THE FUTURE ROLE OF HIGH FREQUENCY TELEMETRY TECHNIQUES FOR THE NATIONAL DATA BUOY SYSTEMS

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1. Introduction

Recently there has been increasing concern with the role high frequency (HF) communications will play in the telemetry subsystems for the National Data Buoy Systems (NDBS). This concern has been brought about by the rapidly changing state-of-the-art in satellite relay systems operating at VHF and above and, specifically, by the development of the Synchronous Meteorological Satellite/Geostationary Operational Environmental Satellite (SMS/GOES) under joint sponsorship of NASA and NOAA. The purpose of this paper is to:

(1) review the theoretical and reported performance of HF telemetry systems for ocean buoys, and

(2) considering (1) and the status of satellite techniques, evaluate the place of HF methods in future NDBS developments.

Consideration of satellite systems will be confined to the SMS/GOES series.

2. HF Telemetry System Performance

HF telemetry systems are being used in current and near-term applications because of (a) the availability of frequencies in this band which are internationally allocated for this purpose, and (b) the lack of a suitable satellite available on a routine basis. The performance of systems using propagation via ionospheric reflection at HF is highly variable. It varies with time of day, season, path location, solar activity, radio noise levels, and other factors. This variability is regular enough to be predicted, however, and, with good engineering (including a good choice of frequencies) and operators, reliabilities in the range from 85-90 percent are routinely obtained. Nevertheless, Shortwave Fadeouts (SWF), Polar Cap Absorption (PCA) events, and magnetic (ionospheric) storms are frequent and severe enough that reliabilities much above 90-95 percent are difficult to obtain. During such events, even a full choice of frequencies, large antennas, and high power may not produce acceptable performance. To support the conclusion that reliabilities in the 85-95 percent range are indeed possible for HF telemetry systems for ocean buoys, theoretical predictions of such performance are described in section 2.1 and operating results are discussed in section 2.2

The term reliability, as used in this section, is the percentage of time that transmitted digital messages from the buoy or buoys are received at the shore station with an acceptable error rate. It does not include the communication equipment (hardware) reliability. Because of diurnal, seasonal, and solar cycle variations, the reliability will vary with time of day, month, and year. Since error rate is a function of the signal-to-noise density ratio (SNR) at the receiver, minimum acceptable performance can be defined in terms of a required SNR.

2.1 Theoretical Predictions

The prediction of HF circuit performance, based on consideration of equipment parameters, atmospheric and man-made radio noise levels, expected ionospheric conditions, and other factors, is a well established practice in the design and operation of such circuits. The advent of digital computers has made the use of sophisticated models a routine process, and there are several such models and programs available. The original ITS program is described in a report by Lucas and Haydon (1966) and the most recent version in a report by Barghausen et al. (1969).

During the initial efforts to secure an international HF allocation for ocean data collection, ITS prepared a report (Haydon, 1967) showing the performance that could be obtained using different HF frequency combinations. At the 1967 World Administrative Radio Conference (WARC), six frequencies, roughly 4, 6, 8, 12, 16, and 22 MHz, were set aside exclusively for ocean data collection. Table 1 shows the averaged predicted performance for individual circuits with this frequency complement as a function of latitude range for distances between 200 and 3000 km, summer and winter, and high and low solar activity. The study assumed a nominal system consisting of a transmitter with 100W RF power output, a 5 m whip antenna on the buoy, a 10 dB antenna gain at the shore station, and a required SNR of 40 dB. Note that the highest reliabilities are predicted at the longer distances and low and moderate latitudes.

Another theoretical study (Adams et al., 1969), evaluating a hypothetical distribution of 35 buoys off the coasts of the U. S., was performed by ITS for the National Data Buoy Project (NDBP). Nominal characteristics similar to those above were assumed. An FSK, 75 bps modem was assumed, resulting in a required SNR of 38 dB for a 10^{-3} binary error rate and diversity reception. Shore stations were assumed to be various combinations of existing USCG radio stations. Predictions were made for the months of June and December 1971. The results are shown in Table 2. Four different power levels are shown because one of the purposes of the study was to determine required buoy transmitter powers. The average reliabilities over the four synoptic hours vary from 83 percent at 25W to 93 percent at 200W in June and from 92 percent to 97 percent in December.

Table 1

Average Reliability
for 4, 6, 8, 12, 16, 22 MHZ Frequency Complement

	Distance (km)					
	200	500	800	1,000	2,000	3,000
Latitude						
0-20 N	81	89	94	94	96	95
20-40 N	73	89	97	98	98	94
40-60 N	50	66	82	87	95	87
60-80 N	45	64	81	86	83	74
0-20 S	72	82	91	94	97	97
20-40 S	63	76	89	95	97	94
40-60 S	57	73	88	93	97	94
60-80 S	42	50	69	76	78	80

Table 2

Comparisons of Reliability for Four Transmitter Powers with USCG Primary Radio Stations

Reliabilities in Percent for June 1971				
	Transmitter Power Output in Watts			
Time-GMT	25	50	100	200
0600	89	92	94	96
1200	90	93	95	96
1800	75	81	86	90
2400	79	83	87	90
Avg. Rel.	83	87	90	93

Reliabilities in Percent for December 1971				
	Transmitter Power Output in Watts			
Time-GMT	25	50	100	200
0600	91	94	96	97
1200	93	95	96	97
1800	89	92	95	96
2400	92	95	97	97
Avg. Rel.	92	94	96	97

A third theoretical study (Hatfield, 1970) treated the reliability of coverage for Engineering Experimental Phase (EEP) buoys to be deployed in the Gulf of Mexico in the 1971-1973 time period. A single shore collection station, namely the USCG radio station at Miami, Florida, was assumed. Roughly the same nominal characteristics as in the previous two analyses were assumed, except that no space diversity was incorporated. The average reliability over the four synoptic hours was predicted to be approximately 90 percent in the ranges between 700 and 1800 km during 1971-1973. With the addition of space diversity as is currently planned for this station, reliabilities well over 90 percent can be expected for buoys deployed in the Gulf of Mexico.

In summary, then, these theoretical predictions confirm that reliabilities on the order of 90 percent are indeed possible with an HF telemetry system of nominal characteristics.

2.2 Actual Performance of Ocean Data Systems

The performance predicted in section 2.1 was, as stated, based on theoretical models of HF ionospheric propagation. There also has been considerable experimental confirmation that such reliabilities are obtainable on buoy-to-shore links. Probably the greatest volume of data on such performance has been gathered by General Dynamics in their experiments with their so-called monster buoy under the sponsorship of the Office of Naval Research. A recent paper by Devereux (1970) documents the interrogation/reception results for this 40 ft diameter, discus shaped buoy equipped with a discone HF antenna when it was deployed in the North Pacific, some 3600 km from the shore station at La Jolla, California. The communication system used was slightly different from the nominal one assumed in section 2.1, but the overall performance should be comparable. The primary differences were that Phase Shift Keying (PSK) instead of Frequency Shift Keying (FSK) was used and in band frequency diversity was employed. The transmitter power output was only about 25W per tone. Devereux reports that interrogation and data transmission were routinely attempted four times daily at 0000, 0600, 1200, and 2400 GMT between 11 August 1968 and 31 March 1969. Successful results were obtained in 170 out of 174 attempts or some 97.7 percent of the time. He defines successful as being when the "oceanographic data were transmitted error free".

Successful results have also been obtained with the HF telemetry system for the XERB-1 buoy. This buoy is also the 40 ft discus type with a discone antenna. It was deployed off the east coast of the U.S. in January 1970. From its deployment until 21 January 1971, the station at La Jolla was used to receive the data, a path length of about 4,000 km. During one interval in this period, 123 consecutive reports were received from the buoy before one was received late (i.e., more than one hour after the synoptic hour) and 152 consecutive reports were received before one was missed. Since 22 January 1971, the USCG station at Miami, Florida, has been used for communicating with the XERB-1 buoy. This path length is about 1,500 km. This station has been equipped with a horizontally polarized log-periodic antenna (HLPA) and other equipment necessary for the shore data collection facility. The recent results are summarized in Table 3. Unsuccessful in this instance is defined as an ocean data message from XERB-1 which is lost or delayed more than one hour due to telemetry problems.

These experiments, with actual ocean data transmissions using HF telemetry links, also confirm that reliabilities on the order of 90 percent or greater are routinely possible.

Table 3

Summary of HF Data Link Performance
for XERB-1

Shore Station	Time	Number of Transmissions	Number Unsuccessful	Percent Unsuccessful
LaJolla	Jan 1-21, 1971	73	7	9.6
Miami	Jan 22-31, 1971	35	5	14.3
Miami	Feb 1-28, 1971	108	4	3.7
	Total	216	16	7.4

3. Satellite Links

Even though HF links promise reliabilities on the order of 90 percent, the use of satellite relay systems for future ocean data transmission systems appears very attractive. The primary reason for this is that satellite relay techniques offer the potential for even higher reliabilities than HF. This is particularly important because of the NDBS goal to deliver to the user 80 percent of the required ocean data at least 50 percent of the synoptic observation periods. If communication link reliabilities are limited to 85-90 percent, it places high demands on the hardware reliability and it may jeopardize this performance goal. As the NDBP has gone on record as stating, this reason alone is sufficient to warrant full investigation of satellite techniques. Another important factor is that fewer shore collection stations would be required because of the greater coverage areas of satellite systems. Other factors such as power consumption, antenna mounting requirements, and complexity are of secondary importance except perhaps for very small, conceivably expendable buoys of the Limited Capability (LCB) type.

The SMS/GOES satellites will use UHF frequencies for the up and down links between the Data Collection Platforms (DCPs), e. g., ocean buoys, and the satellite and S-band frequencies for the up and down links between the satellite and ground Command and Data Acquisition (CDA) station. The potentially higher reliabilities offered by satellite relay techniques result from the greater stability of line-of-sight paths using frequencies such as these which are high enough to avoid most ionospheric effects. This is not to say that such links do not exhibit variable performance. Multipath and atmospheric effects as well as changes in background noise/interference all produce variations. The significant point is that these effects can be overcome by sufficiently conservative engineering, i. e., by providing a generous fade margin. Towards this goal, ITS is currently carrying out a study for NOAA to permit more precise predictions of link performance. Nevertheless, the state-of-the-art for this type of relay is not as advanced as communication satellite relays between two land based stations where very large, high gain, physically stable antennas are possible. Instead the ocean buoy represents a relatively small, unstable platform whose motion is unpredictable. The reliable interrogation and relay of data from such a platform is not yet a proven technique and further experimentation and design refinement will be necessary before the full potential reliability is realized. This is particularly true for buoys located in positions where the elevation angle of the satellite is low and multipath, buoy antenna motion, and tropospheric bending effects are most pronounced.

A recent report prepared for NASA by Radiation Systems (1970) on the DCPs noted that theoretical analyses of such problems as multipath (reflection from a smooth sea), polarization losses, fading, ducting, etc., "must ultimately be verified by extensive testing". It goes on to recommend that operational buoys be deployed to "provide valuable data on the communication link performance figures as a function of sea state (and associated antenna tilt) and link degradation due to low elevation angle transmission (when severe tilts are experienced)". Another report on the DCPs prepared by Magnavox (1970) confirms that "there is little information available on the nature of the channel which exists between the DCP and the satellite when the DCP is a floating platform."

A similar conclusion is reached in a report on a study of space communication techniques for the NDBP conducted by General Dynamics. It notes the multipath and platform motion problems and recommends additional development of "a buoy antenna system with a radiation response that minimizes the effects of sea-reflected multipath radiation and with appreciable gain in the direction of the satellite, regardless of buoy motion".

It is concluded, then, that satellite relay techniques do offer potentially higher reliability than HF, but that further development and experimentation may be necessary to obtain and substantiate the incremental improvement.

4. Scheduling Considerations

The "A" and "B" SMS (prototype for GOES) satellites are scheduled for launch in mid-1972 and mid-1973, respectively. The full operational version (GOES) is scheduled for launch in mid-1975. The schedule for the NDBS calls for deployment of the EEP buoys beginning late in 1971, and prototype LCBs in mid-1972. Pre-prototype high-capability buoys (HCBs) will be deployed in 1973 and the pilot buoy network beginning in 1977.

5. Conclusions and Recommendations

Because of (1) the lack of overlap between the LCB deployment and launch of the first SMS, (2) the further development and experimentation necessary for the buoy satellite communication configuration, (3) the greater difficulty associated with a physically small LCB, and (4) considering that HF has been proven to give reliabilities on the order of 90 percent, it is concluded that the LCBs should include both SMS and HF communication capability.

Since (1) there is only a very limited time to correct any problems between the launch of SMS "A" and the deployment of pre-prototype HCBs in mid-1973, (2) there will have been two year's experience in operating and refining the HF communication system, and (3) the major design and shore collection station costs will have already been absorbed, it is concluded that the preprototype HCBs should also include at least a limited HF capability.

At the end of the preprototype HCB evaluation, a decision on the further use of HF in the NDBS should be made on the basis of the operational performance. To assure that full HF system reliability is obtained in this critical interim period, it is recommended that a minimal development and analysis effort be maintained.

These conclusions are based on the recognition that a reliable, and perhaps redundant, communication system is essential to both the early real time use of the collected data and to the engineering evaluation of all experimental and preprotype buoy systems.

6. References

Adams, J. E., D. N. Hatfield, and J. A. Payne (1969), A feasibility study of a proposed national oceanographic data buoy HF communication system, ESSA Tech Memo ERLTM-ITS 205.

Barghausen, A. F., J. W. Finney, L. L. Proctor, and L. D. Schultz (1969), Predicting long-term operational parameters of high-frequency sky-wave telecommunication systems, ESSA Tech Rept ERL 110-ITS 78 (U.S. Government Printing Office, Washington, D.C. 20402).

Devereux, R. F. (1970), Long-distance interrogation of ocean data stations moored in the North Pacific Ocean, Telecommunication Journal (IY), Vol. 37, No. 2.

General Dynamics - Convair Aerospace Division (1970), Study of feasibility of space communications techniques for the National Data Buoy System, Final Report - Contract DOT-CG-03, 224-A.

Haydon, G. W. (1967), Theoretical evaluation of band 7 frequency complements for ocean data communications, ESSA Tech Memo IERTM-ITSA 54.

Lucas, D. L. and G. W. Haydon (1966), Predicting statistical performance indices for high frequency ionospheric telecommunications systems, ESSA Tech Rept IER-1 ITSA 1 (U. S. Government Printing Office, Washington, D. C. 20402.)

Magnavox Company (1970), Data collection platform study for the Synchronous Meteorological Satellite System, Final Report - Contract NAS5-21182.

Radiation Systems (1970), SMS data collection platform studies, Final Report - Contract NAS5-21184.