



REPORT NO: SRN Research Paper RP-0041

CLASSIFICATION: CONFIDENTIAL - NOFORN

DATE: June 12, 1978

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CONTRACT NUMBER: [REDACTED]

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*See the find*  
- *anal. analysis of*  
- *front end*  
- *anal. waveform*  
- *anal. spectrum*  
- *etc / etc*

Long-Range Signal Propagation Characteristics in the VLF/ELF Spectrum

**1. Introduction**

Very Low Frequency (VLF: 3-30 kHz) and Extremely Low Frequency (ELF: 3-300 Hz) electromagnetic signals exhibit unique propagation characteristics due to their ability to reflect between the Earth's surface and the ionosphere. These signals can propagate over continental and intercontinental distances with relatively low attenuation, making them of significant interest for [REDACTED] applications.

This research programme, initiated in [REDACTED] under contract [REDACTED], seeks to characterize long-range VLF/ELF propagation behavior and identify factors affecting signal stability and coherence.

**1.1 Research Objectives**

1. Characterize signal attenuation rates over continental distances
2. Document ionospheric reflection behavior under varying solar and geomagnetic conditions
3. Identify anomalous propagation phenomena
4. Assess feasibility of [REDACTED] for operational deployment

**1.2 Collaborative Framework**

This research was conducted in partnership with:

- [REDACTED]
- [REDACTED]
- Static Research Network (SRN)

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Funding provided by [REDACTED] under contract [REDACTED]

## 2. Methodology

### 2.1 Monitoring Station Configuration

Three primary monitoring stations were established:

#### Station Alpha:

- Location: [REDACTED]
- Coordinates: [REDACTED]
- Primary equipment: VLF receiver array, ionospheric sounder
- Operational period: March 1976 - December 1977

#### Station Beta:

- Location: [REDACTED]
- Coordinates: [REDACTED]
- Primary equipment: Multi-channel VLF/ELF receiver, magnetic loop antenna
- Operational period: March 1976 - December 1977

#### Station Gamma:

- Location: [REDACTED]
- Coordinates: [REDACTED]
- Primary equipment: Phase-coherent receiver system, precision timing reference
- Operational period: May 1976 - December 1977

All stations employed synchronized timing systems referenced to [REDACTED] to enable phase-coherent measurements across intercontinental distances.

### 2.2 Transmission Sources

Test transmissions were provided by:

- [REDACTED] facility (VLF band)
- [REDACTED] station (ELF band)
- Natural source monitoring (lightning, atmospheric phenomena)

### 2.3 Environmental Monitoring

Continuous environmental data collection:

- Ionospheric electron density (via ionosonde)
- Solar flux measurements (10.7 cm radio flux)
- Geomagnetic activity indices (Kp, Ap)
- Local atmospheric conditions

### 3. Results

#### 3.1 Signal Attenuation Characteristics

Measured signal attenuation over the [REDACTED] km propagation path between Station Alpha and Station Gamma:

##### VLF Band (15-25 kHz):

- Daytime attenuation: 2.8-4.1 dB per 1000 km
- Nighttime attenuation: 1.9-3.2 dB per 1000 km
- Consistent with theoretical waveguide propagation models

##### ELF Band (45-85 Hz):

- Measured attenuation: 0.3-0.7 dB per 1000 km
- Significantly lower than VLF, consistent with reduced ionospheric absorption

#### 3.2 Anomalous Signal Coherence

Phase-coherent measurements between Station Alpha and Station Gamma documented unexpected signal stability:

Observation Period: September-October 1977

Affected Frequencies: [REDACTED] kHz

##### Findings:

Signal coherence maintained over [REDACTED] hour continuous observation periods, exceeding theoretical coherence time by [REDACTED] percent. Phase stability measurements showed variance of less than [REDACTED] degrees over [REDACTED] km propagation path.

Conventional propagation models predict coherence degradation due to:

- Ionospheric irregularities
- Multi-path interference
- Doppler effects from ionospheric motion

Observed phase stability significantly exceeds model predictions. Mechanism responsible for enhanced coherence remains [REDACTED].

#### 3.3 Ionospheric Reflection Behavior

Ionospheric reflection measurements during varying solar and geomagnetic conditions:

##### Quiet Conditions (Kp - 3):

- Stable reflection heights (70-85 km)
- Predictable diurnal variation
- Low signal variability

### **Disturbed Conditions (Kp > 5):**

- Reflection height variability (65-95 km)
- Enhanced signal fading
- [REDACTED]

Anomaly documented: During [REDACTED] geomagnetic storm (October 12-14, 1977), signal strength at Station Gamma increased by [REDACTED] dB despite predicted attenuation enhancement. Ionospheric sounder data shows [REDACTED] during this period. Mechanism unclear.

### **3.4 Reproducible Interference Patterns**

Systematic interference patterns observed at [REDACTED] MHz:

#### **Pattern Characteristics:**

- Repetition interval: [REDACTED] seconds
- Bandwidth: [REDACTED] Hz
- Duration: [REDACTED] minutes per event
- Occurrence frequency: [REDACTED] events per 24-hour period

#### **Source Localization Attempts:**

Triangulation analysis using three-station phase measurements suggests interference originates from region bounded by [REDACTED]. However, no known transmission sources exist in this region. Ground-based surveys conducted in [REDACTED] identified no anthropogenic sources.

#### **Alternative Hypothesis:**

[REDACTED] suggests natural ionospheric phenomenon. However, pattern regularity and frequency stability inconsistent with known natural sources (lightning, atmospheric noise).

Further investigation recommended. [REDACTED]

## **4. Discussion**

### **4.1 Implications for Operational Systems**

Enhanced signal coherence documented in Section 3.2 has significant implications for [REDACTED] applications. If reproducible under operational conditions, coherence times of [REDACTED] hours enable [REDACTED] at continental ranges.

Recommend [REDACTED] feasibility study focusing on:

- Coherence dependence on transmission frequency
- Geographic and seasonal variability
- Operational reliability assessment

#### 4.2 Unexplained Phenomena

Several observations resist conventional explanation:

1. **Enhanced coherence:** Mechanism for phase stability exceeding theoretical limits remains unclear
2. **Storm paradox:** Signal enhancement during disturbed conditions contradicts absorption predictions
3. **Interference patterns:** Source and mechanism for reproducible [REDACTED] MHz interference unidentified

These phenomena warrant continued investigation.

#### 4.3 Environmental Correlation

Statistical analysis reveals weak correlation between anomalous observations and:

- Solar activity levels ( $r = 0.23$ )
- Geomagnetic disturbance ( $r = -0.15$ )
- Ionospheric electron density ( $r = 0.31$ )

Low correlation coefficients suggest additional factors may influence observed behavior.

### 5. Conclusions

Two-year study of VLF/ELF propagation characteristics has documented both expected behavior consistent with theoretical models and anomalous phenomena requiring further investigation. Enhanced signal coherence and unexplained interference patterns represent significant findings warranting expanded research.

Operational implications for [REDACTED] applications are substantial if observed coherence characteristics prove reproducible and reliable.

### 6. Recommendations

#### 6.1 Follow-Up Research

1. Expand monitoring network to [REDACTED] additional stations
2. Conduct dedicated transmission experiments at [REDACTED] frequencies
3. Investigate correlation between anomalous coherence and [REDACTED]  
[REDACTED]
4. Deploy mobile monitoring equipment for interference source localization

## 6.2 Operational Assessment

[REDACTED] should conduct feasibility study for [REDACTED] deployment based on enhanced coherence findings. Recommend [REDACTED] participation.

## 6.3 Funding Requirements

Estimated budget for recommended follow-up research:

- Equipment procurement: [REDACTED]
- Site development: [REDACTED]
- Operations (24 months): [REDACTED]
- Total: [REDACTED]

Funding request submitted to [REDACTED] via contract modification [REDACTED]

## Acknowledgments:

Research conducted under contract [REDACTED]. Field operations supported by [REDACTED] and [REDACTED]. Ionospheric data provided by [REDACTED].

## Distribution:

- [REDACTED]
- [REDACTED]
- Static Research Network Archive
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Security Classification: [REDACTED]

Declassification Review: [REDACTED]

