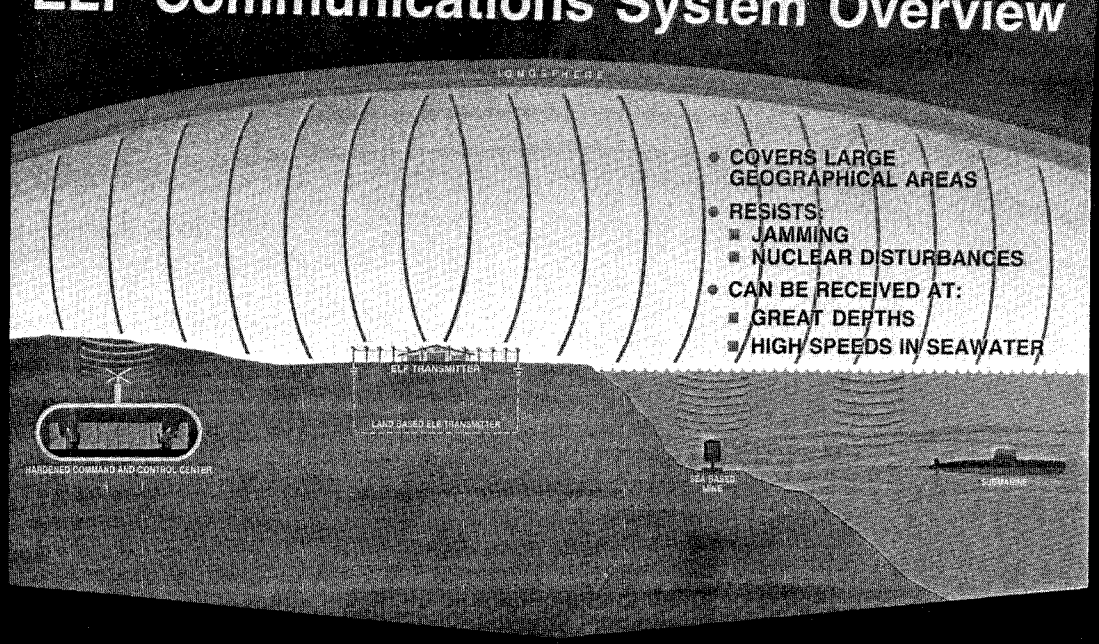
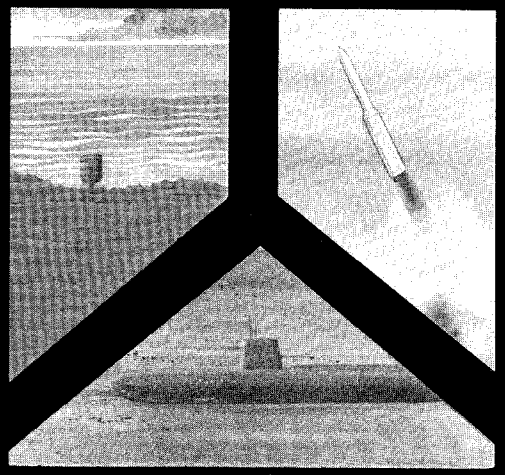
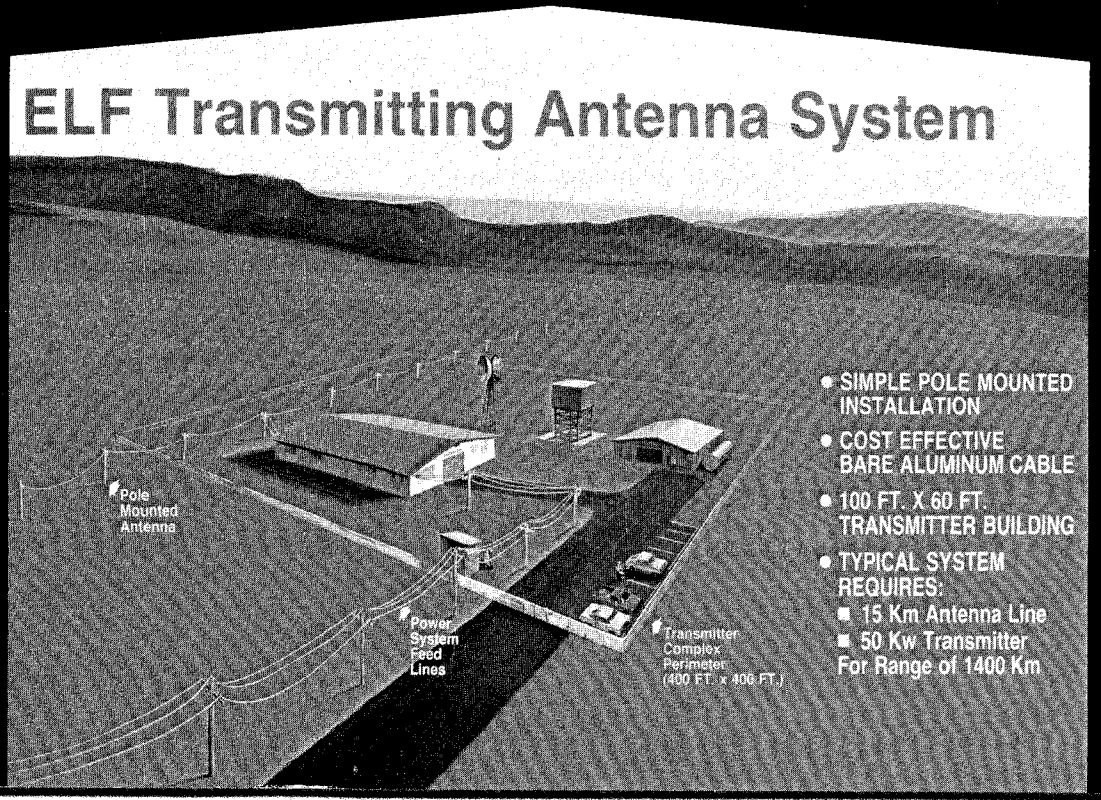


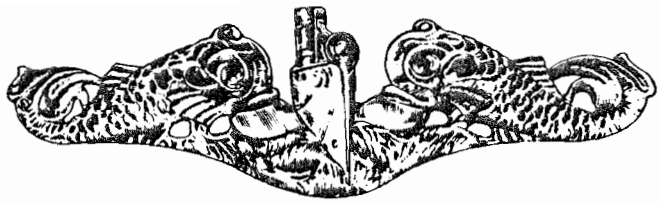
ELF

Communication Concepts and Capabilities



GTE





ELF COMMUNICATIONS

Concepts and Capabilities

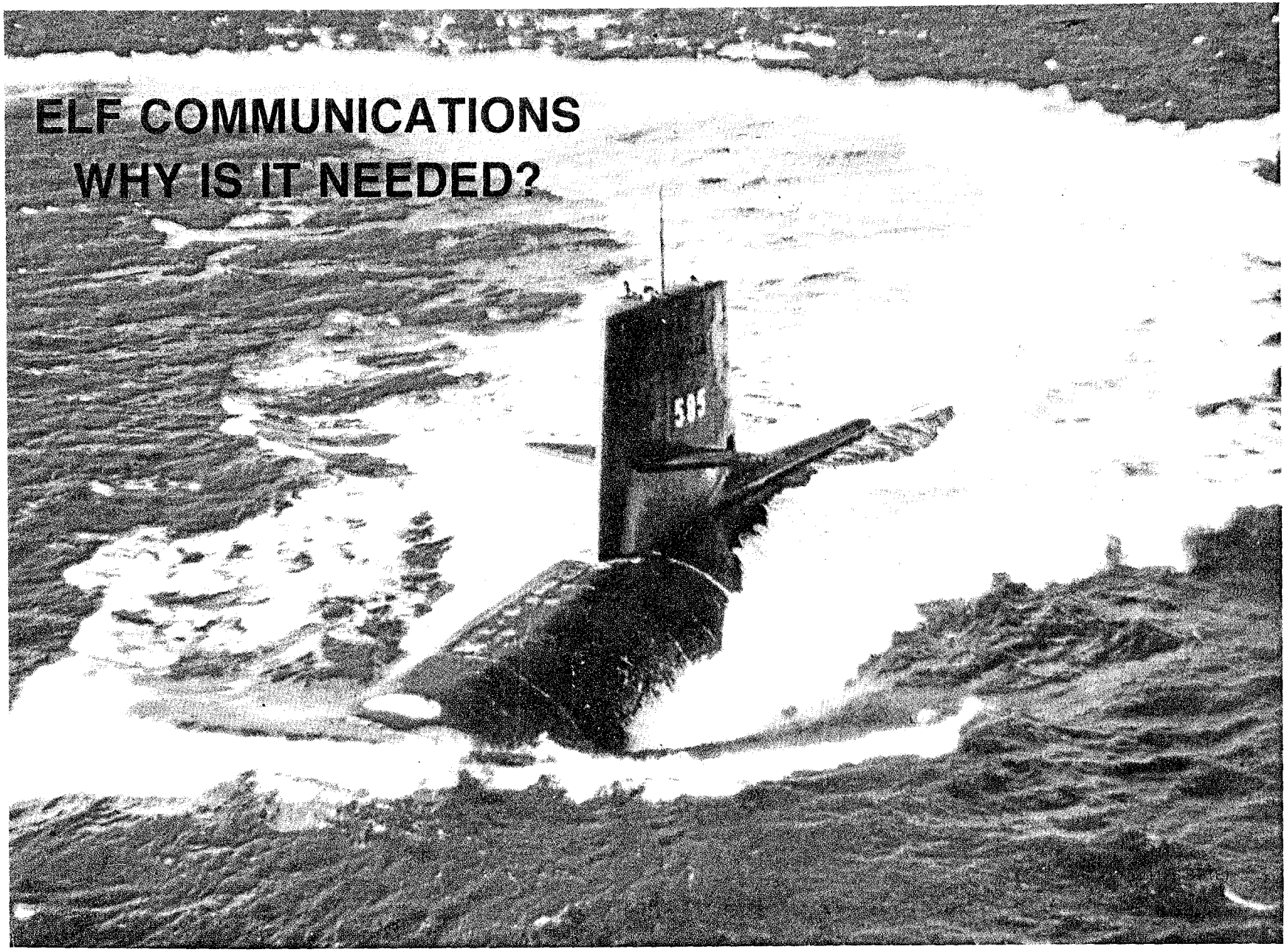
Sylvania Systems Group
Communication Systems Division
GTE Products Corporation
77 A Street
Needham Heights, Mass. 02194 U.S.A.

GTE | **Systems**

1402-81(A)

Outline of Presentation

- ELF communications – Why is it needed?
- GTE – Who are we?
- ELF communications – An overview
- Key features of an ELF system
- Typical ELF transmission system concepts
- Planning for an ELF capability


ELF COMMUNICATIONS
WHY IS IT NEEDED?

ELF Communication for Improved C^3 is Needed Now

- Increasingly complex threat environments and effective surveillance employed by enemy forces establishes urgent need for a secure transmission system to provide one-way C^3 capability to the forces without compromising detection

- ELF communications can survive the link degradation resulting from ECM and disruption by nuclear effects on the propagation path to establish or reconstitute C^3 capability with hardened force command centers and remote survivable weaponry where all other means have been neutralized or destroyed

ELF Communication to Submarines is Needed Now

- Submarines are an essential element of national defense and vital to deterrence of nuclear war
- Dependable command communication is essential if submarines are to be effectively utilized for ASW, antishipping or as missile platforms
- Non-ELF communication techniques require an antenna above or near the ocean surface, and thereby compromise a submarine's most important asset – its ability to remain hidden
- A submarine whose position is known at the onset of hostilities may be effectively neutralized
- A submarine that can be neutralized does not contribute to deterrence of a conflict
- ELF communications allows command reception by submarines while they remain deeply submerged, undetected and invulnerable

Highlights of ELF Advantages and Improvements

Application	Ability to Penetrate Conductive Media		Improved Operational Flexibility	Com. Channel Resistance To Threat Environments		Improved C^3 Survivability & Vulnerability
	Seawater	Earth		ECM	Nuclear Effects	
Submarine C^3	X		X	X	X	X
Mine Field Remote Control	X	X	X	X	X	
Force Command Center C^3		X		X	X	X
Enduring C^3 (Transportable ELF Transmission Systems)	X	X	X	X	X	X

3364-82

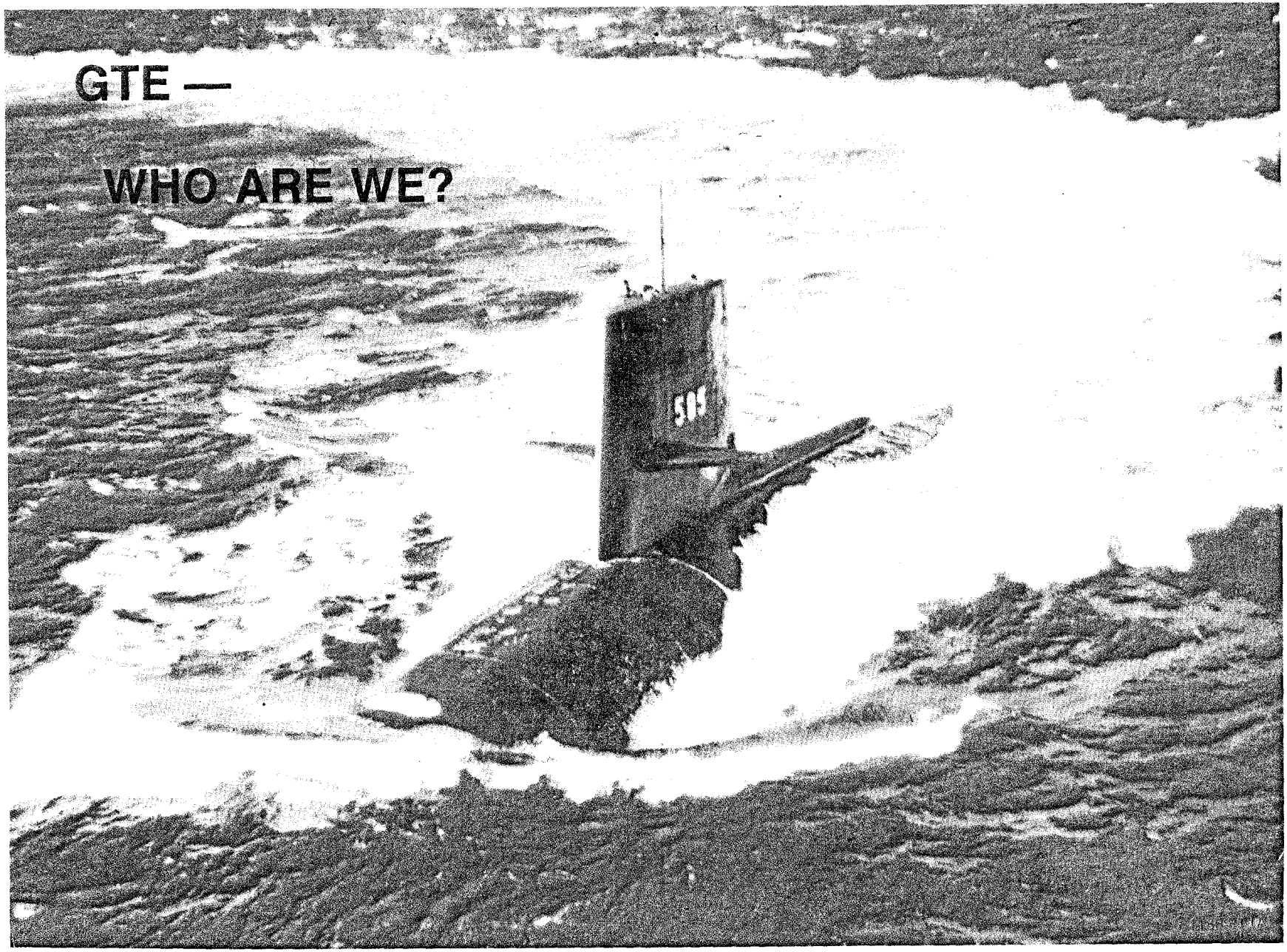
GTE's Role in Communication

- Developed ELF communications for the U. S. Navy
- Produced receivers installed on U. S. submarines
- Operates transmitter facility in U. S.
- Demonstrated message reception at depth and speed in the Mediterranean, Arctic, Western Pacific, North and South Atlantic
- Is able to provide U. S. Allies with a similar ELF submarine or landbased command and control communication capability

GTE Contracts for ELF Communications

- **1973 – System design of nuclear survivable ELF transmitters and submarine receivers for Project Sanguine**
- **1974 – Operate and maintain ELF transmitter test facility**
- **1974 – Design, develop and field ELF Propagation Validation System (PVS)**
  - 15 Receivers and transmitter modulators
- **1974 – ELF Design Validation for Project Seafarer (DV)**
  - Site surveys, environmental impact assessment, preliminary design for 2400-mile antenna, five transmitter sites, and sophisticated receiver
- **1981 – Continuation of PVS and DV contracts**
- **1982 – Design and development for full-scale system**
  - Two transmitter sites and 20 receivers

1364-81

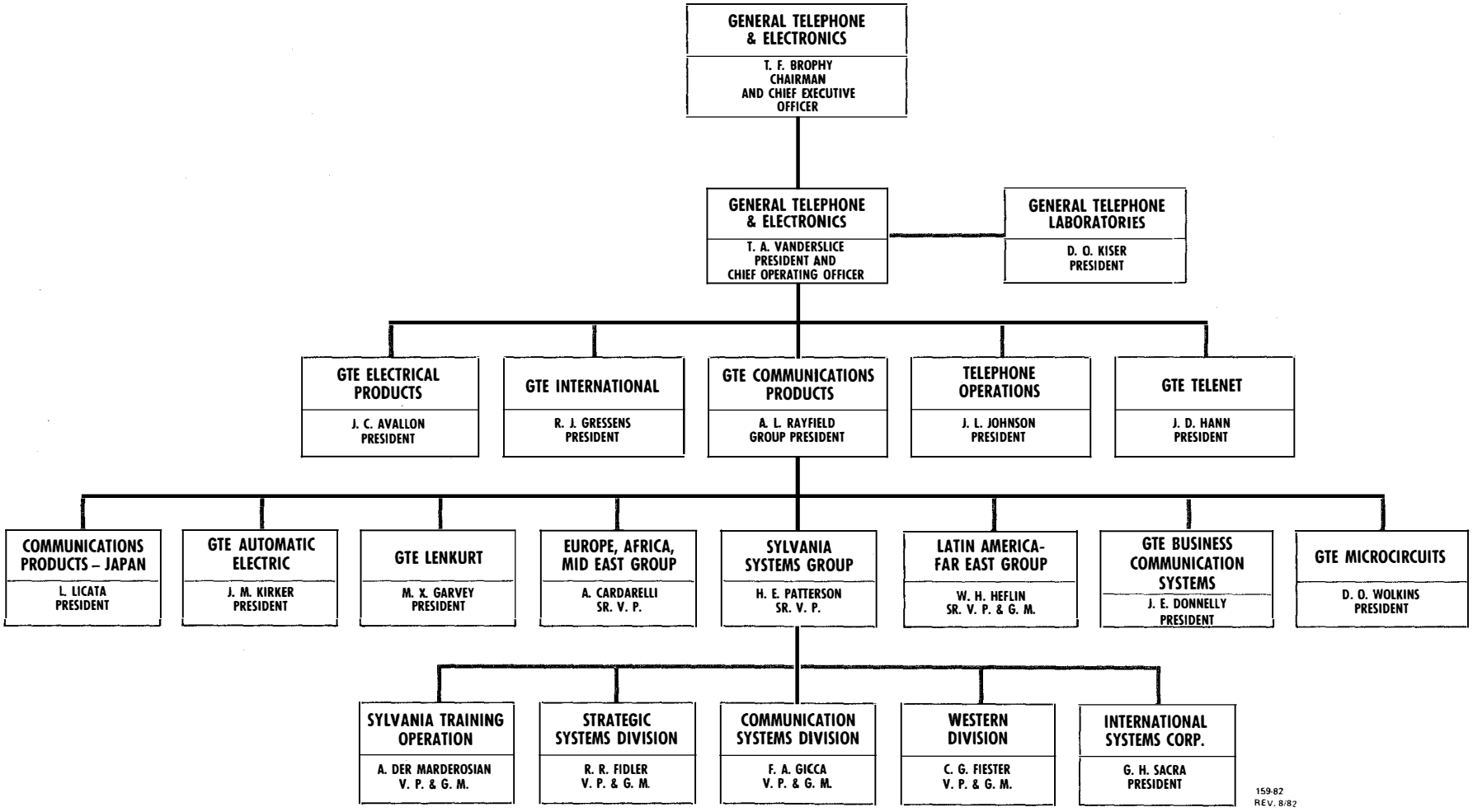

GTE —
WHO ARE WE?

GENERAL TELEPHONE & ELECTRONICS CORPORATION

- Annual sales and revenues, 9.9 billion
- 227,000 employees
- Ninth largest USA company
- Operations in 41 states and 16 countries
- Creatively develops and utilizes new technology
- A world-wide leader in communication products, systems, and services

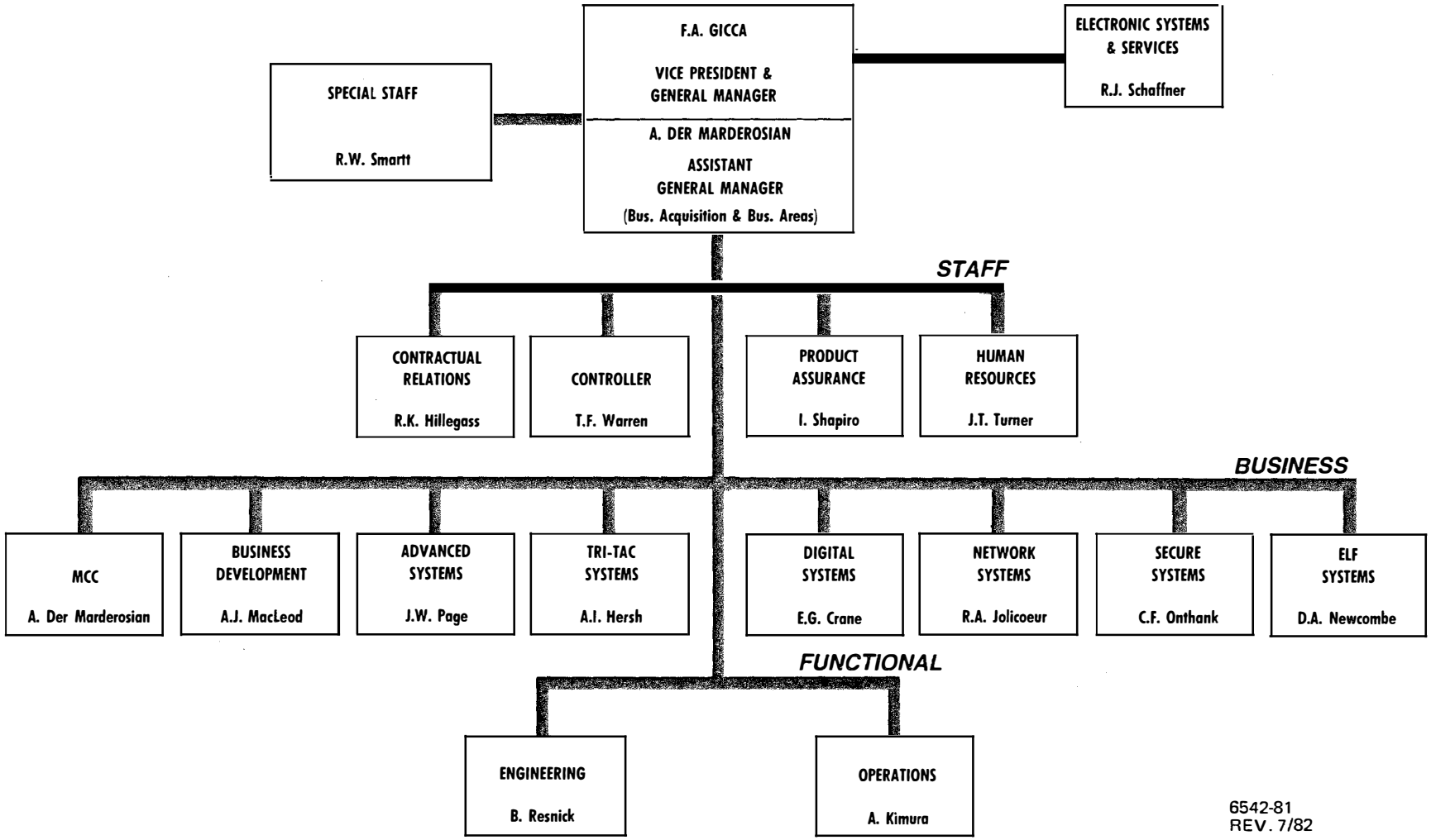
1223-81

GTE CORPORATE ORGANIZATION



159-82
REV. 8/82

SYLVANIA SYSTEMS GROUP
COMMUNICATION SYSTEMS DIVISION



6542-81
REV. 7/82

CSD Talent and Facilities

Provide complete turnkey implementation from conception to installation . . .

CSD Skills

- Systems engineering
- Architectural studies
- Program management
- Equipment design and installation
- Maintenance operations and training

CSD Systems Experience

- Satellite terminals
- Digital data systems
- Secure voice arrangements
- Custom-designed systems
- Special station arrangement
- Fiber optics
- Architectural studies
- Cable transmission
- Microwave transmission
- Wideband switching
- Packet switching

1400-81

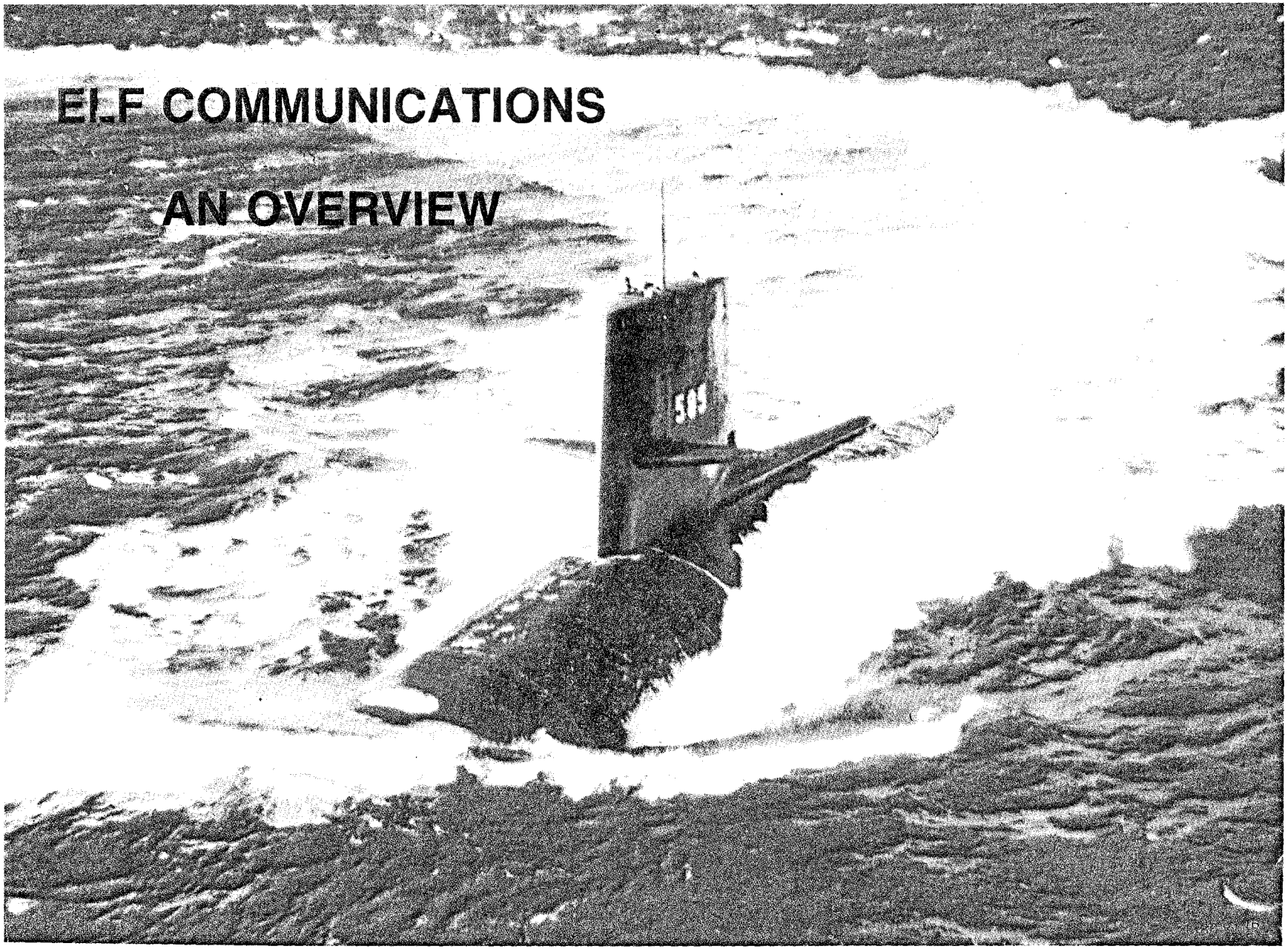
TECHNICAL SPECIALTIES

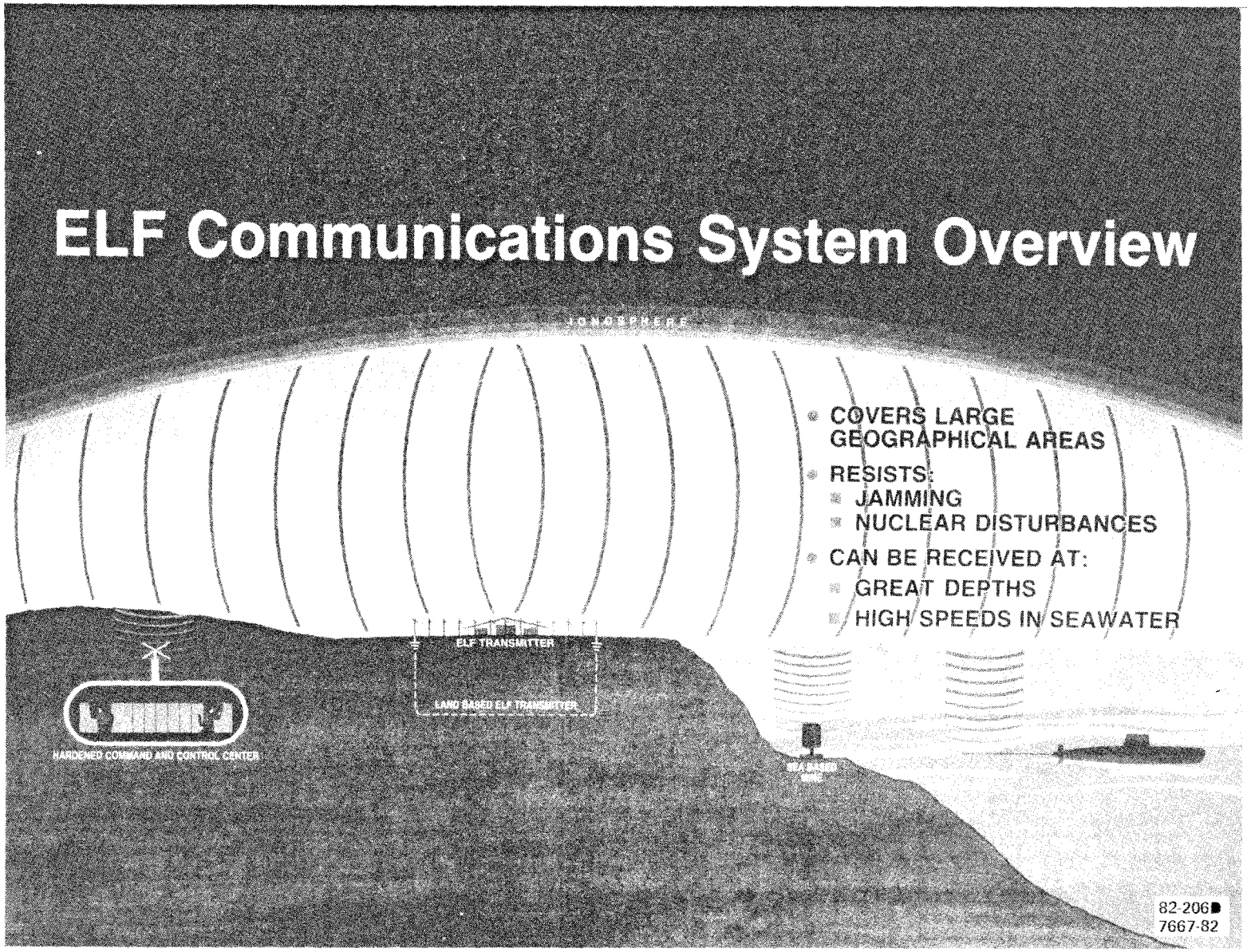
- Communication systems analysis and design
- Radio equipment design, HF modems, signal processing equipments, COMSEC equipment
- Transmission systems design, antenna design, site surveys, antenna and tower erection
- Computer analysis, programming, digital data terminals
- Facilities design, power systems, security systems
- Training, installation support, site administration and logistics support

1224-81

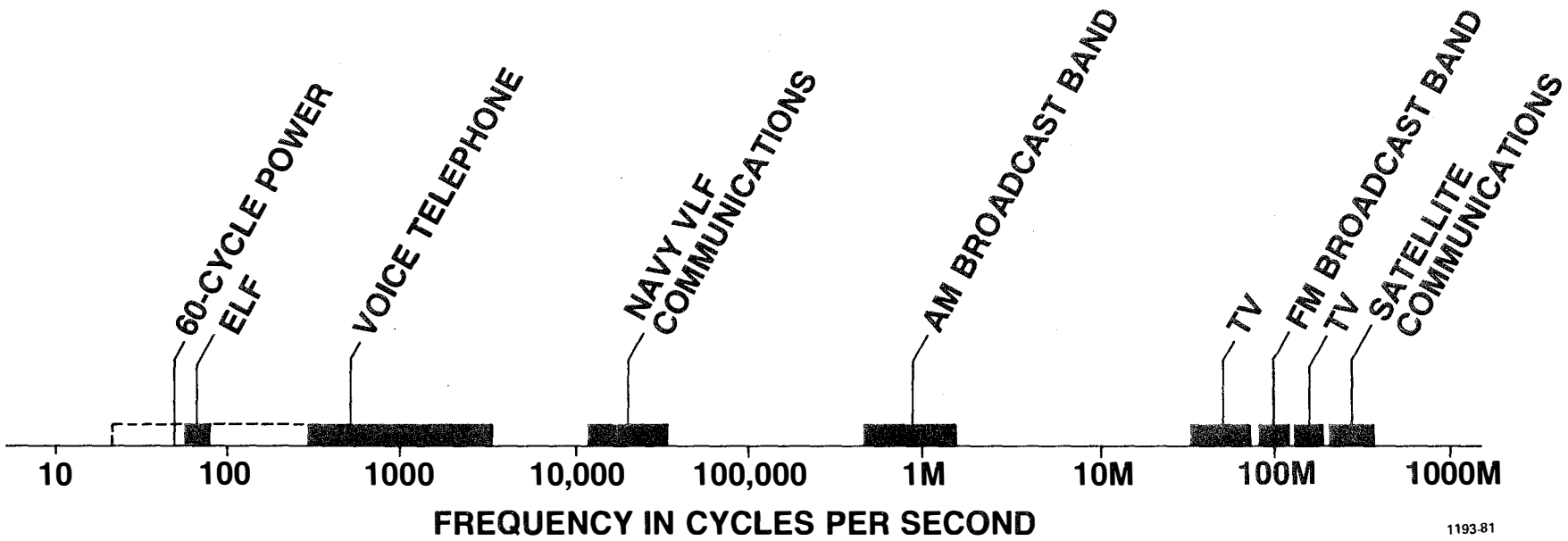
ELF COMMUNICATIONS

AN OVERVIEW

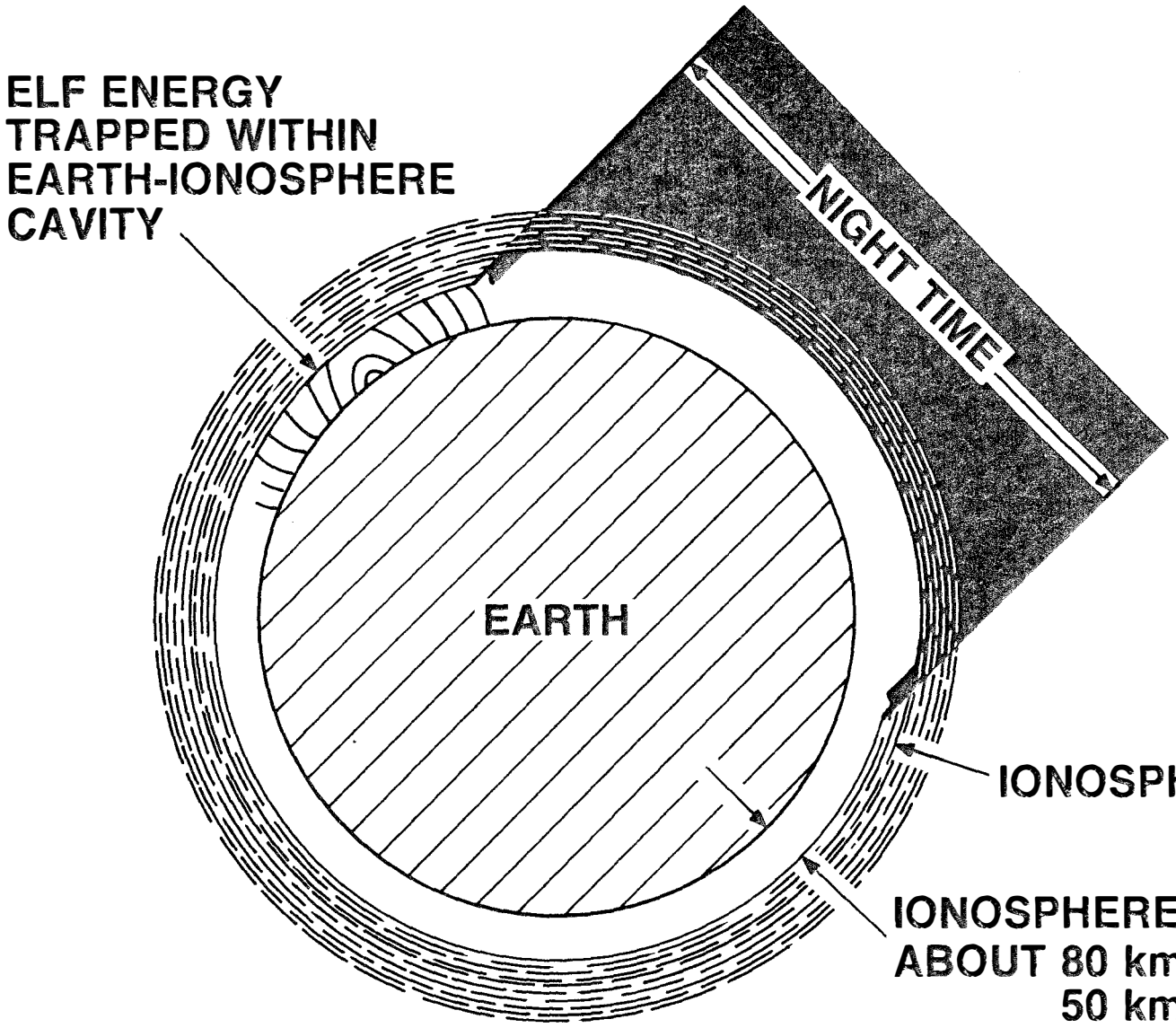



ELF Communications System Overview
IONOSPHERE
COVERS LARGE GEOGRAPHICAL AREAS
RESISTS:
JAMMING
NUCLEAR DISTURBANCES
CAN BE RECEIVED AT:
GREAT DEPTHS
HIGH SPEEDS IN SEAWATER
ELF TRANSMITTER
LAND BASED ELF TRANSMITTER
HARDENED COMMAND AND CONTROL CENTER
82-206
7667-82

ELECTROMAGNETIC SPECTRUM USAGE

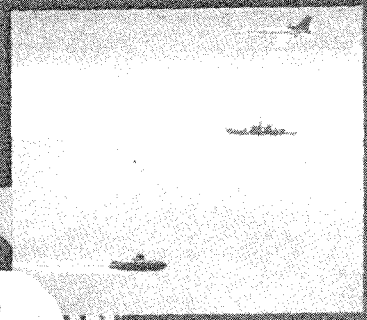


PROPAGATION OF ELF SIGNALS



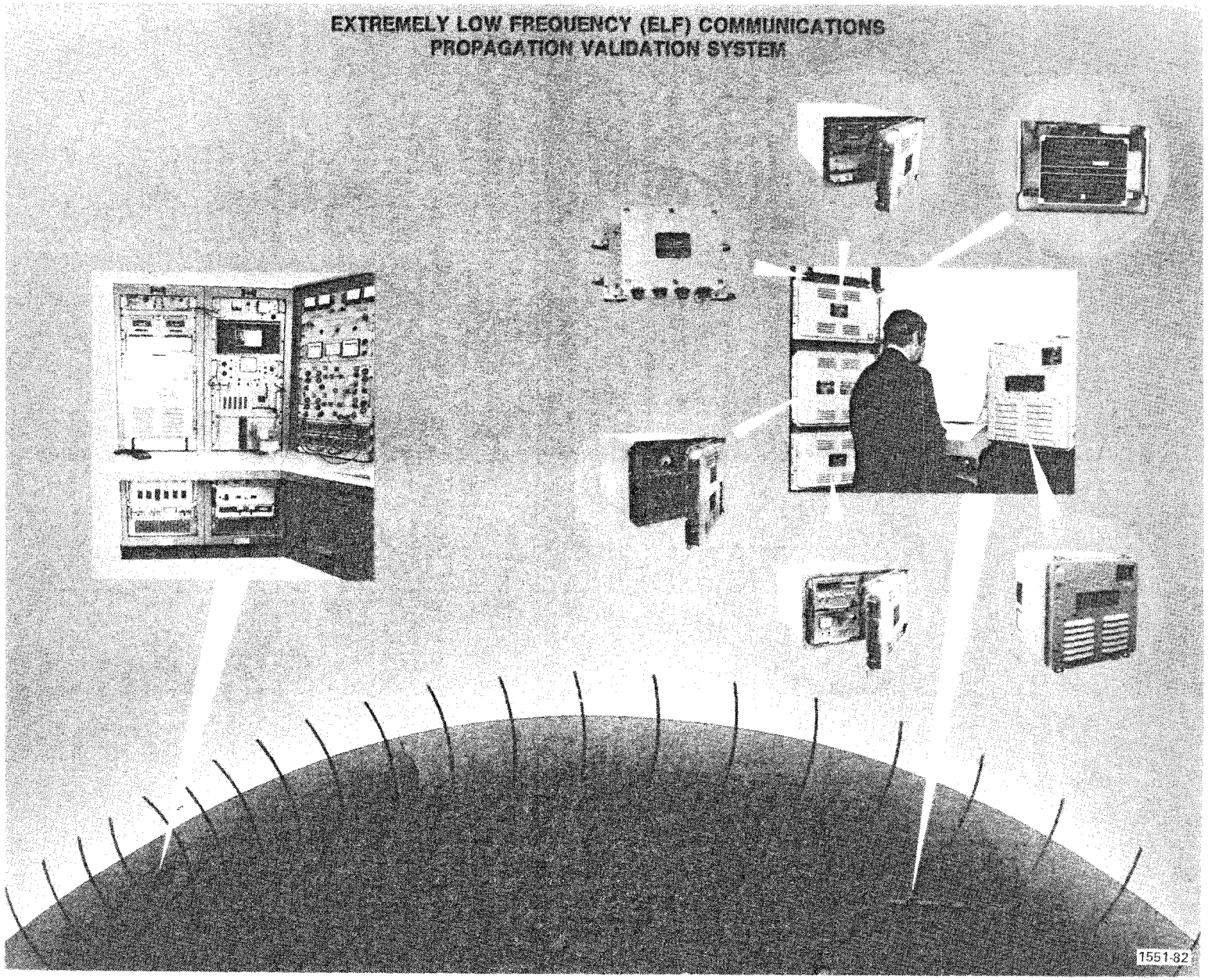
1216-81

United States ELF Global Communication to Submarines

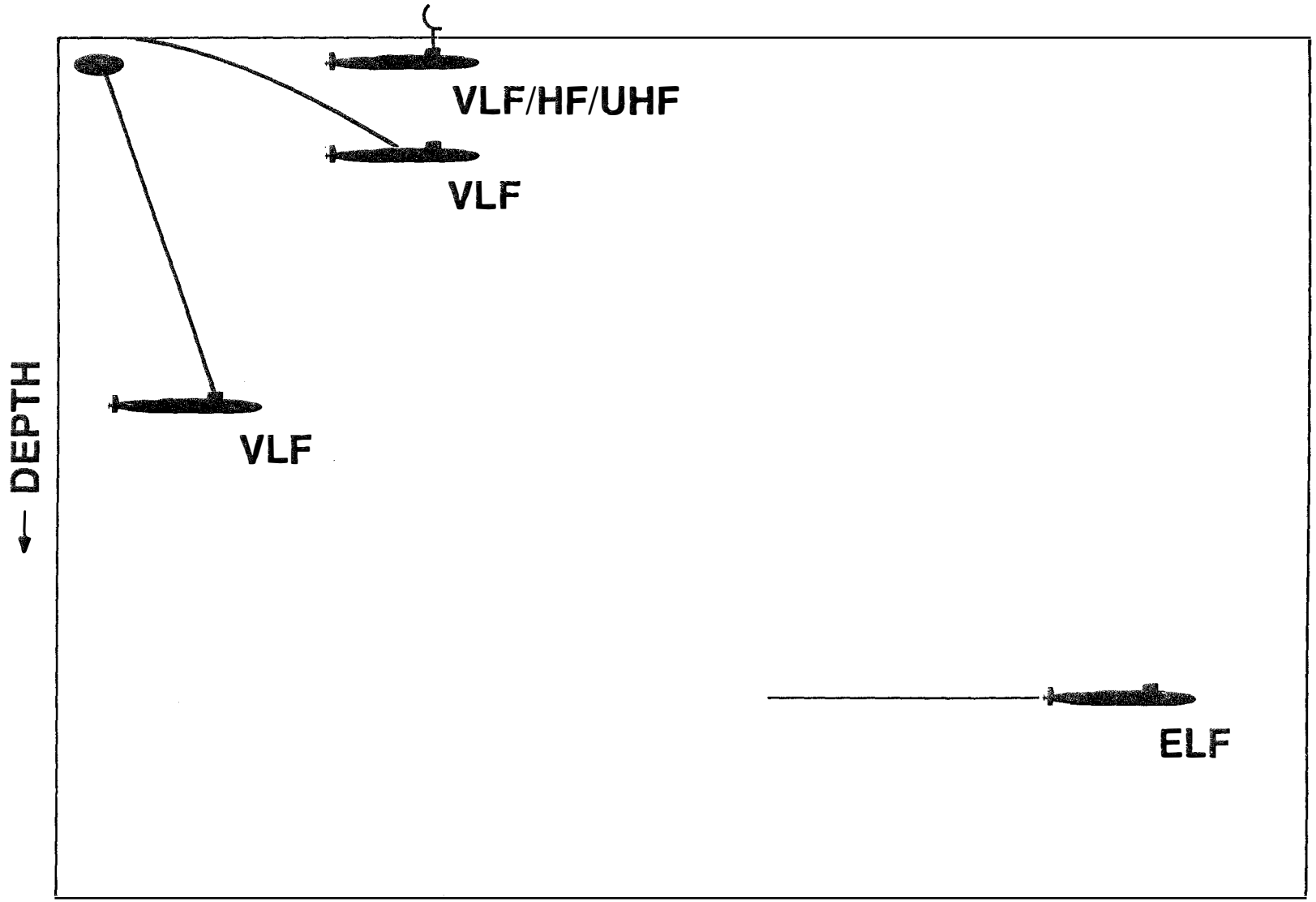


Systems

82 206C
7669-82

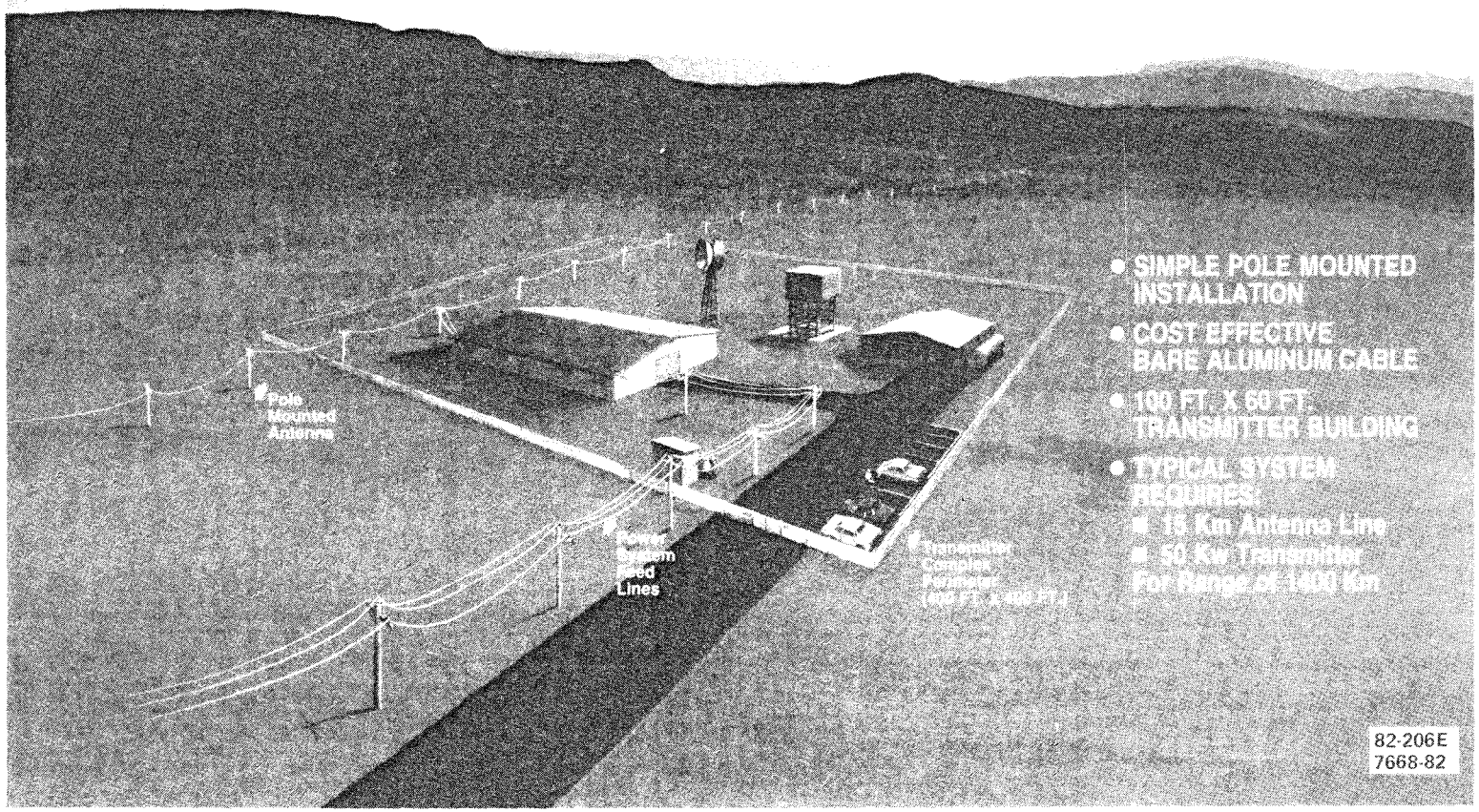

EXTREMELY LOW FREQUENCY (ELF) COMMUNICATIONS
PROPAGATION VALIDATION SYSTEM
1551-82

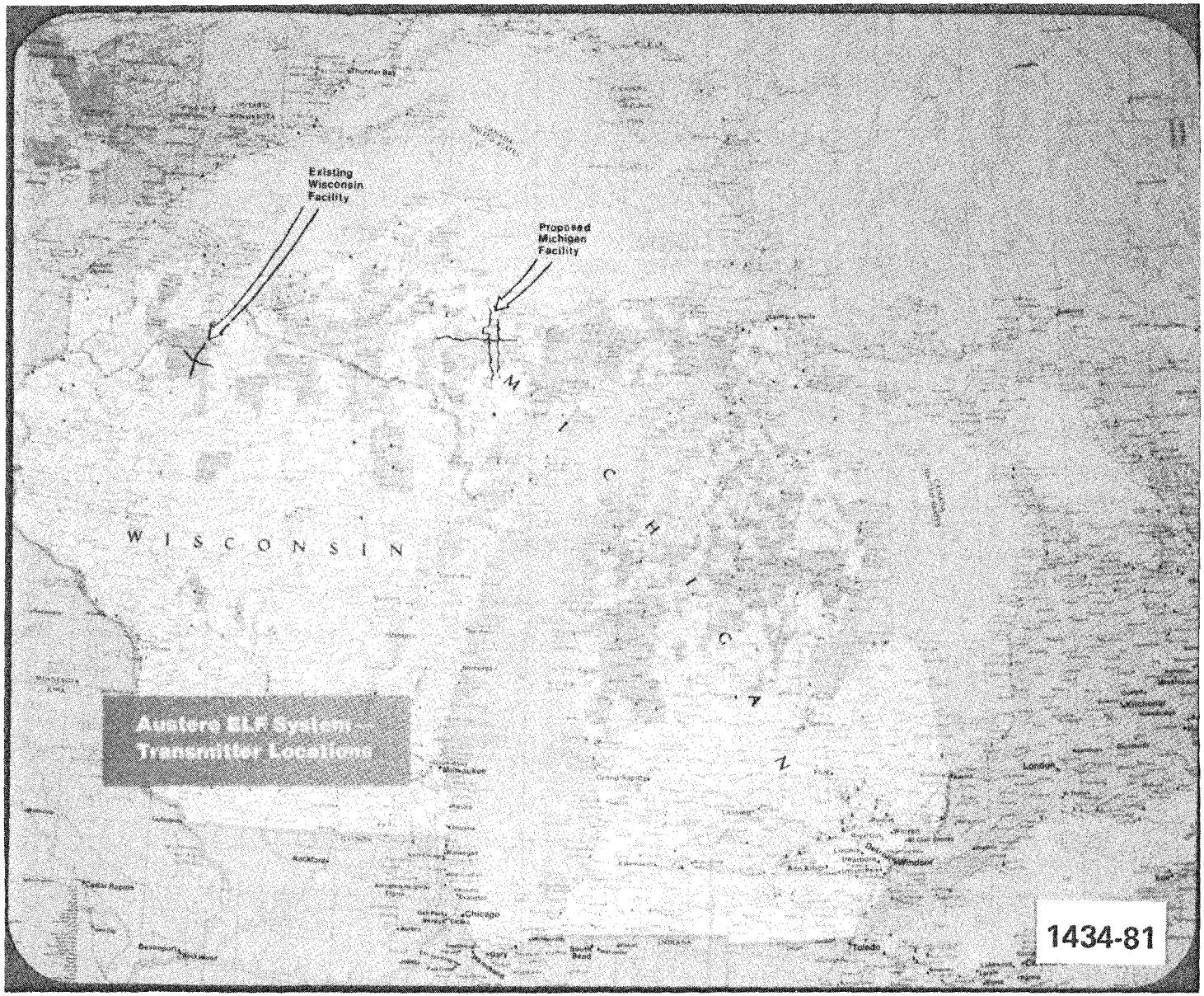
SUBMARINE RECEIVING METHODS



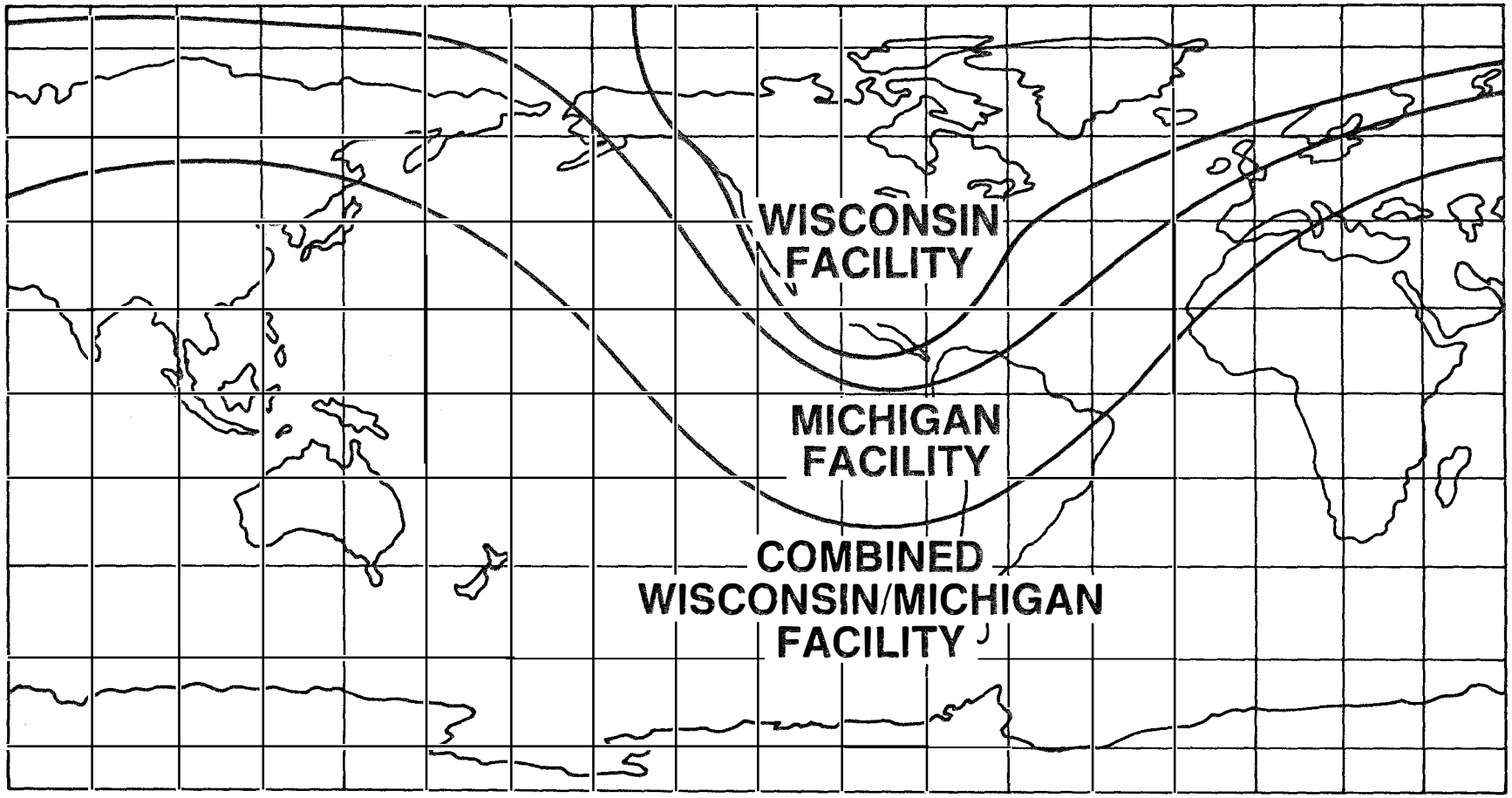
1397-81

ELF Transmitting Antenna System



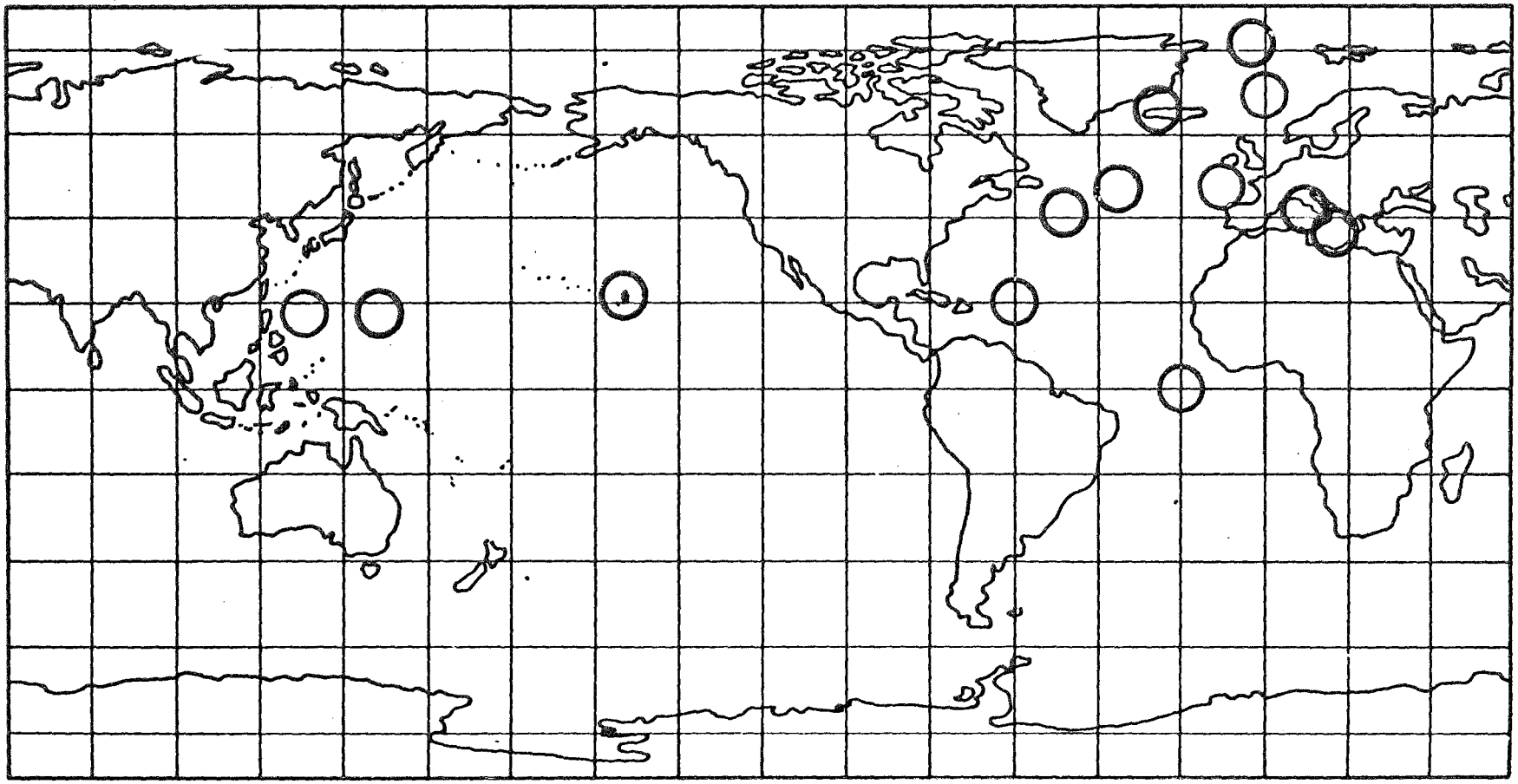

Existing
Wisconsin
Facility
Proposed
Michigan
Facility
WISCONSIN
MICHIGAN
Austere ELF System—
Transmitter Locations
Chicago
Toledo
London
1434-81

COMMUNICATIONS COVERAGE COMPARISON



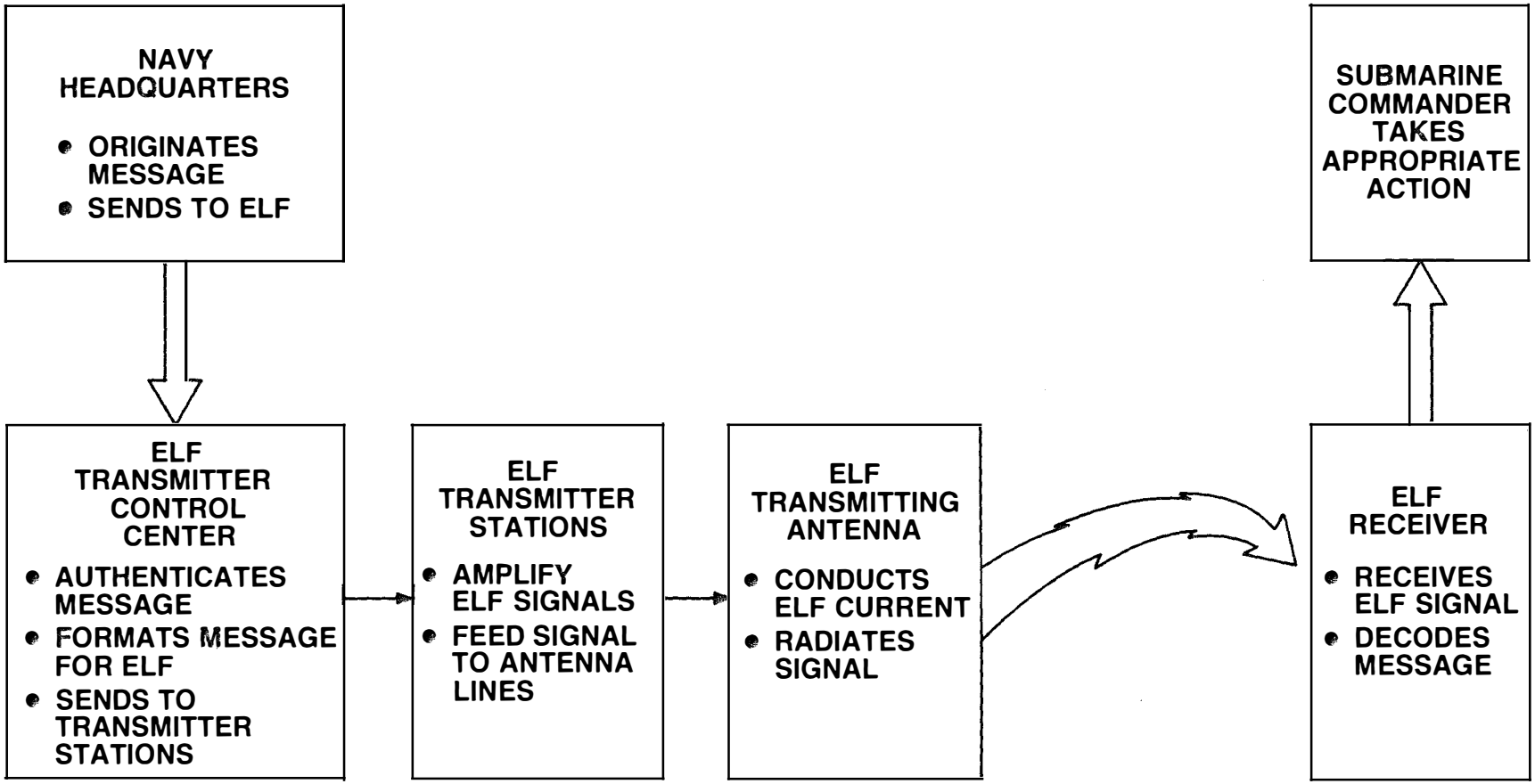
1369-81

PRESENT ELF TEST SERIES RECEPTION EXPERIENCE

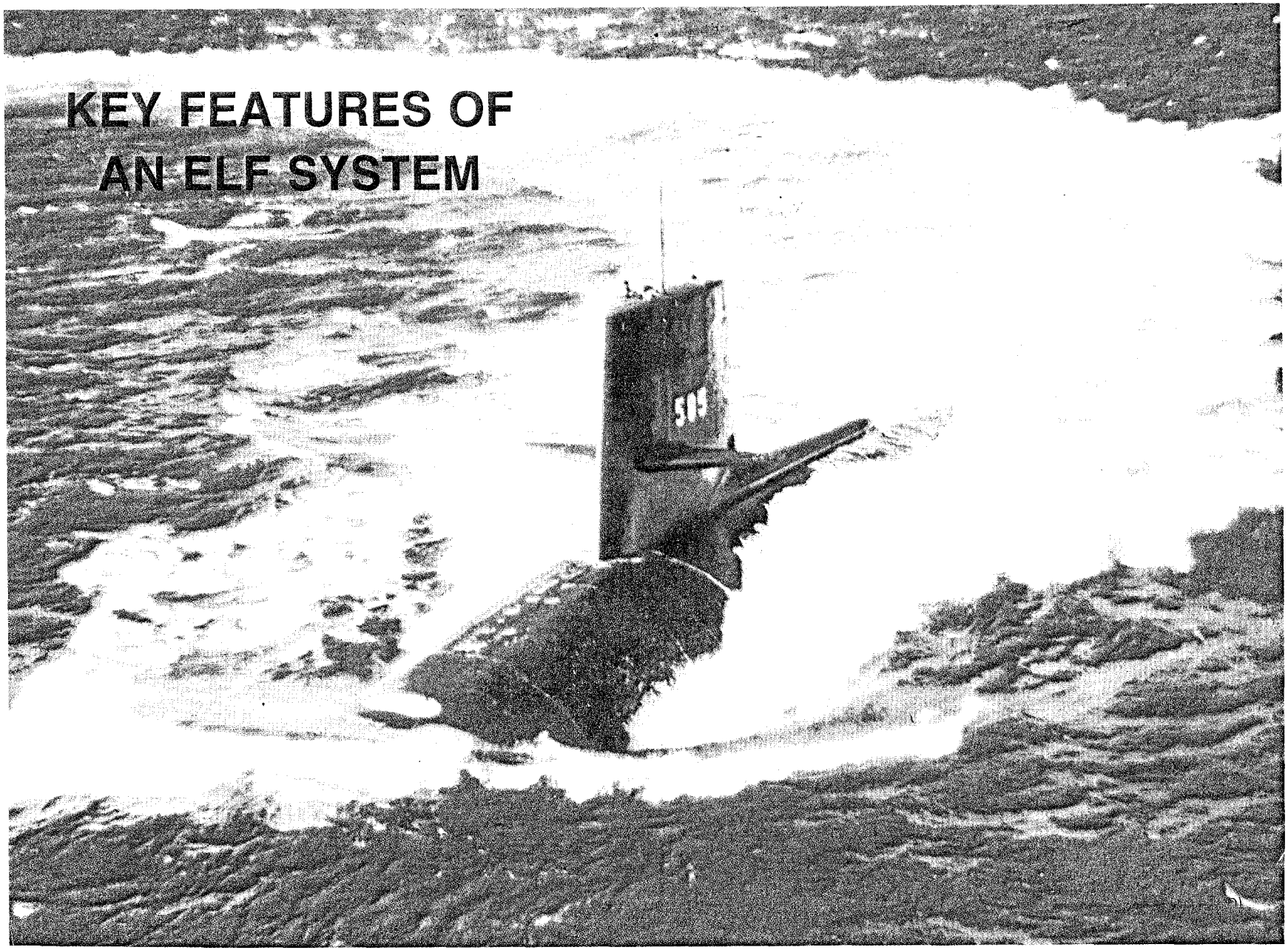


1371-81

ELF USAGE CONCEPT



KEY FEATURES OF AN ELF SYSTEM

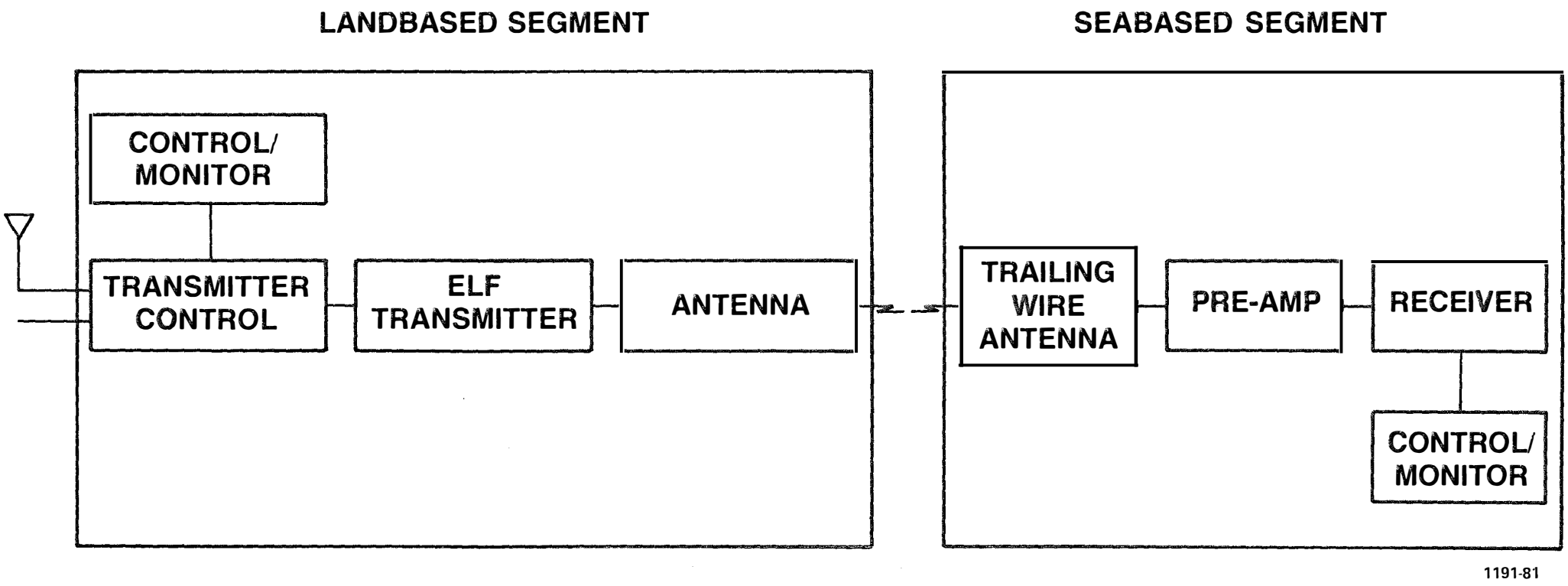


Key Features of ELF Communication

- Penetrates sea water, ice and the earth
- Allows continuous communication reception by submarines at depth, and to hardened force command centers
- Assures submarines will remain undetected and invulnerable
- Maintains submarine's condition of readiness for mission response
- Provides near global coverage from a single transmitter site
- Can be crypto-secure and jam protected
- Is fully within current state-of-the-art

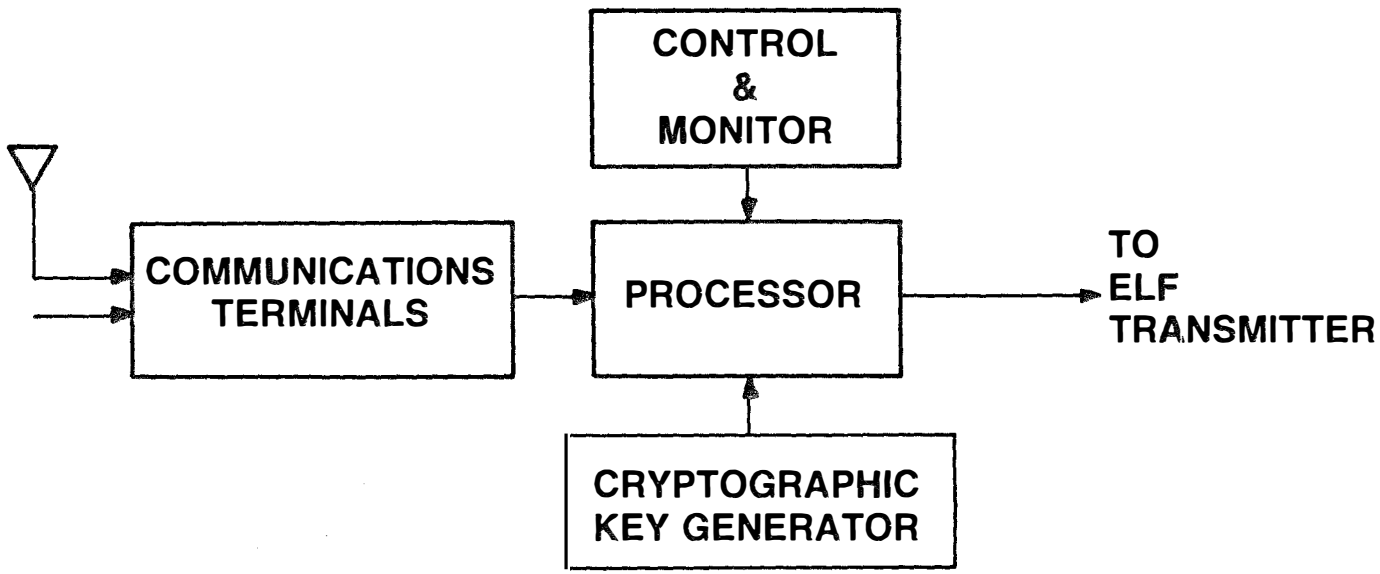
1226-81

ELF COMMUNICATIONS APPROACH



The Transmitter Control Segment and the ELF Transmitter can be separated by large distances and interconnected with appropriate communications

TRANSMITTER CONTROL BLOCK DIAGRAM

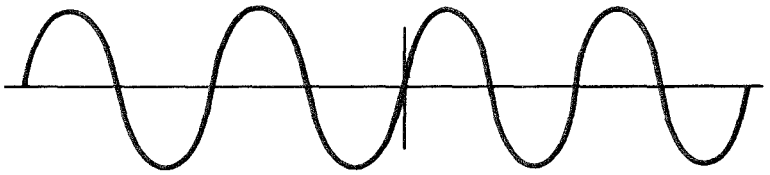


1197-81

MODULATION, FREQUENCY & CODING SELECTION

MODULATION

- MSK GIVES A NEAR OPTIMUM BANDWIDTH AND IS EASILY IMPLEMENTED



FREQUENCY

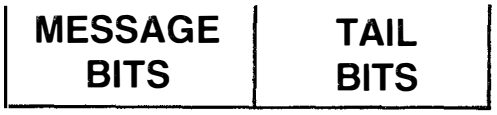
- ELF SIGNALS PROPAGATE WITH VERY LITTLE ATTENUATION, e.g., PATH LOSS OF 1 dB PER 1000 km AT 100 Hz

- ELF SIGNALS PENETRATE USEFUL DISTANCES DOWN INTO THE OCEAN, e.g., 0.09 dB/FT AT 75 Hz

CODING

- ORTHOGONAL (BLOCK)

- CONVOLUTIONAL



1215-81

ELF Transmitting Antenna

- A practical transmitting antenna for ELF consists of:
  - *A long horizontal cable*
  - *Cable may be above, on or below the surface of the earth*
  - *Antenna must be grounded at each end*
  - *Antenna normally powered at or near its center*
- The transmitting antenna excites electromagnetic waves in the spherical cavity bounded by the ionosphere and the surface of the earth
- Radiated power is a function of IL product

$$Pr = \frac{\omega^2 (IL)^2}{8c^2 h \sigma_e} \quad \text{watts}$$

- Low conductivity areas are desirable to improve antenna efficiency

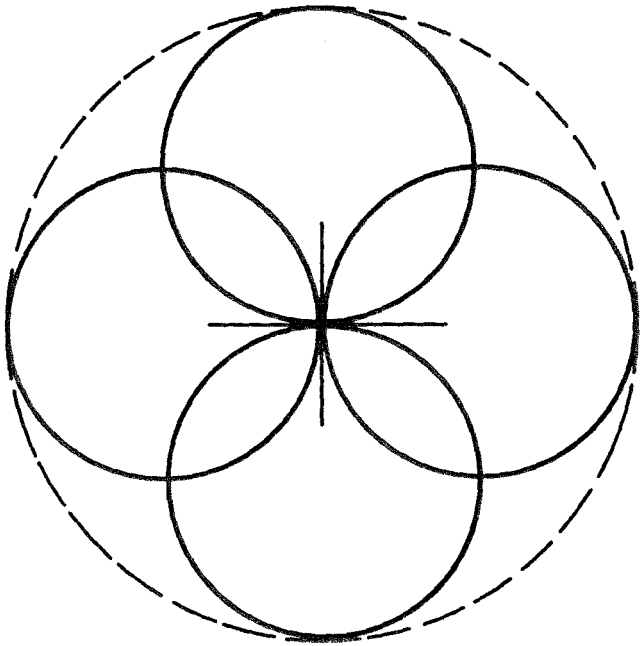
1390-81

ELF TRANSMITTING ANTENNA

- If perpendicular lines are installed and the antenna currents suitably phased, the antenna pattern can be steered
- Attenuation rate of ELF propagation is on the order of 1 dB per 1000 km of path length at 100 Hz

1233-81

RADIATION PATTERN



1192-81

Horizontal Grounds

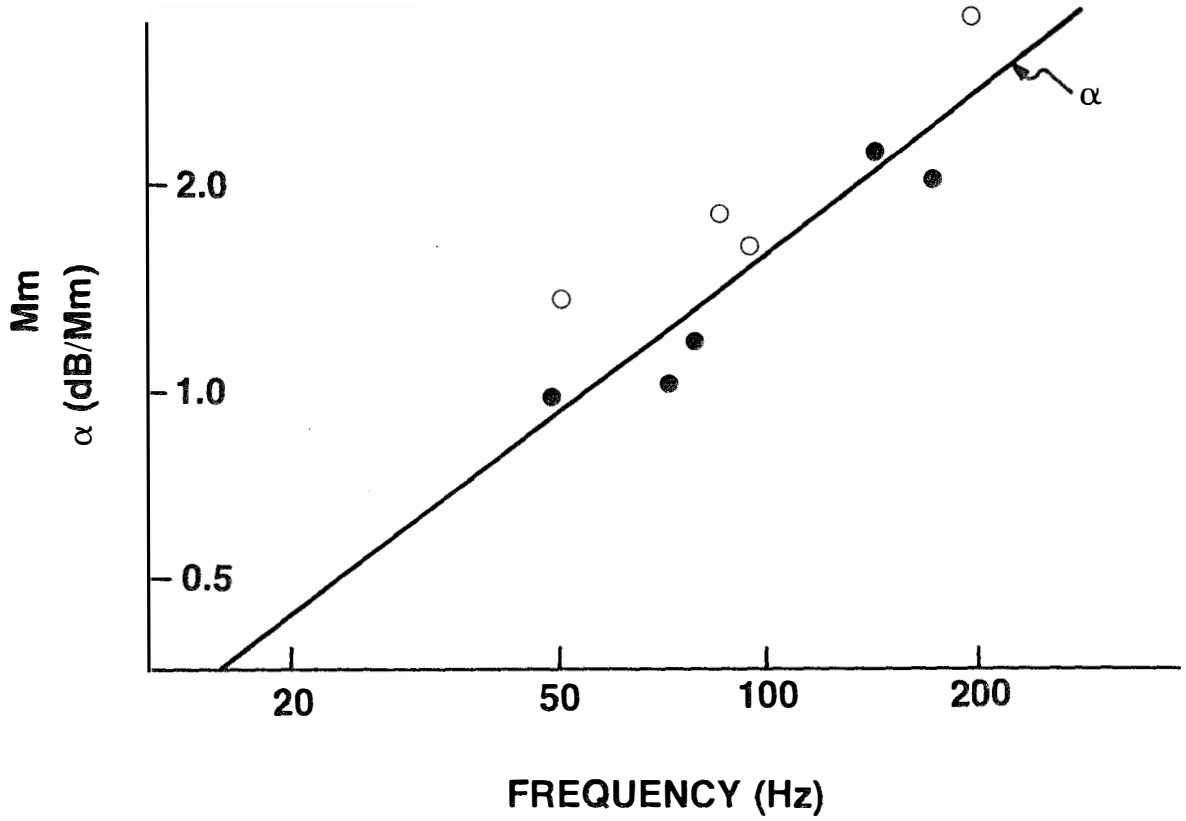
- Resistance of grounds depends inversely on the product of installed length and effective ground conductivity
- Step potential is proportional to

  d = burial depth L = length σ = ground conductivity $\frac{I}{\sigma L d}$
- Installation factors
  - *Multiple wires and feed points*
  - *Horizontal length*
  - *Burial depth*
  - *Long right of way requirements*
  - *Desirable to locate in relatively high conductivity surface layers*
  - *Wire size determined by mechanical handling and strength*
  - *Easy access to wire after burial*
  - *Large area to survey for conformance to safety requirements*
  - *Vertical rods*

1401-81

PROPAGATION MEASUREMENTS

○ = DAY
● = NIGHT



PROPAGATION IS NOT UNIFORM IN POSITION, TIME OR DIRECTION DUE TO VARIATIONS OF THE LOWER STRUCTURE OF THE IONOSPHERE

1195-81

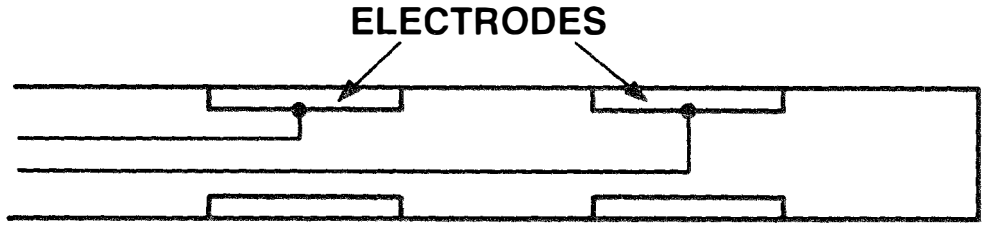
ELF Propagation and Excitation Characteristics

	45 Hz	76 Hz	140 Hz
Propagation loss, dB per 1000 km	0.75	1.2	2.0
Seawater penetration, db per ft	.07	.09	0.12
Relative transmitting antenna efficiency, dB	−4.4	0	+2.5

1399-81

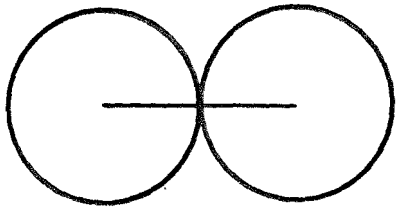
RECEIVING ANTENNA

— BUOYANT E FIELD TRAILING WIRE ANTENNA WITH ELECTRODES SPACED 1000 FT APART



— ANTENNA PATTERN

OPTIMUM DIRECTION FOR RECEPTION
DIRECTLY TOWARD OR DIRECTLY
AWAY FROM TRANSMITTER

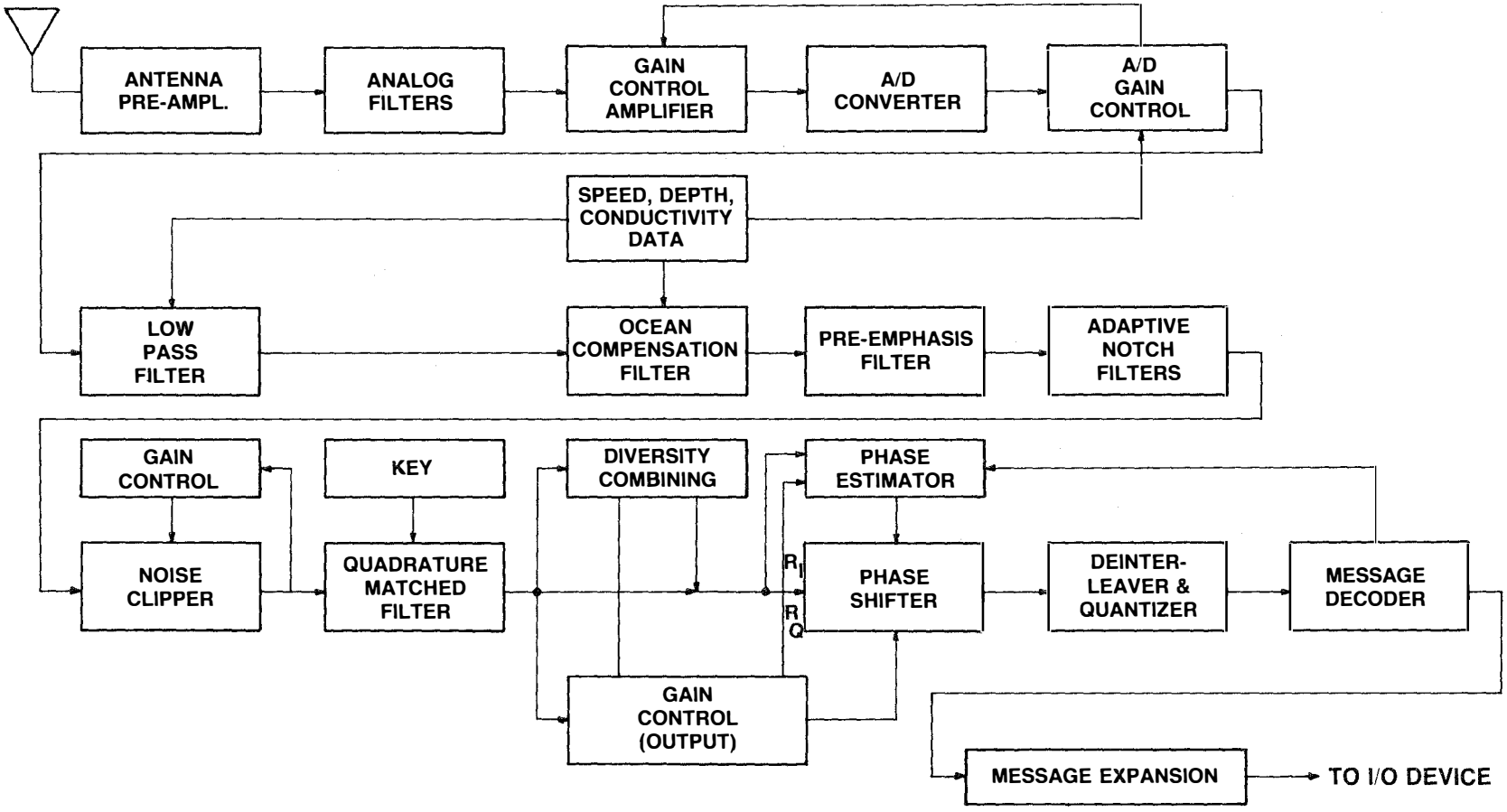


— H FIELD ANTENNA

- BEYOND CURRENT STATE OF THE ART
- OMNI-DIRECTIONAL

1214-81

RECEIVER FLOW DIAGRAM



RECEIVER GENERAL DESCRIPTION

- MSK modulated waveforms represent message chips
- Analog signals received by E field antenna
- The signal is digitized after filtering and AGC
- Receiver computer program performs signal processing to recover the original ELF message
- Decoded messages are provided to the operator

1231-81

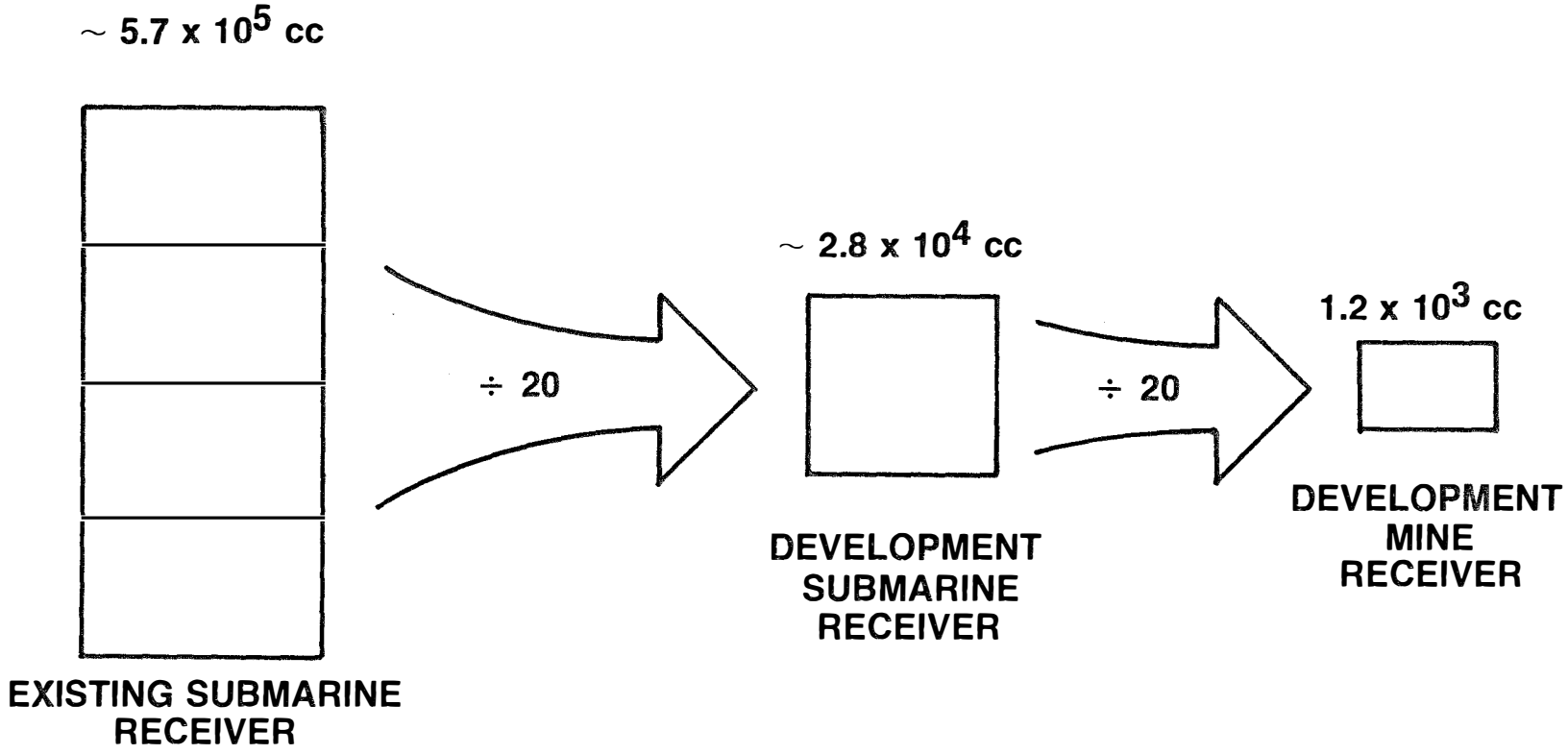
RECEIVER OPERATION

- Receiver segment is chip and keystream synchronized with the MIS/TS through the use of highly stable time and frequency standards located at each site

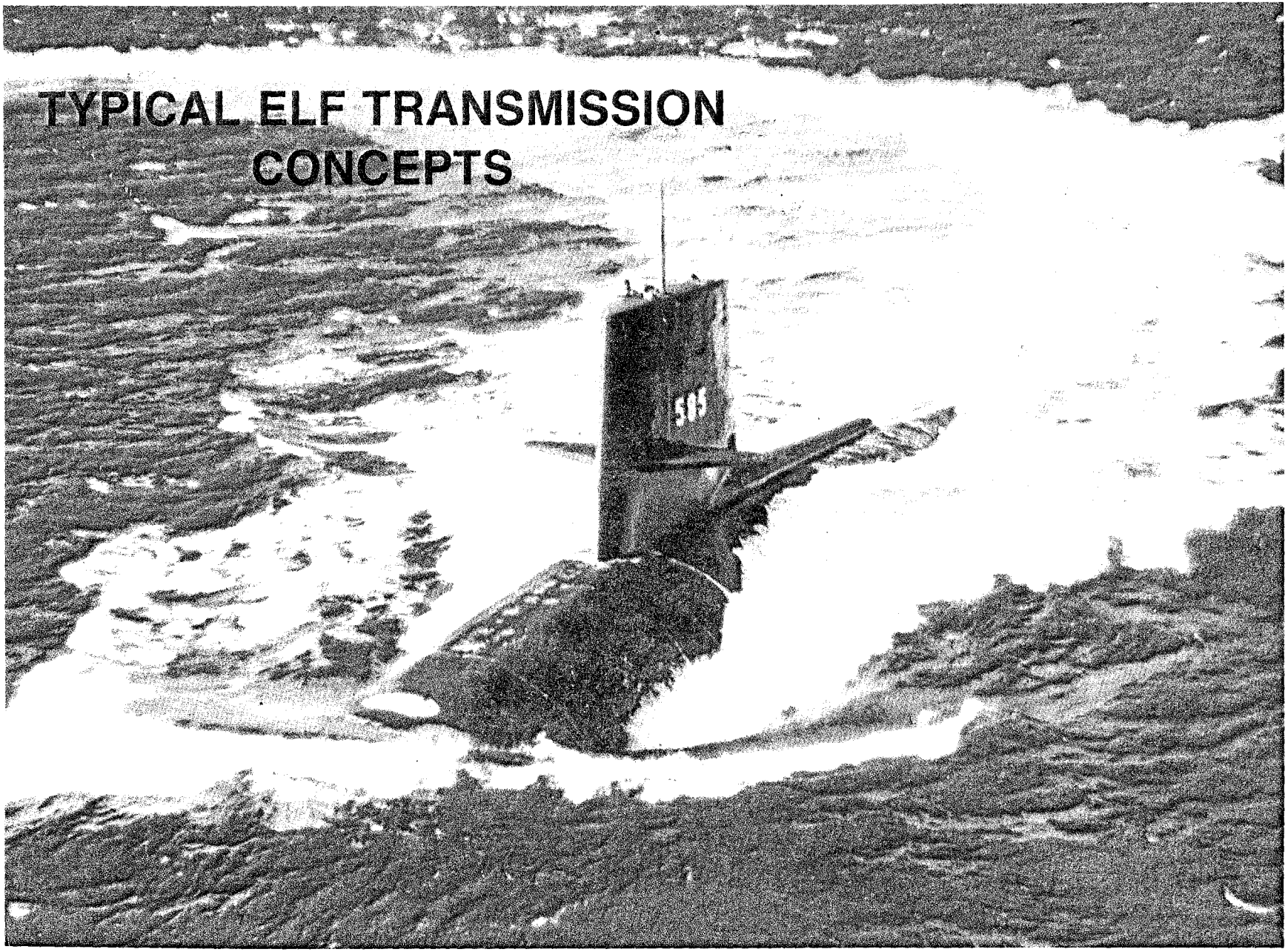
- Message synchronization between the MIS/TS and receiver is achieved through the definition and adherence to predefined times at which the end of the first block of any message will terminate

- The receiver and transmitter operates at R_c chips per second to provide noise and jam protection

Trends in Receiver Development



3740-81

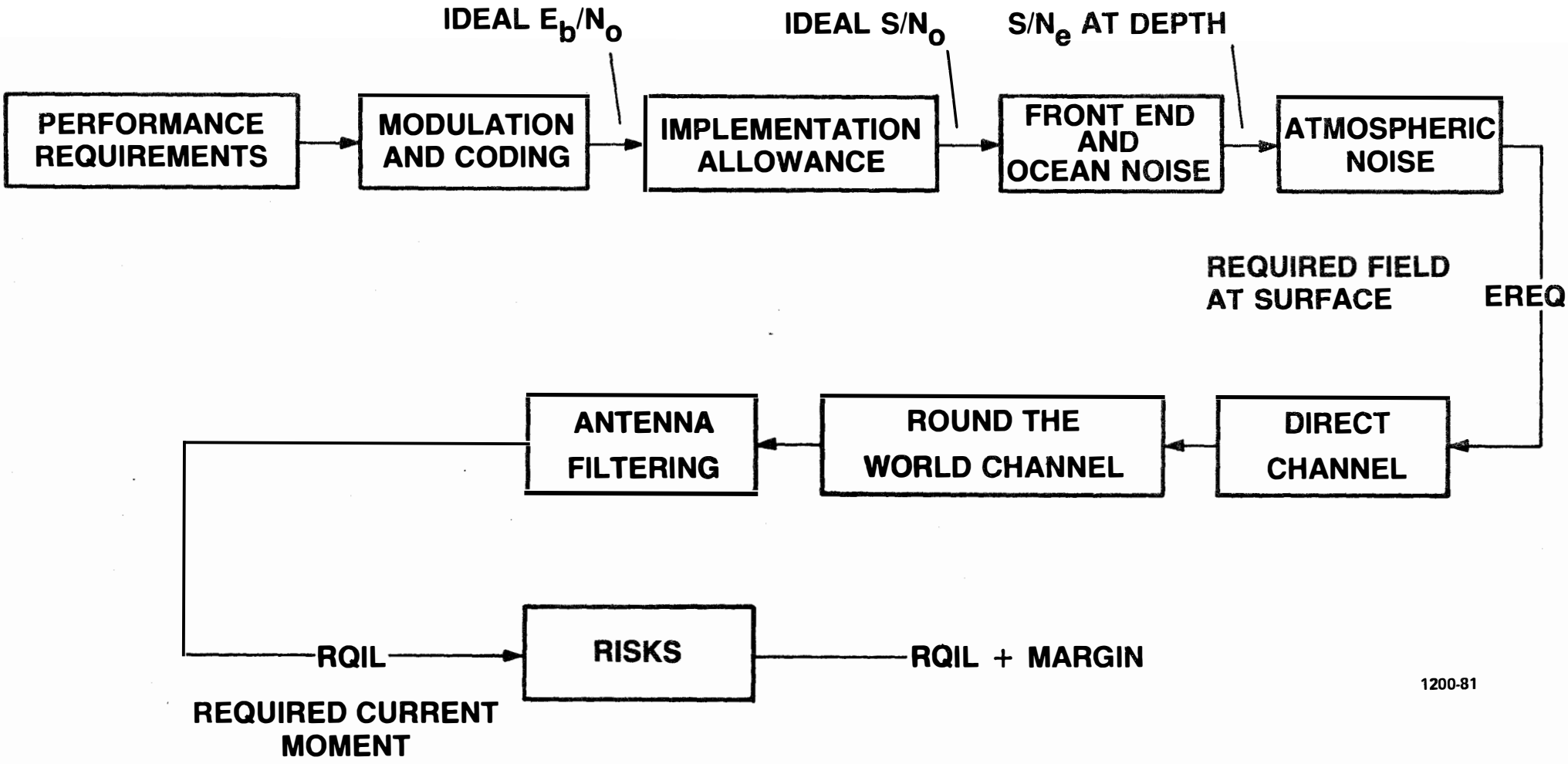

TYPICAL ELF TRANSMISSION
CONCEPTS

Typical ELF Transmitter and Antenna Requirements for Moderate Systems

System Features	Short Range System 400 km	Medium Range System 1400 km	Long Range System 3000 km
Application:	• Reconstitute command center C^3 connectivity in trans- and post-attack environment • Mine reco	• Submarine communications • Mine reco	• Submarine communications
Coverage area:	400 km dipole pattern	1400 km dipole pattern	3000 km omni-pattern
Antenna length:	12 km line	15 km line	20 km crossed dipole
Transmitter power:	One 10 kw P.A.	One 50 kw P.A.	Two 200 kw P.A.

3446-82

DERIVATION OF REQUIRED CURRENT MOMENT



DERIVATION OF REQUIRED CURRENT MOMENTS CONSIDERING DIRECT WAVE ONLY

$$|Ev| = \overbrace{\frac{1Lf}{2}}^{\text{CURRENT MOMENT}} \sqrt{\frac{2\pi\mu_o}{R_C}} \sqrt{\frac{1}{\sin(d/R)}} \sqrt{\frac{1}{h^2\sigma_e\, c/s}}\; e^{-\alpha' d}$$

SPREADING FACTOR

EXCITATION FACTOR

ATTENUATION COEFFICIENT IN NEPERS/Mm

$$20 \log (IL) = 20 \log (EREQ) - 20 \log f - 10 \log \frac{\pi\varepsilon_o}{2R_c}$$

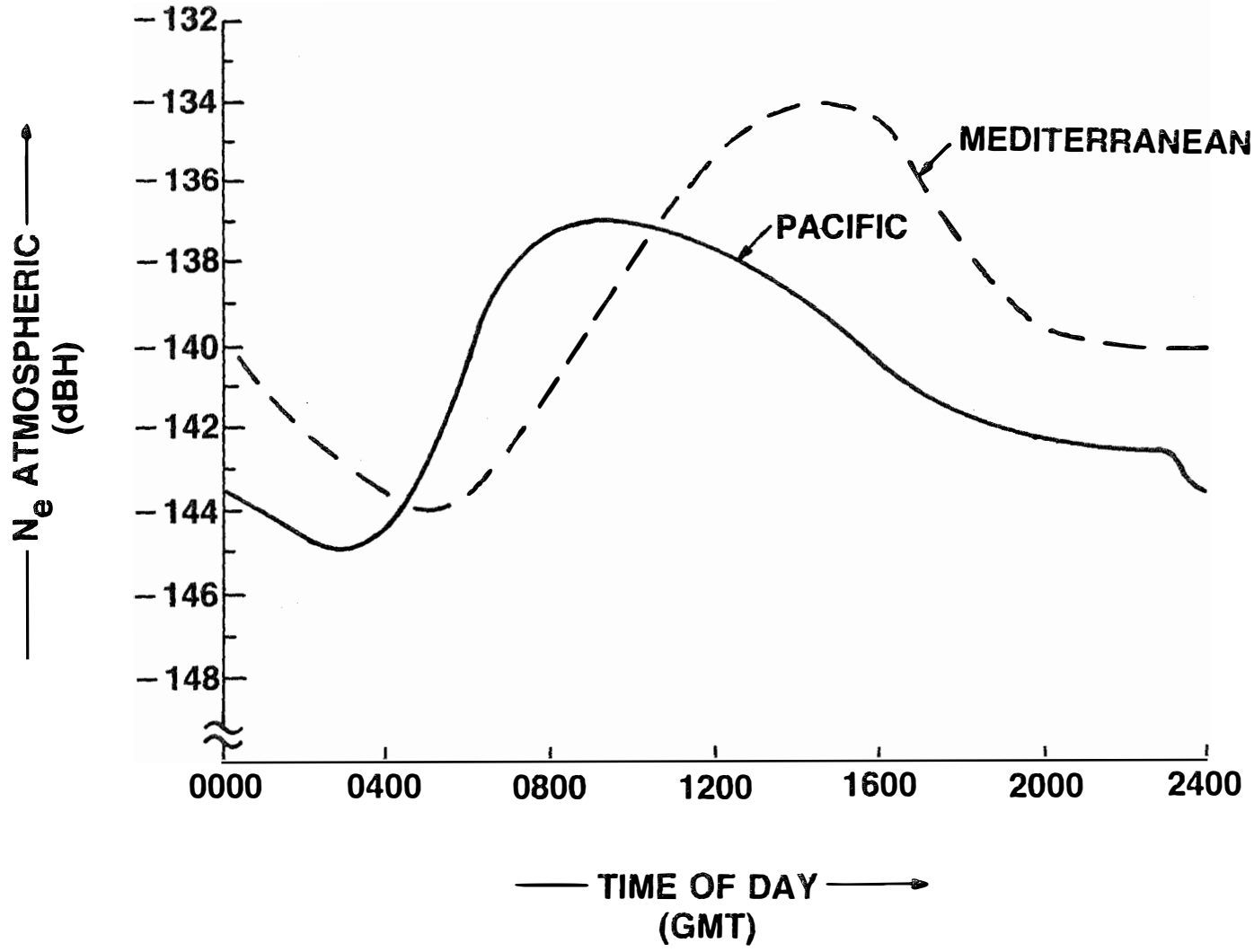
$$+ 10 \log \sin (d/R - 20 \log \sqrt{\frac{1}{h^2\sigma_e c/\upsilon}} + \alpha d$$

$$= 20 \log (EREQ) - 20 \log f + 261.38$$

$$+ 10 \log \sin (d/R) - 20 \log \xi + \alpha d$$

1217-81

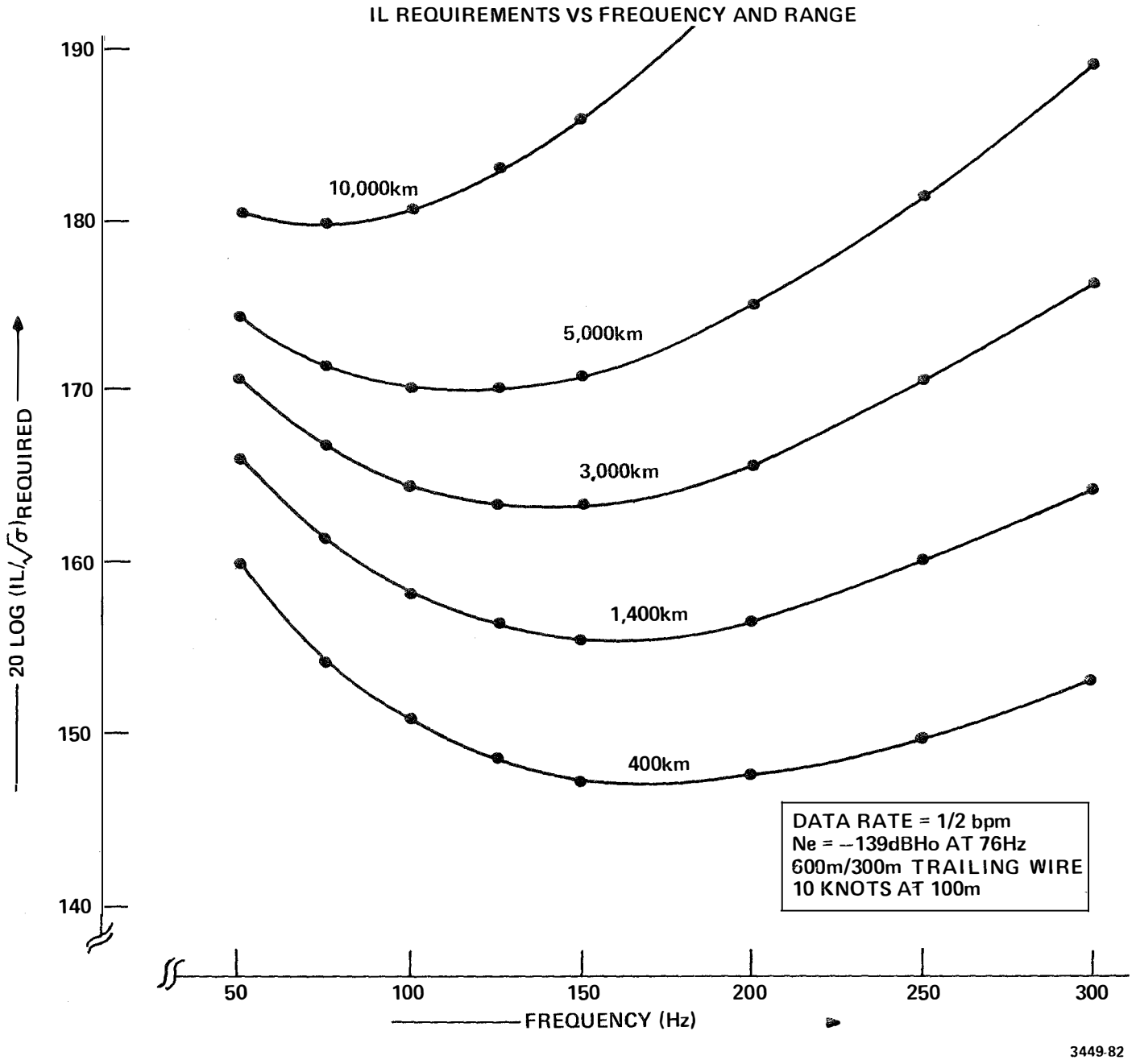
SMOOTHED WORST CASE ATMOSPHERIC NOISE USED FOR SYSTEM SIZING



1201-81

Chief Parameters for IL Requirement Estimate

- **Data rate: 1/2 bit per minute (10 bits in 20 minutes)**
- **Receiving antenna**
  - Performance similar to 300m electrode spacing (600m total length) trailing wire submarine antenna towed at 10 knots (5.1m/s) at 100m depth
  - 100m of seawater produces the same attenuation as about 4 km of "average" earth

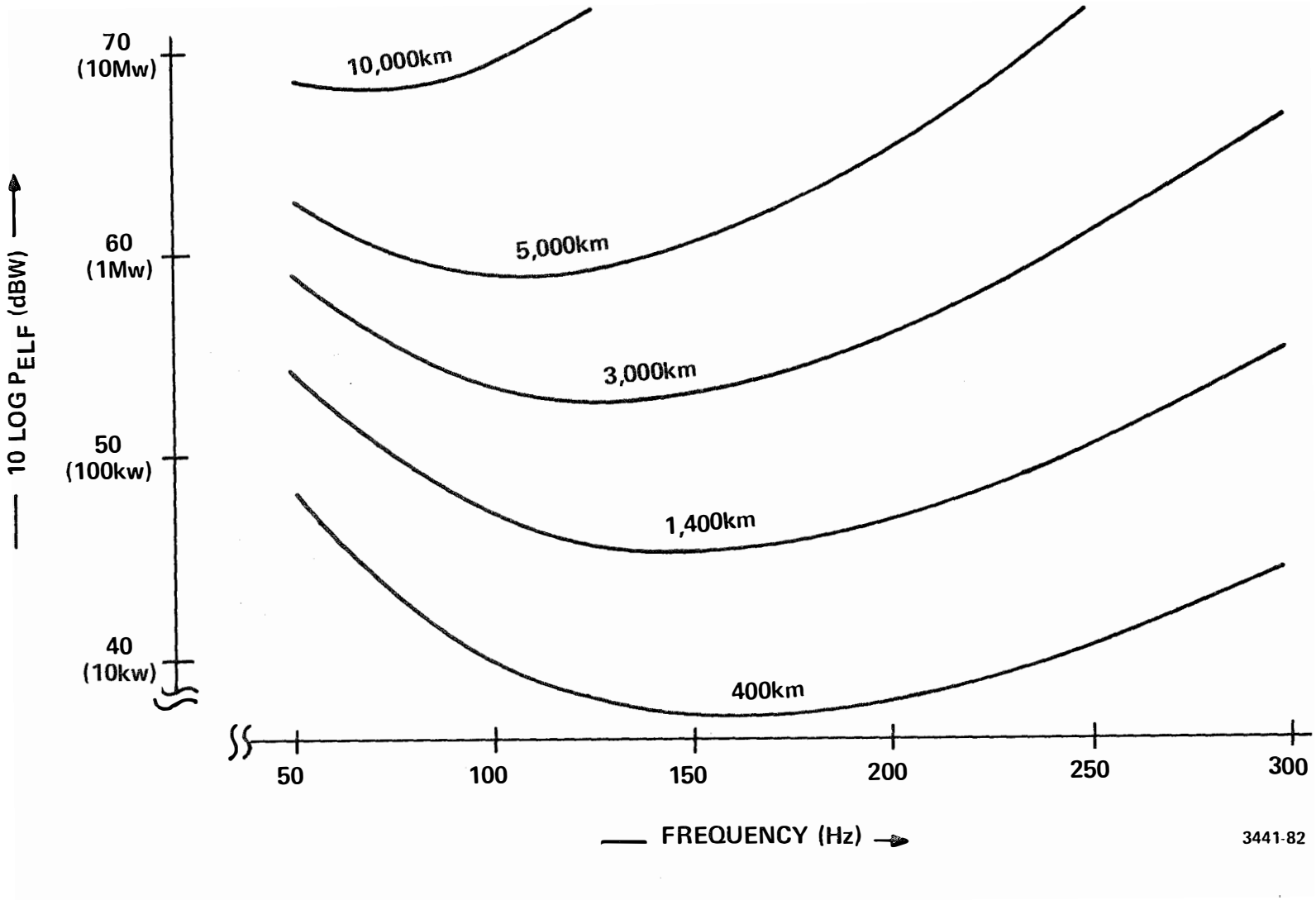

IL REQUIREMENTS VS FREQUENCY AND RANGE
190
180
170
160
150
140
20 LOG (IL/√σ)REQUIRED
10,000km
5,000km
3,000km
1,400km
400km
DATA RATE = 1/2 bpm
Ne = –139dBHo AT 76Hz
600m/300m TRAILING WIRE
10 KNOTS AT 100m
50
100
150
200
250
300
FREQUENCY (Hz)
3449-82

Assumptions for Estimating ELF Power Requirements

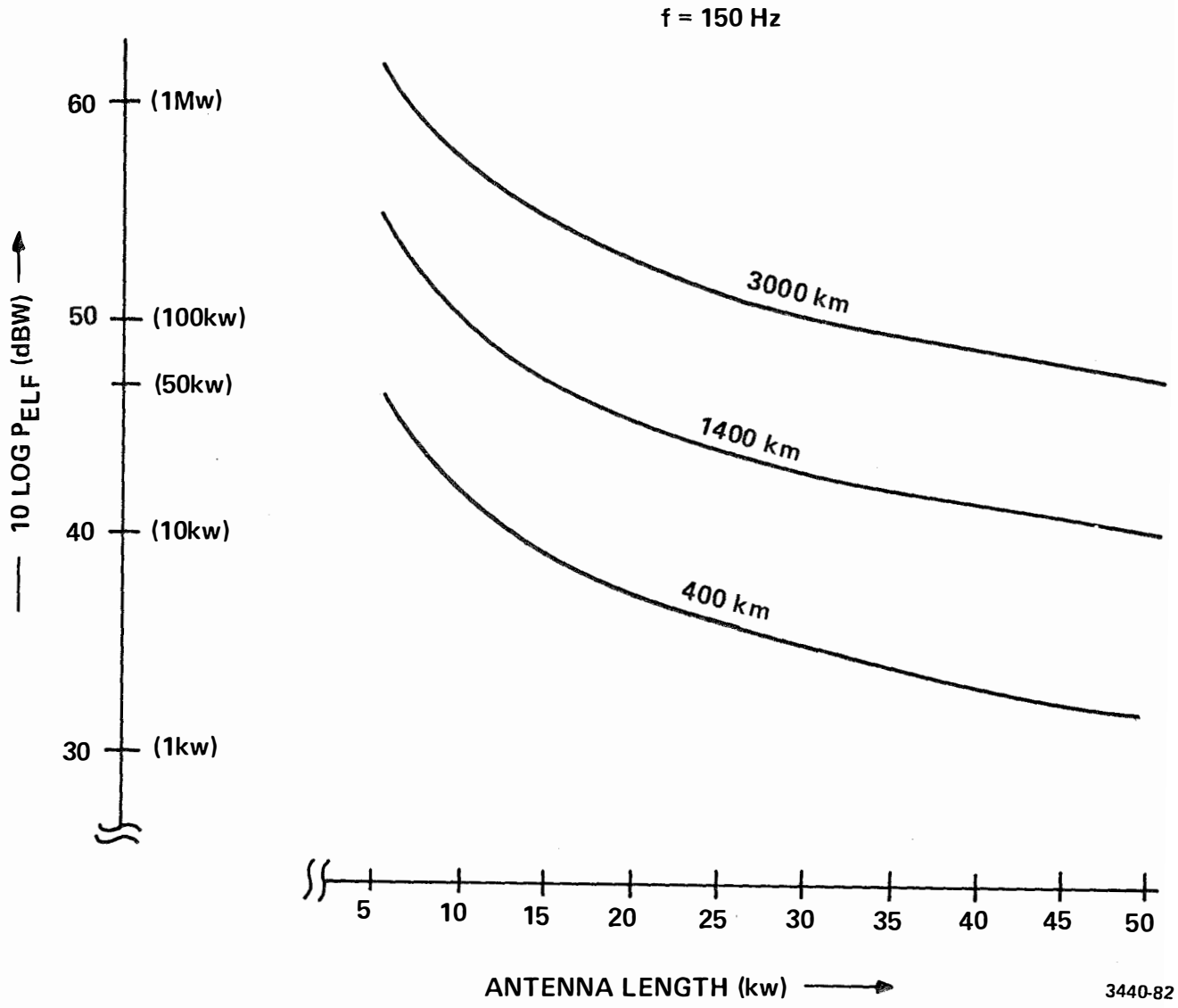
- **Antenna length: 20 km (plus ground assemblies)**
- **Site effective conductivity: 5×10^{-4} S/m**
- **Antenna cable: 10^6 circular mils (25.4mm effective diameter) aluminum**
- **Terminal grounds: 1.5 Ω each (two per antenna line)**
- **One antenna line**
  - Coverage will not be omniazimuthal unless two orthogonal lines are used
  - Double ELF power for two lines

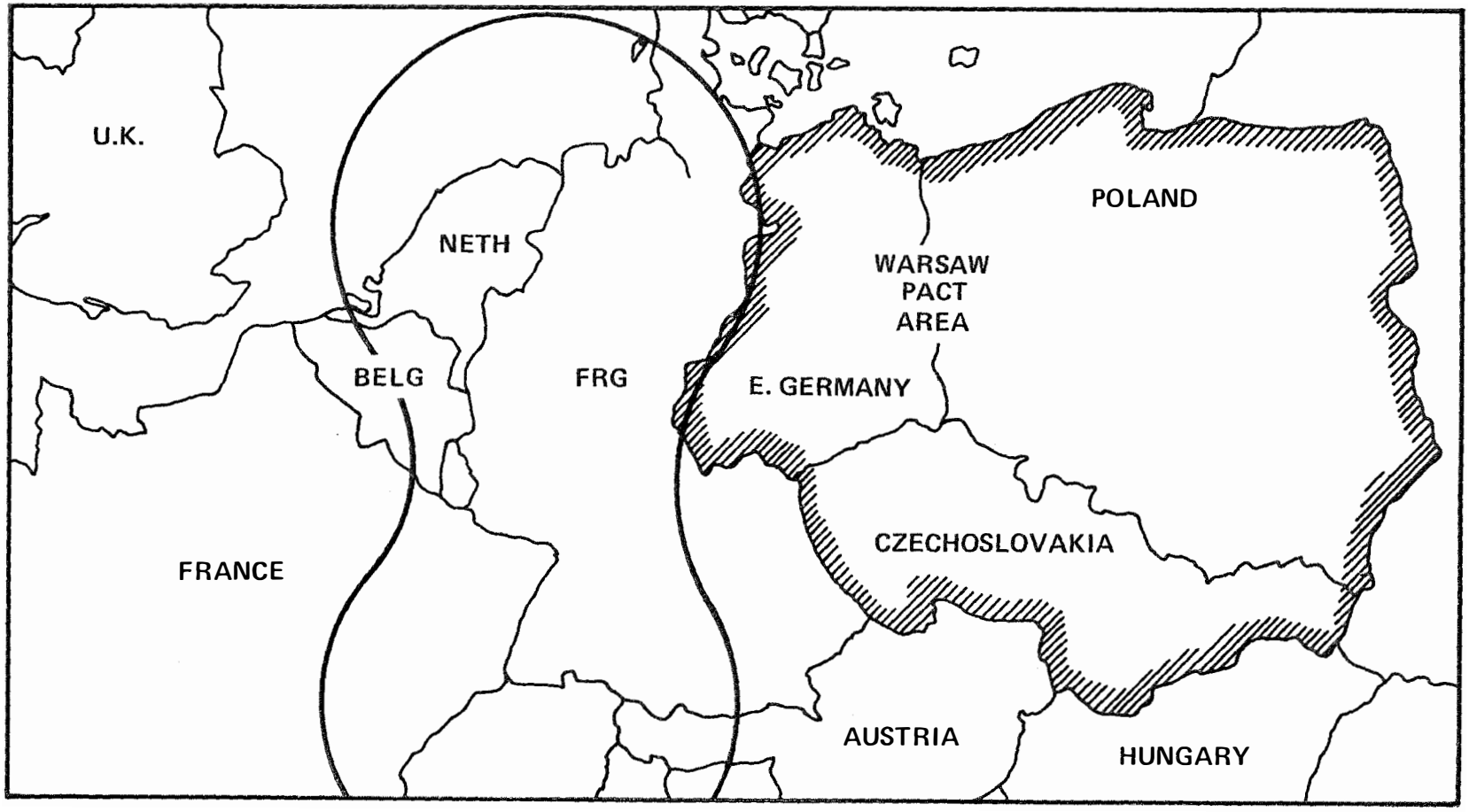
3442-82

ELF POWER REQUIREMENTS VERSUS FREQUENCY AND RANGE FOR EXAMPLE SYSTEM (SINGLE ANTENNA)



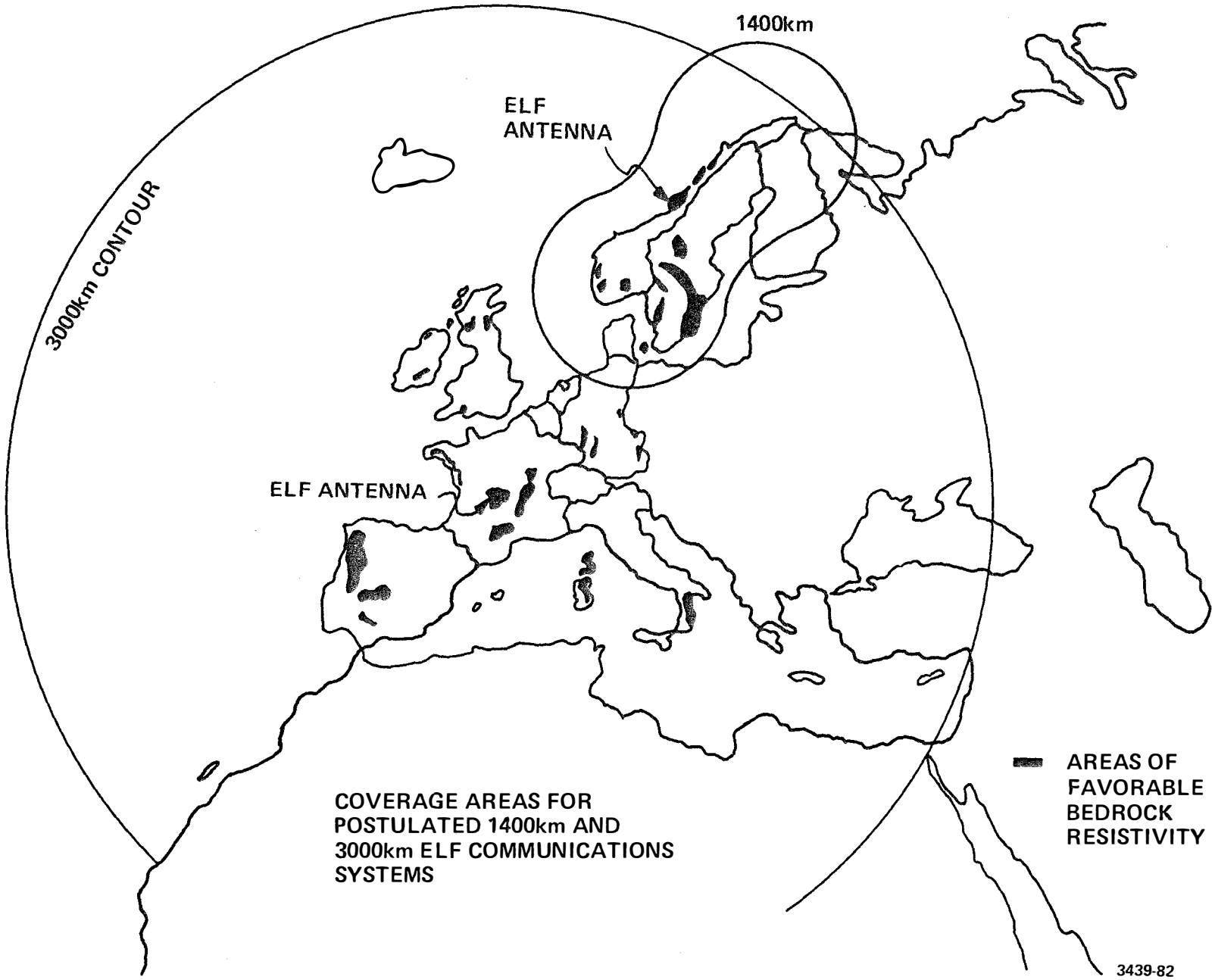
ELF POWER REQUIRED FOR EXAMPLE SYSTEM
VERSUS LINE LENGTH AND RANGE (SINGLE ANTENNA)





3450-82

COVERAGE AREA FOR POSTULATED
400km ELF COMMUNICATIONS SYSTEM

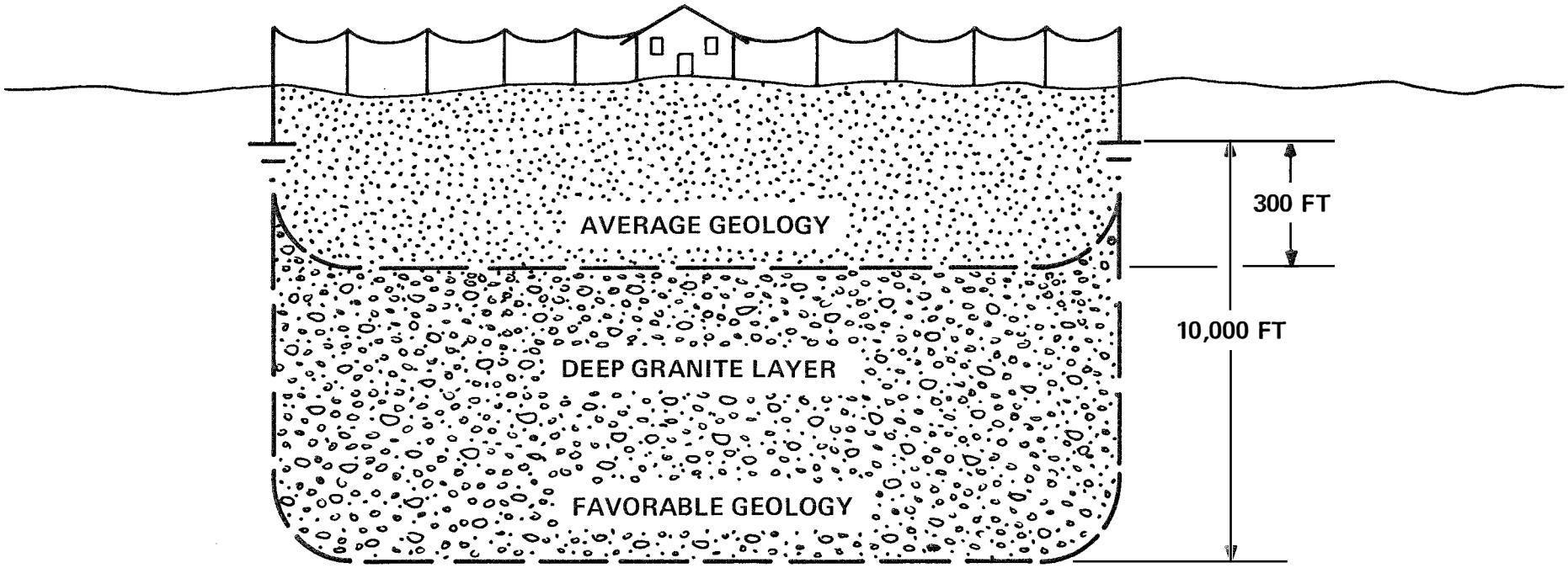


COVERAGE AREAS FOR POSTULATED 1400km AND 3000km ELF COMMUNICATIONS SYSTEMS

ELF EFFICIENCY
VS
BEDROCK RESISTIVITY

100 TIMES HIGHER
RESISTIVITY MEANS

100 TIMES MORE
ELF POWER



3447-82

TRANSMITTER AND ANTENNA SENSITIVITY TO SITE LOCATION

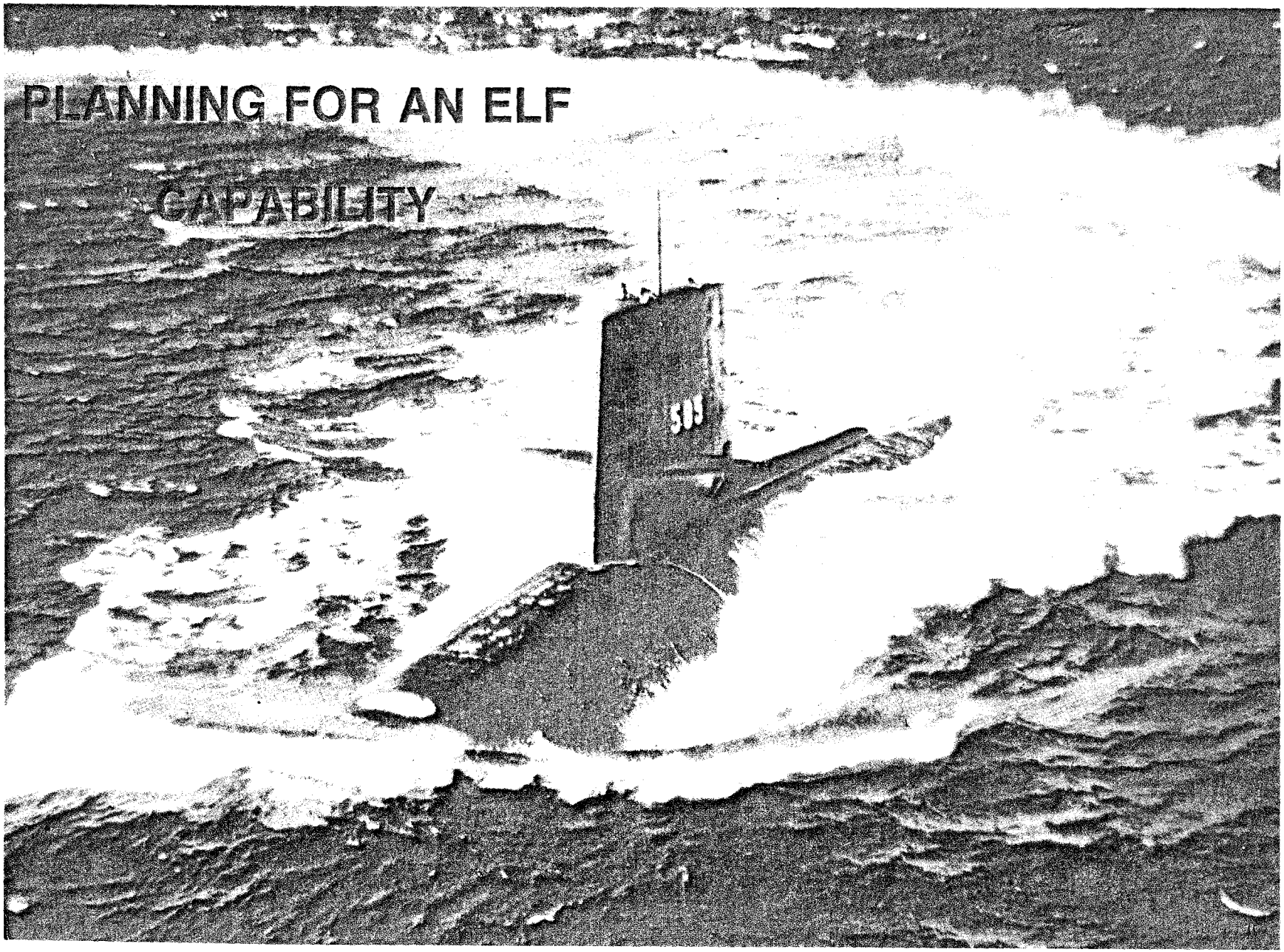
PARAMETER	SITE A	SITE B
SITE CONDUCTIVITY	10^{-5} MHOS/m	10^{-3} MHOS/m
RQIL	10^{6} A-m	10^{7} A-m
LINE LENGTH	6 km	6 km — 60 km
TRANSMITTER POWER	152 kw	15,200 kw — 523 kw

1227-81

Summary Table of Applications For ELF Communications

Application	Force Elements	Basing Location	Major Improvements
1. Submarine communications	• SSBNs • SSNs • SSGs • SSs • Surveillance vehicles	Undersea	• Improved S&V • Resistance to jamming and nuclear effects • ASW detection • Covert operation flexibility • Maintain station depth and speed
2. Undersea weapons C^2	• Mines • Captor mines	Undersea	• Establish C^2 where none otherwise existed • Flexibility in mine deployment • Recovery
3. Land based weapons C^3	• Missile CPs • Command and control centers • Mine fields • Tactical fusion centers	Underground	• Reconstitute C^3 during severe ECM and nuclear stressed environment • Mine field C^2 and recovery • Improved mission planning C^3I
4. Survivable/ transportable ELF transmitters to support enduring C^3	• Land mobile transmitter • Shipboard transmitter	Land, sea	• Establish or reconstitute C^3 post attack • Resistant to jamming and nuclear effects

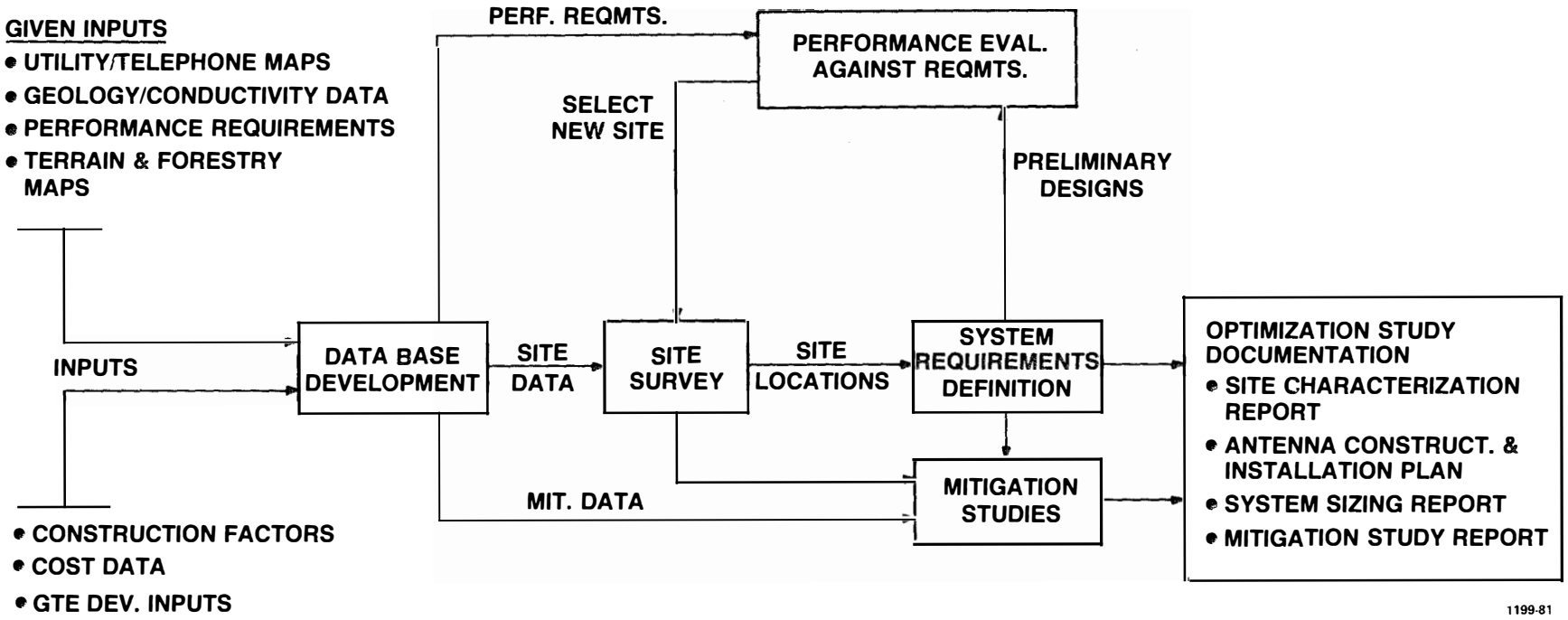
3365-82


PLANNING FOR AN ELF
CAPABILITY
503

Planning an ELF Program

- **Establish requirements for ELF utilization in defense planning**
- **Perform an ELF site optimization study to determine the following planning objectives:**
  1. Determination of a site location for an ELF transmitting antenna
  2. Size the transmission system and define requirements for the transmitter, antenna, grounds, and receiver
  3. Develop construction and implementation plans for the initial and final operating capability

Site Optimization Study
Functional Activities Diagram



1199-81

Site Optimization Study
Task Development

TASK 1

PERFORM SITE SURVEY

INPUTS

- GEOLOGIC MAPS
- MAPS OF TERRAIN
- MAPS OF NATIONAL GRID
- GROUND CONDUCTIVITY DATA

SUBTASKS

- DEVELOP PRELIMINARY SITING PARAMETERS
- PERFORM CONDUCTIVITY MEASUREMENTS
- SELECT CANDIDATE EX. SITES
- PERFORM ANTENNA SYSTEM REQUIREMENTS ANALYSES
- CONDUCT ANTENNA AND GROUND PERFORMANCE ANALYSIS
- DEVELOP BEDROCK GEOLOGICAL DATA
- DEVELOP SURFICIAL GEOLOGICAL LAND USE AND SOILS DATA
- DEVELOP ANTENNA CONSTRUCTION AND INSTALLATION PLAN

PRODUCTS

- RECOMMENDED FULL SCALE ELF ANTENNA SYSTEM LOCATION
- RECOMMENDED EXPERIMENTAL ANTENNA SYSTEM LOCATION
- GEOGRAPHICAL DATA
- CONDUCTIVITY DATA
- ANTENNA INSTALLATION PLAN

OUTPUT

- TECHNICAL REPORT
- BRIEFING

TASK 2

SYSTEM REQUIREMENTS DEFINITION

INPUTS

- ANTENNA LOCATIONS
- COMMUNICATIONS REQUIREMENTS
- CONDUCTIVITY
- GEOGRAPHICAL DATA

SUBTASKS

- DEVELOP SYSTEM PERFORMANCE REQUIREMENTS
- DEVELOP TRANSMITTER REQUIREMENTS
- DEVELOP ANTENNA REQUIREMENTS
- DEVELOP ANTENNA GROUND REQUIREMENTS
- DEVELOP TEST REQUIREMENTS

PRODUCTS

- COMMUNICATION SYSTEM DEFINITION
- MODULATION, CODING AND MESSAGE FORMATS
- TRANSMITTER, ANTENNA AND GROUND DESIGN
- POWER REQUIREMENTS
- SITE SELECTION

OUTPUT

- TECHNICAL REPORT
- BRIEFING

TASK 3

CONDUCT MITIGATION STUDIES

INPUTS

- MAPS OF POWER DISTRIBUTION SYSTEM
- COMMUNICATIONS CHARACTERISTICS
- MAPS OF TELEPHONE NETWORK

SUBTASKS

- DEFINE MITIGATION THRESHOLDS
- DEFINE POWER SYSTEM MITIGATION CONTOURS
- DEFINE TELEPHONE SYSTEM MITIGATION CONTOURS
- DEFINE TELEPHONE AND POWER SYSTEM TECHNIQUES
- DEFINE SPECIFIC CUSTOMER MITIGATION REQUIREMENTS

PRODUCTS

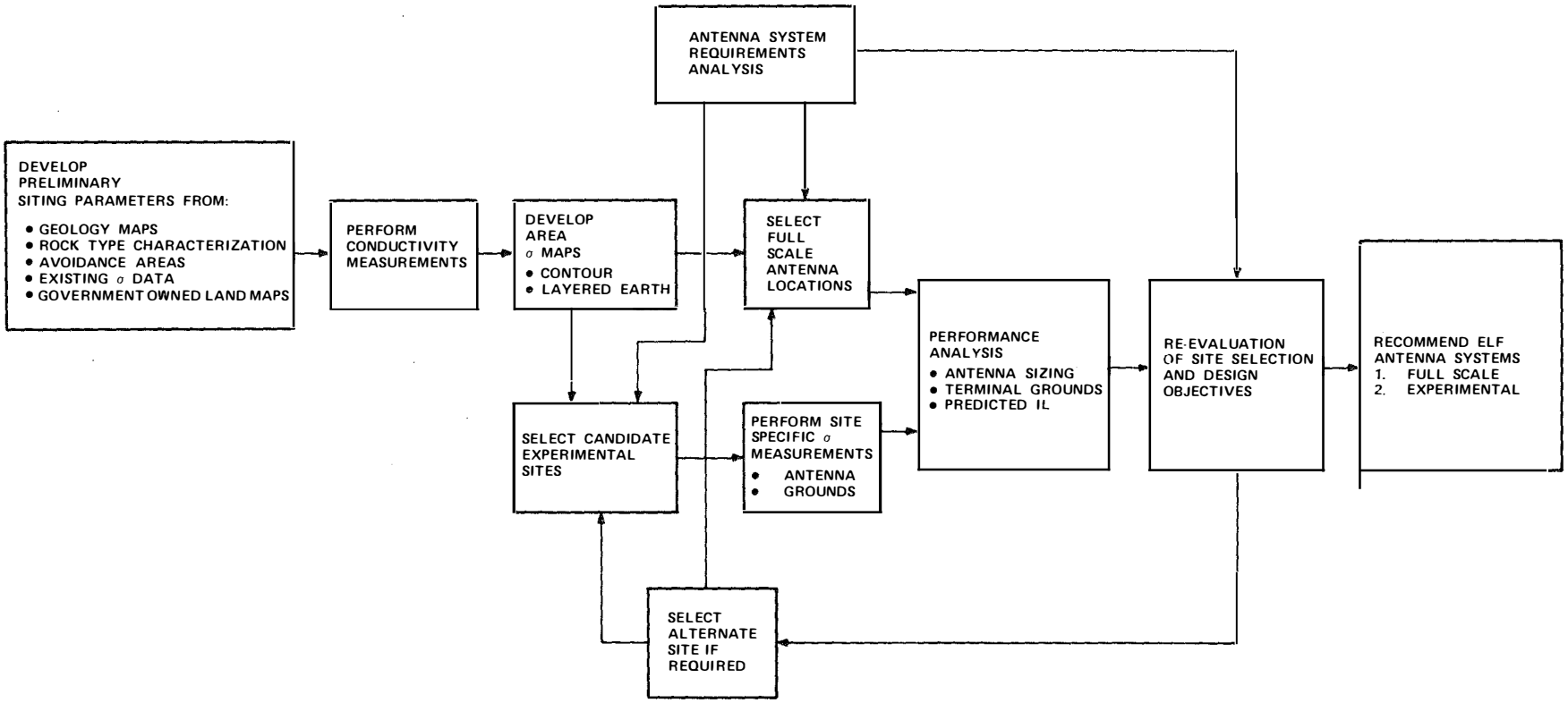
- MITIGATION TECHNIQUES
- MITIGATION REQUIREMENTS
- COMPUTER PROGRAMS FOR MITIGATION PREDICTION
- DESIGN GUIDELINES

OUTPUT

- TECHNICAL REPORT
- BRIEFING

5980-80E

ELF SITE SURVEY APPROACH AND EVALUATION METHODOLOGY



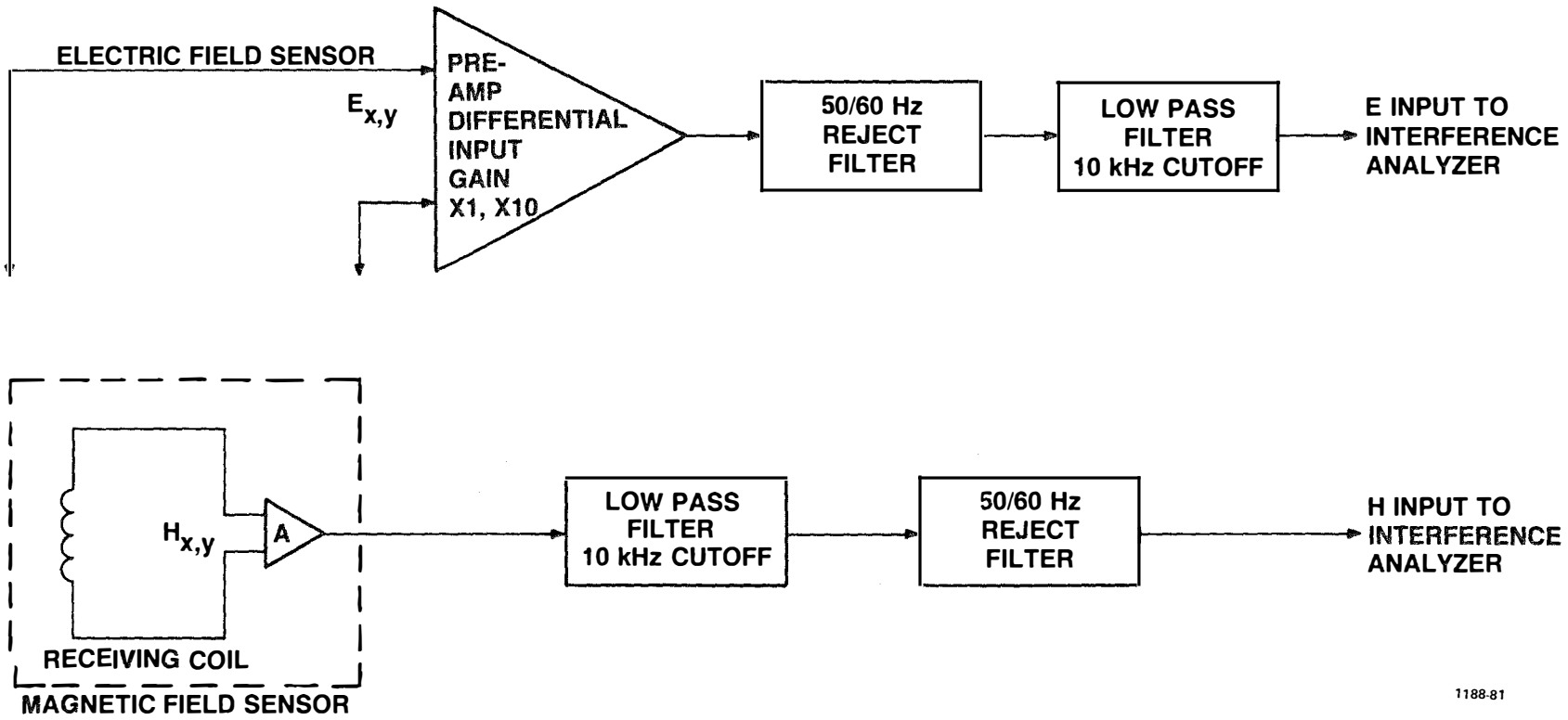
5965-80E

CONDUCTIVITY MEASUREMENT TECHNIQUE

- Audio frequency magnetotelluric (AMT) method is used.
- AMT technique measures the impedance of natural electro-magnetic energy propagating into the ground.
- The energy source is generated by world-wide thunderstorms.
- The propagated energy is refracted into the earth and depth of penetration is dependent on conductivity and frequency.
- Instrumentation measures the horizontal magnetic (H) and electric (E) fields as a function of frequency.
- Conductivity $= \dfrac{f}{1.26 \times 10^5 \times (E/H)^2}$ MHOS/M
- Instrumentation consists of horizontal dipole E-field sensor, a coil H-field sensor, and a variable frequency receiver
- Frequency range from 10 Hz to 10,000 Hz provides information on earth conductivity as a function of depth into the earth.

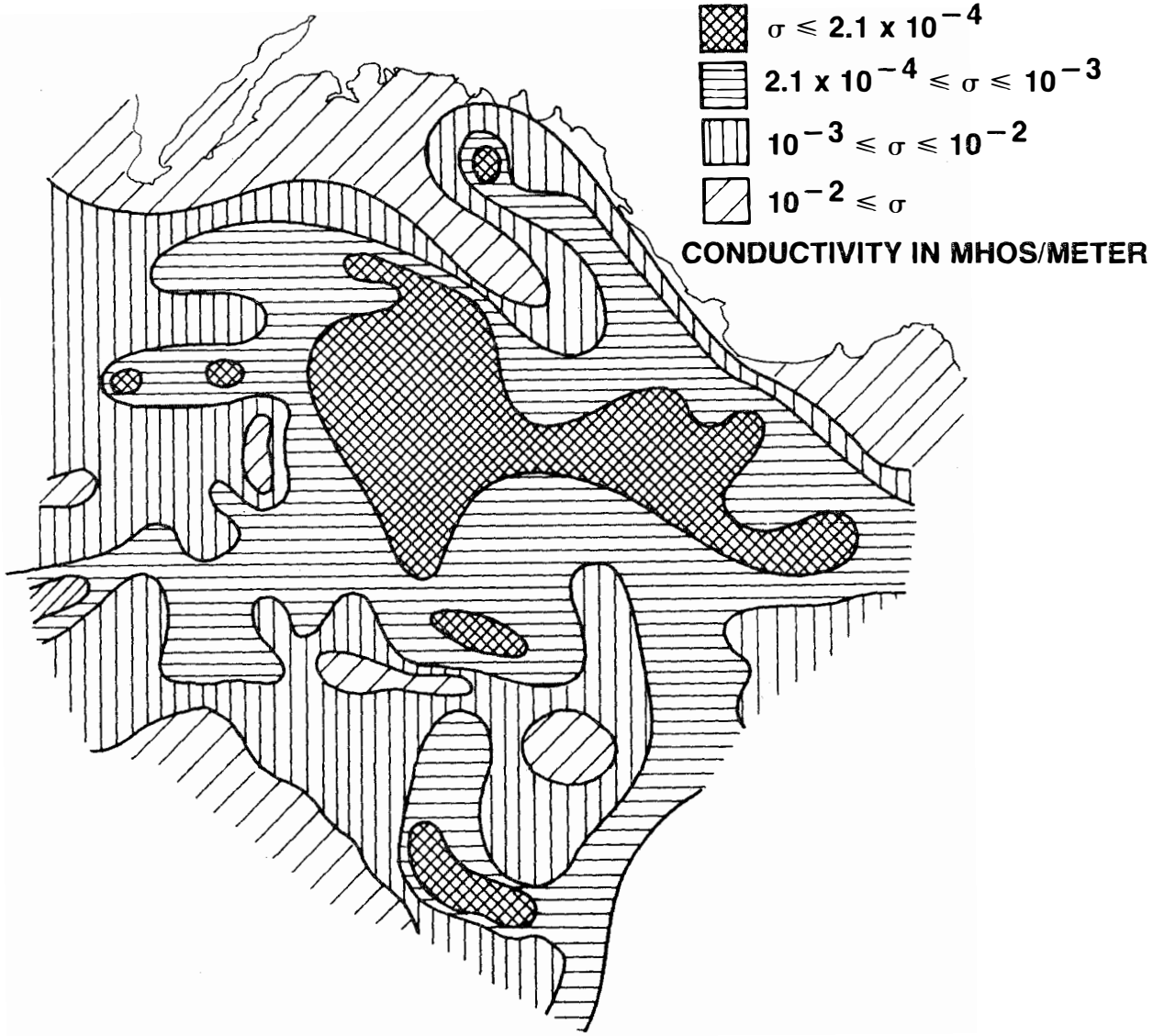
1218-81

SCHEMATIC DIAGRAM OF AMT DETECTION EQUIPMENT



1188-81

CONDUCTIVITY CHARACTERIZATION
BASED ON GEOLOGY ANALYSIS



1204-81

Suggested ELF Development Program

- **Phase 1 – Site optimization study (8 months)**
  - Site survey
  - System requirements definition
  - Mitigation studies
  - Full-scale system site location
  - Develop construction and implementation plans
- **Phase 2 – Full-scale system**
  - Detail design for antenna and grounds
  - Facilities design for transmitter and tuning
  - Site construction and antenna installation
  - System checkout and test

7688-82

ELF Communications

- **ELF provides continuous communication to deeply submerged submarines and hardened force command centers**
  - Assures mission readiness
  - Assures invulnerability
- **ELF has proven "world wide" performance**
- **GTE provides off-the-shelf system and equipment designs and turn-key operational capability**