will serve as point of access for the local users.

APPENDIX B: GENERAL SATCOM SYSTEM CONCEPT

B.1 Introduction

A concept for a future RNLAF SATCOM system will be presented in this appendix. This SATCOM system will be used to interconnect the various RNLAF operating bases in the rear area (The Netherlands) with the RNLAF units deployed in OOA operations. This appendix contains three sections: section B.2 presents an architecture for a future RNLAF SATCOM network. The terminal architectures are subsequently discussed in section B.3, while section B.4 presents a network architecture based on the utilisation of the EUMILSATCOM satellites.

B.2 Network architecture

A general architecture for the RNLAF will be presented in this section. The same situation and resulting network topology as already described in appendix A will apply here. Most probably, one fixed SATCOM ground station will be placed in The Netherlands and will serve as entry point to the rear area. Five separate SATCOM links are needed at maximum for the communications between the rear area and the OOA areas (due to the operational scenarios of the RNLAF which state that at maximum five units may be deployed in OOA operations at the same time). In some cases, sharing of one SATCOM terminal between two different RNLAF units may be possible (if the two units are deployed very close to each other), but it is recommended that each unit is equipped with one SATCOM terminal in order to achieve maximum flexibility. As mentioned in appendix A, each deployed RNLAF unit needs only to communicate with its operating base in The Netherlands and with the RNLAF centre of operations (OCKLu) in The Netherlands. It is therefore advantageous to apply a SATCOM network with a physical star topology. A large fixed ground terminal placed in The Netherlands will serve as the centre of the star. The resulting network topology is depicted in figure B.1.

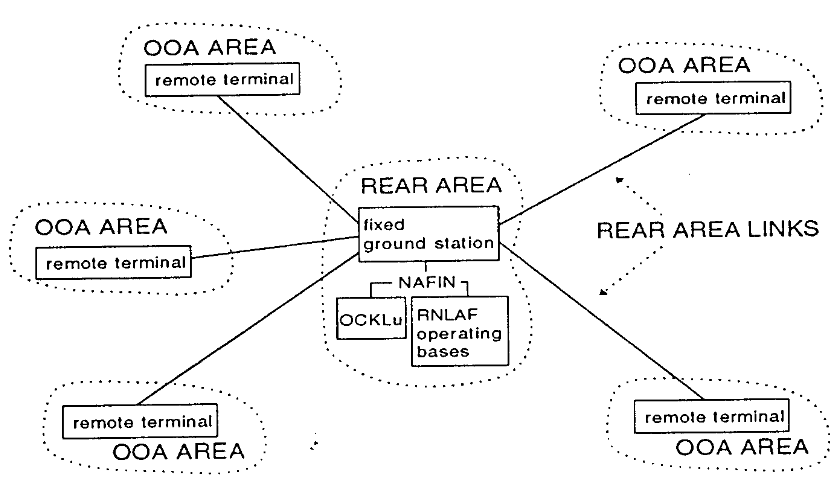

Figure B.1: Outline of the future RNLAF SATCOM network.

B.3 Terminal architecture

This section discusses the architecture of the various network terminals. A RNLAF SATCOM network will consist of two different types of terminals: a fixed large ground station and a small number of remote mobile terminals. The architecture of both terminal types will be discussed.

B.3.1 Architecture of the fixed ground station

It is advantageous to connect the fixed ground station via a gateway to NAFIN. In this way, the various RNLAF operating bases may easily access the SATCOM network without the need for an operator. This requires, however, the use of a gateway which automatically performs the access control functions and all required interfacing functions, such as protocol conversions. The gateway passes all requests for service to the SATCOM network management centre which assigns satellite capacity to the relevant end-users.

A more detailed architecture of the fixed ground station is depicted in figure B.2. The ground station contains the gateway described above, the SATCOM network management centre, five separate modems and radio frequency (RF) equipment.

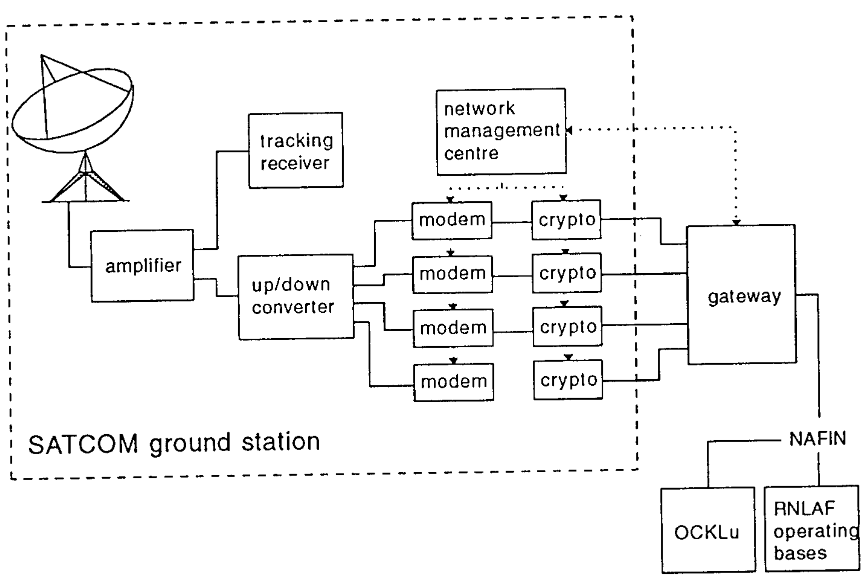

Figure B.2: Architecture of the fixed ground station.

B.3.2 Architecture of the small mobile terminals

In the OOA area, the SATCOM terminals are connected to the local communications infrastructure via a gateway. The gateway will serve as access point for the local users to the SATCOM terminal and will perform all required protocol conversions.
The architecture for the SATCOM terminals in OOA areas is depicted in figure B.3

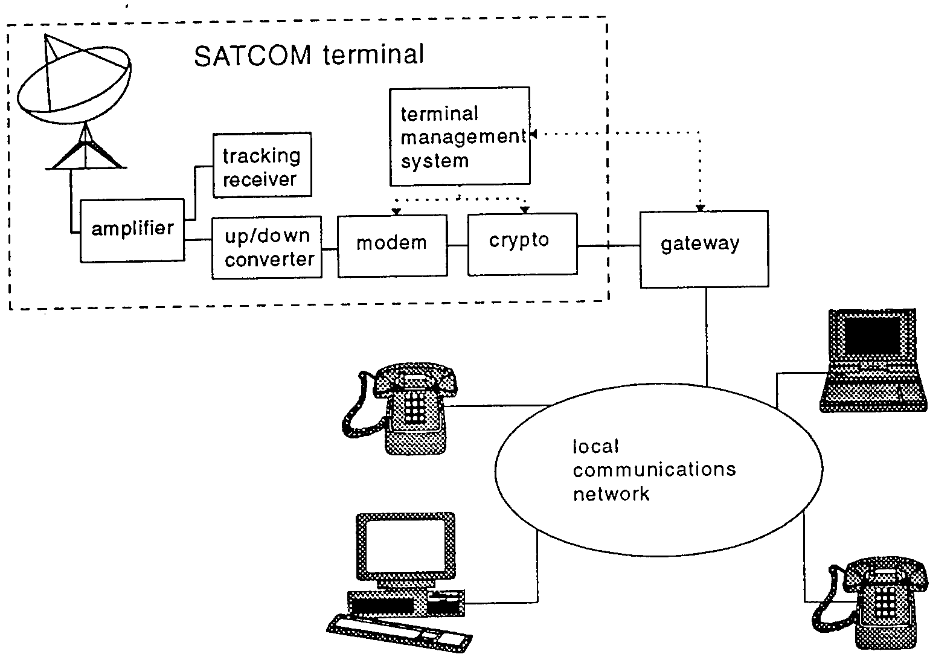

Figure B.3: Architecture of SATCOM terminals in the OOA area.

B.4 EUMILSATCOM

As mentioned in chapter 6, the EUMILSATCOM programme currently is the most important future military SATCOM programme for the Netherlands Armed Forces. It can therefore be expected that as well the RNLAF as the Royal Netherlands Army and Navy (RNLA and RNLN) will utilize EUMILSATCOM satellites for their long-distance communications.

Most probably, an interservice fixed ground station will be built in The Netherlands. This ground station will serve as anchor station for the satellite communications of the Netherlands Armed Forces and will be connected via a gateway to NAFIN. All RNLAF operating bases and the RNLAF centre of operations (OCKLu) will also be connected to NAFIN. NAFIN will therefore be used for the transport of information between the various RNLAF bases and the fixed SATCOM ground station. The resulting RNLAF SATCOM network is a physical star network and is depicted in figure B.4.

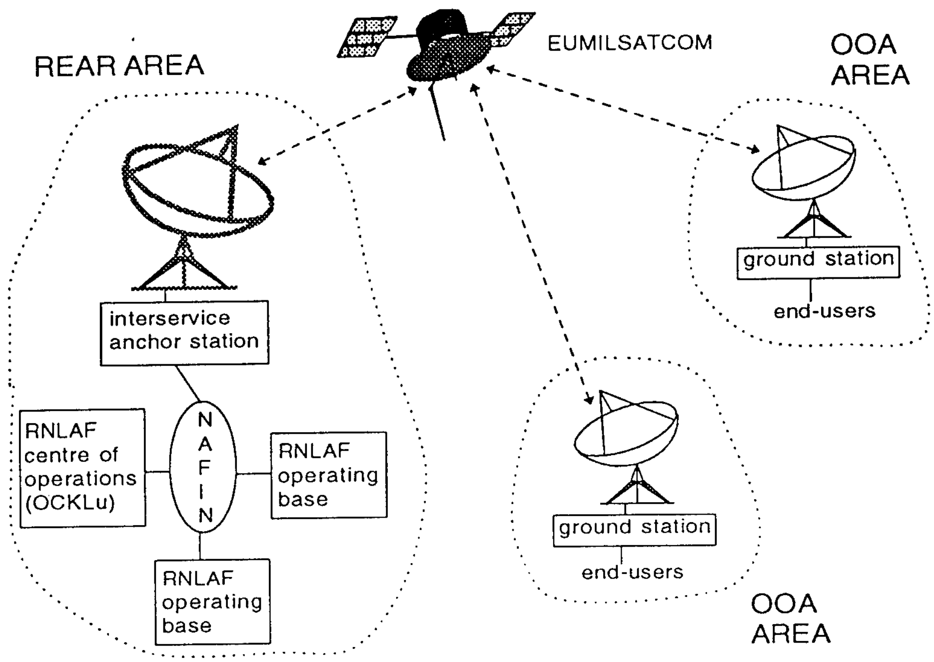

Figure B.4: *Outline of the future RNLAF SATCOM network using EUMILSATCOM satellites.*

APPENDIX C: GLOSSARY OF TERMS

Apogee
The point in the orbit of an earth satellite which is situated at the maximum distance from the centre of the Earth [CCIR Rec. 673].

Automatic link establishment (ALE)
Method of automatic station contact initiation. Communication links are automatically established on the best authorized HF frequencies available.

Automatic link set-up (ALIS)
Automatic link set-up processor implemented in the current RNLAF HF system. The ALIS processor chooses the best available HF frequency and establishes the link. During the message transmission ALIS performs link quality analysis and adapts the operating frequency or power level if necessary.

Automatic repeat request (ARQ)
A method of error correction on a communications link by automatic repetition of the data that was received with errors.

C-band
In relation with SATCOM this frequency band designator is used for: different frequency bands between 3.4 - 4.2 GHz and 4.5 - 4.8 GHz (downlink) and frequency bands between 5.725 - 7.075 GHz (uplink).

Code division multiple access (CDMA)
A technique whereby a number of terminals are able to share the transmission capacity of a link by using different codes. An example of CDMA is spread spectrum multiple access (SSMA) whereby a number of terminals share a link by using direct sequence spread spectrum (DS-SS) modulation with different spreading codes.

Communications security (COMSEC)
Communications security denotes protection of the data flow, using data encryption techniques.

Digital signal processing (DSP)
Processing signals using (digital signal) algorithms in order to change the properties of the signals in a desired way.

Direct sequence spread spectrum (DS-SS)
A signal structuring technique utilizing a digital code sequence having a chip rate (encoding bit rate) much higher than the information signal bit rate. Each information bit of the digital signal is transmitted as a pseudo-random sequence of chips [CCIR Rep. 651-2].

Downlink
A radio link between a transmitting space station (satellite) and a receiving earth station [CCIR Rec. 573-3].

Electromagnetic compatibility (EMC)
The capability of electrical and electronic systems, equipments, and devices to operate in their intended electromagnetic environment within a defined margin of safety, and at design levels of performance without suffering or causing unacceptable degradation as a result of electromagnetic interference [NATO glossary of terms and definitions].

Electromagnetic interference (EMI)
Any electromagnetic disturbance, whether intentional or not, which interrupts, obstructs, or otherwise degrades or limits the effective performance of electronic or electrical equipment [NATO glossary of terms and definitions].

Electromagnetic pulse (EMP)
An electromagnetic pulse originates from a nuclear detonation. An EMP is caused by secondary reactions that occur when gamma radiation is absorbed into the air or ground. During a very short time a very strong electromagnetic field strength occurs.

Electronic counter counter measures (ECCM)
That division of electronic warfare involving actions taken to ensure friendly effective use of the electromagnetic spectrum despite the enemy's use of electronic warfare [NATO glossary of terms and definitions].

Electronic counter measures (ECM)
That division of electronic warfare involving actions taken to prevent or reduce an enemy's effective use of the electromagnetic spectrum [NATO glossary of terms and definitions].

Electronic protective measures (EPM)
EPM techniques counter electronically both electronic counter measures (ECM) and electromagnetic pulse (EMP) effects.

Equinox
Time or date at which the sun crosses the equator, and day and night are equal (around 20 March and 22 September).

Frequency division multiple access (FDMA)
A technique whereby a number of terminals are able to share the transmission capacity of a link by using different frequencies.

Frequency hopping (FH) spread spectrum
A signal structuring technique employing automatic switching of the transmitted frequency. Selection of the frequency to be transmitted is typically made in a pseudo-random manner from a set of frequencies covering a band wider than the information bandwidth. The intended receiver would frequency hop in synchronization with the code of the transmitter in order to retrieve the desired information [CCIR Rep. 651-2].

Ionosphere
That part of the upper atmosphere characterized by the presence of ions and free electrons mainly arising from photo-ionization, the electron density being sufficient to produce significant modification of the propagation of radio waves in certain frequency bands [CCIR Rec. 573-3].

Ka-band
In relation with SATCOM this frequency band designator is used for the frequency bands: 17.7 - 21.2 GHz (downlink) and 27.5 - 31 GHz (uplink).

Ku-band
In relation with SATCOM this frequency band designator is used for: different frequency bands between 10.7 - 11.7 GHz (downlink) and frequency bands 12.75 - 13.25 GHz and 14 - 14.5 GHz (uplink).

L-band
In relation with SATCOM this frequency band designator is used for the frequency bands that are allocated to the mobile-satellite service around 1.5 GHz (downlink) and 1.6 GHz (uplink).

Lowest usable frequency (LUF)
The lowest usable frequency is the lowest frequency that would permit acceptable performance of a radio circuit by signal propagation via the ionosphere between given terminals at a given time under specified working conditions [CCIR Rec. 373-6].

Low probability of detection (LPD)
Provision of signals with a low probability of detection means that the possibility of detecting the signals, by an unintended receiver, is small.

Low probability of exploitation (LPE)
Signals that have a low probability of exploitation increase the difficulty of exploitation, even after being intercepted. With exploitation is meant in this case that an unauthorized party can use the signals for its own benefit.

Low probability of interception (LPI)
Provision of signals with a low probability of interception means that an unintended intercept receiver is denied the signal features that could be used to distinguish between signals.

Maximum usable frequency (MUF)
The maximum usable frequency is the highest frequency that would permit acceptable performance of a radio circuit by signal propagation via the ionosphere between given terminals at a given time under specified working conditions [CCIR Rec. 373-6].

Perigee
The point in the orbit of an earth satellite which is situated at the minimum distance from the centre of the Earth [CCIR Rec. 673].

Polar cap absorption (PCA)
Enhanced absorption of radio waves in the ionosphere can occur due to polar cap absorption. Polar cap absorption occurs on relatively rare occasions at geomagnetic latitudes greater than 64°. The absorption is produced by ionization at heights greater than about 30 km. It usually occurs in discrete, though sometimes overlapping, events which are nearly always associated with discrete solar events. The absorption is long-lasting and is detectable over the sunlit polar caps. Polar cap absorption occurs mostly during the peak of the sunspot cycle, when there may be 10 to 12 events per year. Such an event may last up to a few days [CCIR Rec. 531-2].

Scintillation
Rapid and random fluctuation in one or more of the characteristics (amplitude, phase, polarization, direction of arrival) of a received signal, caused by fluctuations in the refractive index of the transmission medium (troposphere, ionosphere) [CCIR Rec. 310-7].

Short wave fade (SWF)
When a major solar flare produces radio wave absorption over the sunlit portions of the earth resulting in a suddenly (or gradually) fade out and disappearance of HF signals, the phenomenon is called a short wave fade (SWF). HF radio transmissions are absorbed for a period of minutes to hours; normally between 20 and 50 minutes.

Skip zone
The area between the coverage area of groundwave signals and the coverage area one hop skywave signals of an HF transmitter. Within the skip distance no signals are received via the ionosphere.

Sudden ionospheric disturbance (SID)
HF propagation anomalies due to ionospheric changes resulting from solar flares, proton events and geomagnetic storms.

Time division multiple access (TDMA)
A technique whereby a number of terminals are able to share the transmission capacity of a link by using different periods of time to access the link.

Transmission security (TRANSEC)
Transmission security means that the physical transmission is secured from interception, employing for instance spread spectrum techniques.

Uplink
A radio link between a transmitting earth station and a receiving space station (satellite) [CCIR Rec. 573-3].

Vocoder
A voice coder decoder (Vocoder) is a device that encodes and decodes speech signals. Normally, the analogue speech signal is digitized and limited in bandwidth.

X-band
In relation with military SATCOM this frequency band designator is used for the frequency bands: 7.25 - 7.75 GHz (downlink) and 7.9 - 8.4 GHz (uplink).

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15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTE))

This report presents the relative assessment of various long-haul communication systems in order to fulfil the need for communications between the rear area and Royal Netherlands Airforce (RNLAF) units deployed in out-of-area operations. Four different communication systems are compared with respect to the operational aspects:

- High Frequency (HF) radio communication systems;
- Military satellite communication (SATCOM) systems;
- Public access SATCOM systems (such as the INMARSAT system);
- Private SATCOM networks (based on the use of very small aperture terminals (VSATs)).

The comparison is based on the current available communications assets. Future technical developments and their consequences for the system comparison are also discussed.

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