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Gentlemen:

Radio Propagation Systems, Inc., (RPSI) is pleased to submit our response to the referenced Docket Number.

Very Truly Yours,

John W. Ballard
President

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Reliable and Rapid Long Distance Operational Control

June, 2003
RPSI Technical Staff Document

Ref: Docket No. FAA-2002-14002

Radio Propagation Services (RPSI) analyzes and designs radio systems, concentrating in HF systems. We also provide the operational frequency management for ARINC's global HF data link service, based on a near real-time process of observations and modeling.

This document is in response to the issue of "Rapid Communications" raised in reference document and directed to clarifying 14 CFR §121.99, intended to "... ensure reliable and rapid communications, under normal operating conditions over the entire route (either direct or via approved point-to-point circuits) between each airplane and the appropriate dispatch office, and between each airplane and the appropriate air traffic control unit ...".

The present Long Distance Operational Control (LDOC) services are in economic, physical and operational shambles. Under the present LDOC structure, the impaired revenue picture prevents the modernization and restructuring that would result in rapid and reliable service performance. In this document, we outline an approach toward an effective and efficient global LDOC service. We believe that the approach we recommend will have compelling economic advantages over other alternatives while meeting the four-minute standard for dispatch contact referred to in reference document.

The causes of the present decrepitude of LDOC services are several:

1. The very triumph in reliability of modern turbine engines over reciprocating engines means that the need for LDOC services per hour of flight is now, and will remain, a small fraction of what it was in 1955. LDOC revenues are permanently reduced.

2. The ease of use of satellite services has further eroded HF LDOC revenues.

3. Because of shrinking revenues, the present HF LDOC infrastructure has atrophied and is totally out of balance with that which is now required. Most service providers use ancient, fixed-tuned transmitters, a multitude of narrow band antennas, frequencies unique to their station, their own operator staff and expensive long-distance dial-up for phone patch. Due to lack of knowledge of current radio propagation conditions, frequencies which would support good service frequently are not guarded.

4. The pilot, who must initiate contact, can be faced with a large choice of service providers and a vast choice of frequencies, many of which either won't work, are not monitored or both. He has no way of knowing which few of the many LDOC frequencies have been chosen by the ionospheric propagation gods to permit reliable communications at the moment between the flight and the desired station. Thus, a desired contact may not be made.

A comment regarding the "four minute" proposal (maximum time to make contact with company dispatch) in reference document). RPSI engineers have examined the practicality of "reliable and rapid" LDOC communications in the north polar region. We modeled the radio circuits between all service providers and north polar routes 1, 2, 3, and 4. We selected a period of five minutes to make contact as reasonable and allowed one and one-half minutes per contact attempt. We then asked a very senior B474-400 captain to select frequencies and service providers as a typical flight would have progressed along these routes. In these flight examples we considered and absent any reliable propagation information, the station and frequency selections made by this experienced pilot did not once result in contact within five minutes.

The potential for an in-flight emergency always exists. Many regulations have been established which acknowledge the many possibilities. When an emergency occurs, it must be dealt with promptly. Invariably, an emergency is dealt with most effectively if reliable voice communications are available between the pilot and the provider of the service required.

The north polar region is extreme, with difficult radio propagation conditions and a paucity of appropriate station assets. Other regions, such as the South Atlantic, Indian Ocean, Africa and Central and South America have different, but difficult radio propagation challenges and a similar paucity of station assets. In none of these cases does the pilot have any informed help in choosing a frequency -station pair. LDOC services in these regions are generally regarded as unsatisfactory.

The remedies for this unsatisfactory state of affairs are to be found in the application of modern radio and network engineering and in the use of modern management of the choice of operating frequencies.

Contrary to popular belief and general experience, HF can be made quite reliable with good quality. In a landmark HF propagation experiment[1] the signal-to-noise ratios of all HF frequencies were measured every half hour over twenty-nine northern paths during an eighteen-month period. It was shown that with adaptive frequency selection using at least eight aeronautical bands and with at least four ground stations within reasonable service range, long term availabilities of 0.9999 on a scale of 1.0 were possible for an HF data circuit of the general characteristics described in ARINC 635 and 753. Each of these circuits was measured directly.

Making allowances for the additional signal-to-noise ratio required for voice and for the fact that frequency management in a practical HF voice service will have to be based initially on the predicted effects of current solar, interplanetary and geophysical observations modulated by extrapolated current propagation measurements (similar to the spectrum management service we supply ARINC

[1] Goodman, Ballard and Sharp. A Long-Term Investigation of the HF Communications Channel over Middle and High Latitude Paths. *Radio Science Vol 32, No. 4 July-August 1997.* (Provided herewith as Attachment1.)

for their HF Data Link Service), we can expect long-term availabilities approaching 0.99.

The key to high quality and high availability HF voice is modern, adequate station and spectral assets and near real time adaptive use of adequate HF spectrum. Both the aircrews and ground stations must know what combinations of frequencies and stations will perform best in light of current, actual radio propagation conditions.

Modern, optimized, totally unmanned, all band stations along the lines of the design we suggested for a major service provider can be furnished for around $300,000, plus installation for perhaps $200,000. Such stations are now in service.

This station design is quite unlike the traditional design. The antenna covers the 2 to 30 MHz spectrum with an elevation plane pattern which is optimized for air-ground service and with a polarization which couples into the lower loss ordinary wave. The transmitters are highly redundant and can transmit on multiple frequencies simultaneously. The receivers feature DSP squelch permitting all frequencies to be guarded all the time. Moreover, we envision all stations in a region sharing the same frequencies in each of the aviation bands.

The use of timely radio propagation data along with the use of common frequencies should guarantee contact in three minutes or less ninety percent of the time.

With the use of voice over Internet Protocol (I.P.), the formerly formidable back-haul costs can now be de mimimus.

Good global coverage requires a network of seventeen stations. This and the above considerations lead to the suggestion of one global system operating on regional nets of at least eight common frequencies, with one Global Operations Center.

We have reason to believe that most of the existing, struggling HF LDOC service providers would contribute spectral and station assets in return for a share of system revenues. Spectral assets abound. They are simply wasted today. A modern, effective global LDOC service with appropriate spectral and station resources could come together quickly.

Emergency communications are both a safety of flight and a security issue. While these needs are clear, their attendant economics are not. The system we outline could be supported on revenues of $2.1 million per year. Such revenues might come from a small per remote-region flight fee for US carriers and a per contact fee for foreign carriers. Were these revenues to be guaranteed by the Government in return for a rapid and reliable service, such a service would come to pass.

The alternative is effectively to force all carriers to use satellite services. The relative economics of such a strategy are not attractive.

As of September 10, 2001, there were approximately 9,000 civilian aircraft suitable and equipped for service in oceanic and remote regions. Of these, approximately 2,500 were equipped with satellite equipment. Not all of these had voice capability. Some were equipped for data link only - not considered adequate for emergency communications by many operators. Not all U.S. international scheduled carriers are satellite equipped.

The subject NPRM would require only Part 121 operators to reach their dispatch centers within four minutes. Our estimate of the cost for one major US carrier to convert to satellite services is on the order of $25 million, based on a representative conversion cost of $300,000 per aircraft. No new aircraft equipage is required to implement our approach.

The need for reliable and rapid communications during emergencies is real. Ask any pilot who has dealt with a major emergency over water, at night, <u>without</u> communications services and you are likely to hear a rather passionate argument for responsive communications. The support of the dispatch function is essential in developing a safe diversion plan. Timely support is not irrational; it is vital.

With the approach we suggest, the "four-minute" proposal can be met 90% of the time. In order to do so, a modest revenue guarantee or its financial equivalent would be necessary to bring about essential structural changes to the LDOC services.

There are those who would argue that it is not the responsibility of the FAA to provide communications assets around the world. We would argue that the FAA has a statutory obligation to promote aviation safety, as well as the economic well-being of the aviation industry. We are advocating an incentive so that private industry will develop and operate the needed communications infrastructure and that, while all oceanic carriers will fly more safely and securely, arguably, more than half the beneficiaries will be U.S. operators.

John W. Ballard
President

ATTACHMENT 1

RPSI Response to Docket No. FAA-2002-14002

Radio Science, Volume 32, Number 4, Pages 1705–1715, July–August 1997

A long-term investigation of the HF communication channel over middle- and high-latitude paths

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Abstract. A study of HF communication link and network availability has been carried out using frequency modulated continuous wave (FMCW) swept-frequency sounders operating in an oblique-incidence configuration. The sounder deployment enabled 28 middle- and high-latitude paths to be evaluated; the time period of the study was from December 1994 until the summer of 1996. Propagation conditions including ionospheric mode information, maximum observable frequencies, signal-to-noise ratios, and channel availabilities for digital data communication were derived and archived. The objective of the study was to ascertain the efficacy of HF data link communication for a proposed aeronautical-mobile service. Data were used to simulate the propagation environment which would be experienced in actual operation and to evaluate the value of path and frequency diversity in overcoming various propagation effects. It has been concluded that path and frequency diversity will lead to channel availabilities approaching nearly 100% and that a practical engineering solution was possible. These positive results are achievable if and only if dynamic frequency management methods are invoked. The paper outlines the nature of a real-time system, which is based upon a terrestrial FMCW swept-frequency sounder constellation and by which communication nowcasts and short-term forecasts are developed to drive a dynamic frequency management system.

1. Introduction

There is a common perception that long-haul HF communications are intrinsically unreliable owing to the fact that the sky wave channel is a dispersive, birefringent, and dissipative medium. This perception has largely been based upon the experience obtained over the years prior to the advent of digital data communications and the development of modern digital signal processing (DSP) technologies and adaptive HF schemes. While the reality is distinctly different from perception in the modern era, designers of communication systems must still be mindful of the variabilities of the HF channel. The HF channel has a rich personality which is far from featureless. Even the benign channel exhibits a diurnal texture, and frequency management strategies must account for variations in the instantaneous propagating bandwidth.

The nature of ionospheric variability is well known and has been outlined in numerous articles and monographs [*Goodman*, 1992]. The HF channel is more chaotic in those phenomenological regimes which are characterized by abnormal values of temporal and spatial variability. The most obvious of these phenomenological regimes are exemplified by natural disturbances associated directly or indirectly with solar flares, geomagnetic storms, atmospheric tidal forces, atmospheric gravity waves, and related disturbances. These effects are decidedly region-specific and may exhibit complicated storm-time variations. From the vantage point of a communication network manager, the situation must be assumed to be largely unpredictable, except for the median behavior which may be characterized through specification of time-averaged magnetic and solar indices.

Accordingly, system designers have incorporated organic mitigation technologies, such as automatic link establishment (ALE), to cope with the problems of unpredictable variability. Unfortunately, there may be some difficulties associated with such techniques under highly stressed conditions [*Goodman et al.*, 1996]. This arises as the HF network begins to devote

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inordinate quantities of system capacity to organize itself at the expense of actual communication. The nature of these difficulties has been outlined by *Sutherland* [1992]. Nonorganic processes which provide a basis for connectivity decisions without reducing network capacity would appear to be an optimum solution, provided the information derived from the external processes may be incorporated efficiently. An examination of this approach is being undertaken as part of the independent research and development effort described in this paper. The basic measurement tool is the Chirpsounder®, a system which has incorporated many new features since it was first introduced by the military services in the 1970s.

An HF application of special relevance is the maintenance of connectivity for aircraft flying in oceanic areas and especially in those zones for which SATCOM (satellite communication) reliabilities are degraded by virtue of limited visibility (namely, transpolar routes) or because of various media impairments, including rainfall attenuation and ionospheric scintillation. We maintain that space diversity and dynamic frequency reallocation (i.e., full sharing of frequencies as required) among designated HF service providers (i.e., ground transmitters) will have the potential for development of a practical high-frequency data link (HFDL) system, even for high latitudes.

However, there are still questions to answer. For example, how many frequencies are really needed for the regional service? How many service providers are needed, and where should they be located to achieve the degree of space diversity required? Accordingly, TCI/BR investigators initiated the Northern Experiment to assist in answering these questions. The purpose of this experiment was to gather propagation data over numerous high-latitude paths, enabling an analysis to be made of the projected performance of an HFDL system. Some aspects of the experiment have been presented elsewhere [*Goodman et al.*, 1995a, b].

2. Nature of the Experiment

Propagation conditions in the North Atlantic present significant concerns for HFDL operation since the region corresponds to a major corridor for commercial air traffic. The testing of propagation conditions using operational aircraft in the region was not practical, and this led to a scheme of static measurements of a different geographical region using oblique-incidence sounders. A large array of ground stations was used to mimic representative path geometries for typical ground-to-air links. A major consideration in station selection for the Northern Experiment was a need to mimic as closely as possible the climatological conditions to be experienced by HFDL. To do this, we recognized that ionospheric conditions in the *F* region are best organized by the geomagnetic field rather than geographic coordinates. As the north magnetic pole lies somewhat equatorward of its respective geographic pole in the American sector, Chirpsounder® deployments in Canada and the continental United States may correspond to the relatively higher geographic latitudes within the North Atlantic region. We map the sounded (i.e., proxy) region to the unsounded (i.e., target) region along lines of magnetic latitude, a process which hopefully preserves the underlying physics. These deployments consist of systems which transmit frequency modulated continuous wave (FMCW) swept-frequency "chirp" signals and specially designed receiving systems. If the entire process is carried out successfully, we may represent the appropriate geophysical regimes as well as the ground-to-air propagation geometries of interest. This is a process we refer to as climatological invariance.

A comprehensive HF channel data collection campaign was initiated in December 1994 and continued well into calendar 1996. Using selected Chirpsounder® systems deployed throughout the northern hemisphere, concentrating on the North American sector, over 28 paths have been evaluated. These paths have been grouped to ascertain the relative correlation properties, and the resultant data are being used to validate emerging real-time ionospheric and HF performance prediction models. Transmitters are located at Jan Mayen, Reykjavik, Stockholm, Madrid, Tors Cove (Newfoundland), Puerto Rico, Edmonton (Canada), Vancouver (Canada), and San Francisco. Receivers are located in Stockholm, Reykjavik, Tors Cove, Iqaluit, Fairbanks, Churchill (Canada), Winnipeg (Canada), Austin (Texas), Henrico (North Carolina), and San Francisco. Oblique-incidence ionograms are recovered remotely and downloaded to a data collection center at TCI/BR headquarters in Sunnyvale, California. Figure 1 is a map showing the communication paths which were monitored during the Northern Experiment. The transmitters and receivers are indicated by TX and RX, respectively. Path distances (in kilometers) between nodes are shown.

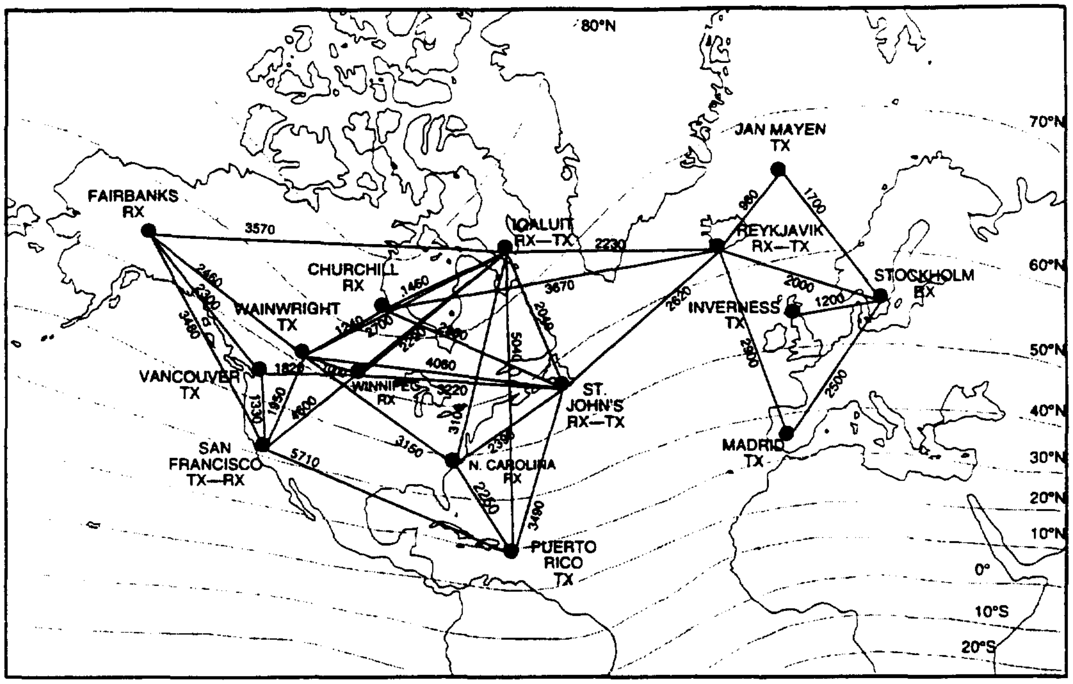

Figure 1. Geometry of the Northern Experiment. Distances are given in kilometers.

Each receiver site was programmed to recover ionograms from up to four transmitters at a rate of twice per hour. The Chirpsounder® receiver passed the digital ionograms to a storage device which was controlled by a collocated PC. The receiver sites were equipped with a downloading feature which could be initiated through a dial-up capability. All data sets were passed to a central processing facility located in Sunnyvale, California.

While a considerable amount of scientific information is contained in the database which has been archived, our analysis has been principally conducted with the view directed toward the elucidation of HFDL performance for specified service areas (determined by a given group of sounder nodes) for various groups of frequencies. The Chirpsounder® system provides data for the entire HF band, excluding a limited number of blocked channels. We extracted data from the sounder records at frequencies in specified aeronautical-mobile (A-M) bands which were also covered by the sounder scan. The A-M bands are represented by the following frequencies: 3.0, 3.5, 4.6, 5.6, 6.6, 9.0, 10.1, 11.4, 13.3, 18.0, and 22.0 MHz. We also obtained estimates of the noise level for each A-M band, and we computed the signal-to-noise ratio (SNR) for each band. These data were compared with the minimum values of SNR required to pass traffic at bit rates from 300 to 1800 bits/s.

Figure 2 contains analyzed data obtained at Iceland from transmitters at Iqaluit, St. Johns, Jan Mayen, and Peña Grande. These plots address the issues of space and frequency diversity. Figure 2a gives the percentage of successful threshold crossings as a function of frequency band designation, for each path involved and for the period December 13, 1994, to February 14, 1995. (In this instance the threshold corresponds to the SNR requirement for successful modem operation at a data rate of 300 bits/s).

To characterize system performance, we use a term called availability, which is similar to communication reliability. Reliability is deduced from codes such as VOACAP (Voice of America version of IONCAP (Ionospheric Communications Analysis and Predictions Program)) and it involves statistical treatment. We define availability in the HFDL context as the probability that the measured SNR exceeds a value prescribed to enable a specified quality of service to be achieved. In this way we obtain an observational measure of system performance rather than a statistical estimate. The question then becomes one of communication availability at a fixed level of reliability. Sufficient margin is prescribed such that the

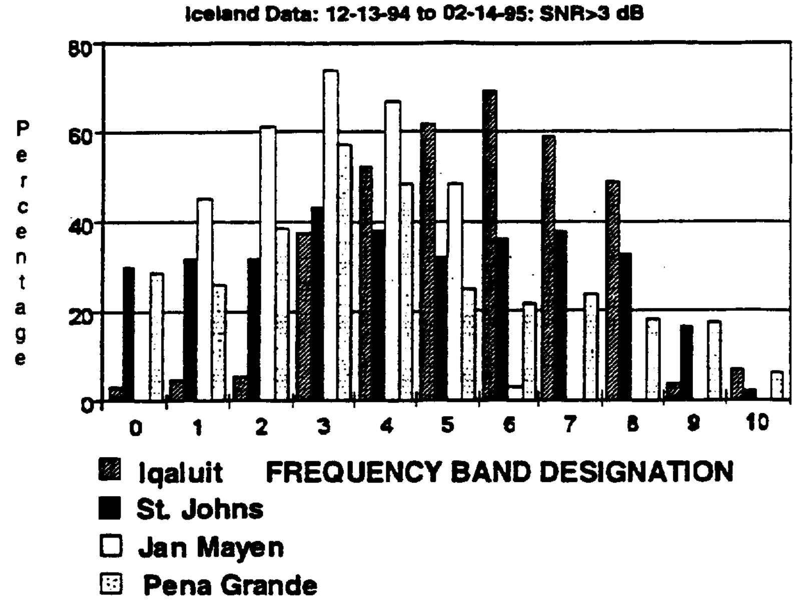

Figure 2a. Percentage availability of signals in the aeronautical-mobile bands received at Iceland and transmitted from Iqaluit, St. Johns, Jan Mayen, and Peña Grande (Madrid, Spain) over a 2-month period (December 13, 1994, to February 14, 1995).

HFDL modem will produce an uncorrupted (i.e., highly reliable) data stream when the SNR exceedance criterion is reached. HFDL availability, unlike point-to-point, single-frequency circuits, is based upon a multifrequency star-net configuration. Thus we deduce a consolidated form of availability based upon the exceedance of the specified SNR for any one of a number of frequency-path combinations. For this reason, we expect HFDL availabilities to be very high, given the diversity which is possible. In some of the following discussion, we shall use the inverse term, unavailability, or (1-A), where A stands for availability.

Figure 2b exhibits the percentage availability of HFDL service for each path and for frequency groups of 11, 8, 6, and 4 frequencies, respectively. The advantage of combining paths is obvious. It is of some interest to note that if all stations are used, then four frequencies will suffice in this particular example. Obviously, it is essential that we have a good selection of frequencies, and the more we have, the better. However, they must be the correct frequencies. In any case, there should be no dispute that station diversity is an important mitigation tool.

Correlation of variability relates directly to the issue of network diversity. From the point of view of nowcasting, in which we wish to use a control path as an update source for a remote communication path, high spatial correlation is desirable. From a network engineering point of view, however, rapid decorrelation of disturbance amplitude with distance only assists in the successful application of diversity solutions in netted communications. Figure 3 exhibits the distinction in correlation for benign and disturbed conditions. We see that the correlation is greater as the magnetic activity grows, a fact which has been observed by other workers. This suggests that link impairments are larger in amplitude and larger in scale as the magnetic activity level increases. In practical terms, this means that we must select widely separated paths under stormy conditions or accept lower diversity gain.

3. Synopsis of Results

A practical system design includes a specification of the number of stations (i.e., service providers) and frequencies needed to provide HFDL communication on a worldwide basis. As HF practitioners are well aware, a variation in network topology or a change in the frequency list will lead to differing levels of link and network performance. This situation is also quite region-specific. The most critical region was deemed to be the high-latitude zone, for several reasons. First,

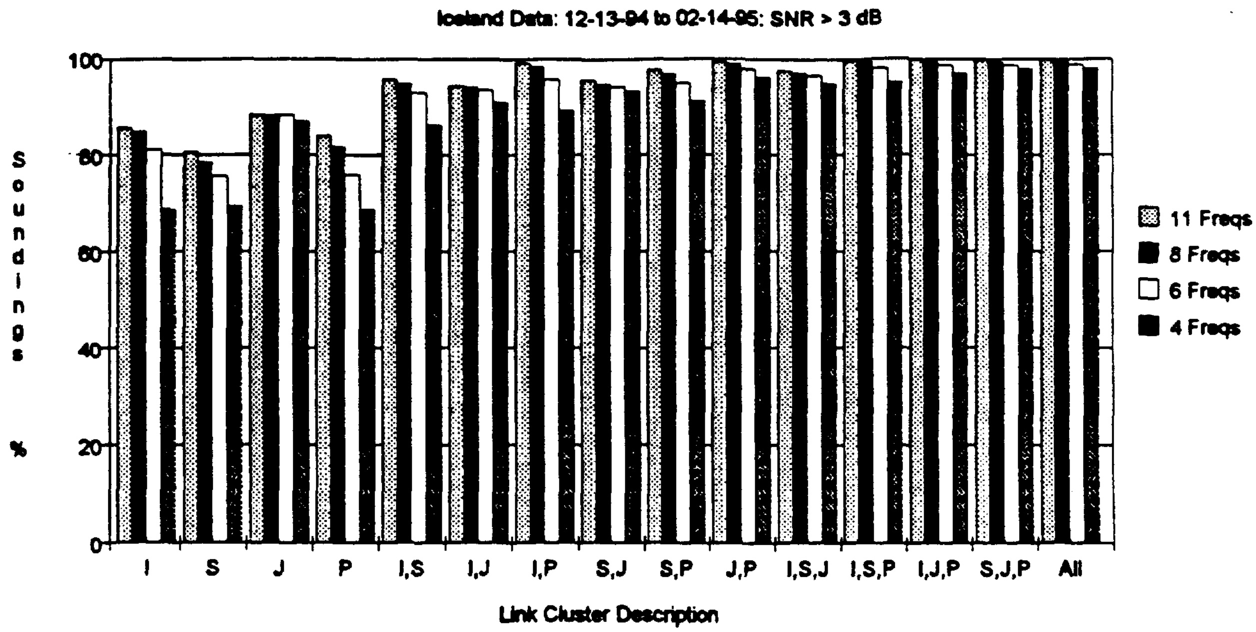

Figure 2b. Percentage availability of signals at Iceland for selected frequency groups and transmitter station combinations. (For each group of four, the ordering from left to right is 11, 8, 6, and 4 frequencies, respectively.)

it is an area for which satellite connectivity might be vulnerable and therefore a region for which HFDL service might be of critical importance. Second, it constitutes a major air route corridor, especially the corridor between North America and Europe. Another region of principal interest is the North Pacific. Of secondary interest are South Pacific routes and flights between North and South America. In addition to the issues noted above, the TCI/BR propagation studies have addressed station diversity gain and methodologies for dynamic frequency management [*Aeronautical Radio*, 1996].

3.1. Topological and Spectrum Considerations

There are a number of conclusions which have been reached based upon the data collected during the Northern Experiment and the analyses which have been carried out. The major conclusions are given below. Some flow directly from axiomatic principles of HF propagation and the ionospheric interaction.

1. Adequate spectrum must be available to achieve optimum connectivity. This seems self-evident. The conditions for adequacy will ultimately depend upon factors such as traffic loading. Studies have shown that connectivities approaching 100% (but certainly never reaching such a lofty value) may be achieved, provided one has access to four widely separated service providers (SPs) and can select from among a pool of frequencies residing in the 11 aeronautical-mobile bands, wherein the selections are dynamic, based upon full-band sounding. (The term service provider refers to a designated ground station and not an organizational entity. It is composed of a transmission and reception capability located within the same general area, but split-site operation may be employed for electromagnetic compatibility.)

2. On the basis of the principle of space diversity, we find that HF connectivity between a central node (i.e., aircraft) and a cluster of service providers (SPs) is improved substantially if the cluster population is increased. Conditions dictate the size of the cluster of SPs, but it has been shown that four stations are fairly optimum if the geometry is specified properly.

3. The cluster (i.e., network) connectivity is enhanced if the correlation between the paths linking the clusterhead (i.e., aircraft) and the SPs is low. The other condition is that the paths being cross correlated are viable, because low correlation is always possible if one or both of the paths do not permit propagation. This principle suggests the following strategy for selection of cluster members: (1) association of paths having widely separated control points, (2) association of paths residing in differing geophysi-

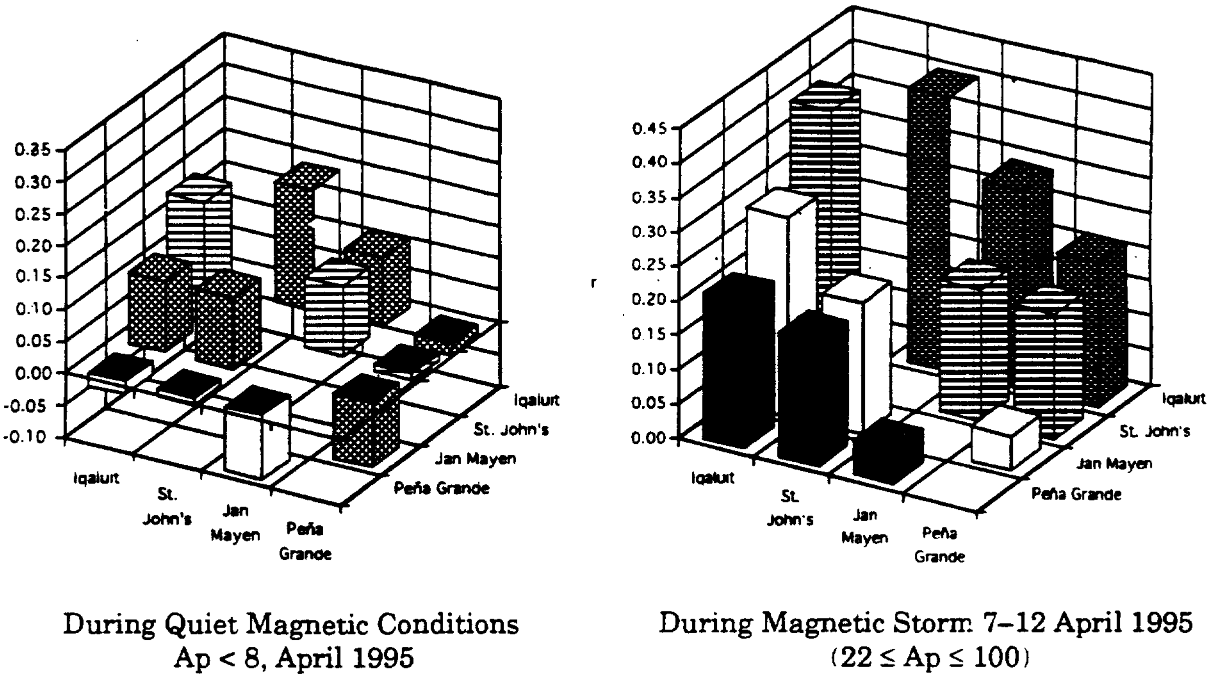

Figure 3. Correlation r between pairs of paths. Reykjavik is the common node in all cases. The largest correlation was observed between the Reykjavik–Iqaluit and the Reykjavik–St. Johns paths. The lowest correlation was observed between the Reykjavik–Peña Grande (Madrid) and the Reykjavik–Jan Mayen paths.

cal regimes, and (3) the use of paths with the largest potential propagating bandwidth. These include preference for the longest possible paths in the equatorward direction and use of paths possessing the largest possible solar elevation angle. This suggests, for four circuits in the cluster, that we might "box in" the clusterhead (or aircraft), enabling as much diversity as possible. However, given the greater possibility of limited viability for paths in the poleward direction, we should strive for specification of equatorward circuits with as much diurnal separation as possible. Two or more separated equatorward circuits might be part of the mix. In general, and for polar flights, the "box" formed by the SPs may actually be fully equatorward of the aircraft (clusterhead). Another candidate pattern for less pathological conditions might involve the use of an eastward and a westward circuit (which do exhibit some ultimate equatorward penetration) and a pair of paths along the north-south baseline. The poleward (or northward, in the case of the northern hemisphere) path may be of any length, while the equatorward path should be as long as possible without coming too close to the equatorial anomaly crest.

4. The overall network consists of an assembly of subnets or clusters, with the primary distinction between them being the respective clusterheads (i.e., aircraft designation), although not all clusters will have the same SPs. By definition, these clusterheads are evolving, first, because the aircraft is moving, and second, because the ionosphere is changing. Frequencies which were once optimum will not remain so for very long. We have monitored outage duration for paths in the Northern Experiment, and these data indicate persistence which increases with magnetic activity, which might be troublesome unless steps are taken to enhance the level of space diversity. This geophysical condition also points to the importance of dynamic management of network resources, including the swapping of frequencies between service providers. Evidence for an excess of capacity from a given SP to a generalized "cloud" of aircraft owing to sporadic E is abundant. While E_s is recognized as a summer daytime phenomenon for midlatitudes, our Northern Experiment data show that E_s bands due to the auroral zone may be used to circumvent F region propagation disturbances.

3.2. Regional Considerations

It is clearly important to recognize that HF communication connectivity is critically dependent upon the nature of the climatological regime involved. For a fixed point-to-point circuit, the geographical coordinates are prescribed, and the solar zenith angle has a well-defined diurnal behavior. This is useful in the forecasting of normal E and F_1 layer modes but is not especially useful in situations for which the F_2 layer is expected to dominate or sporadic E is in evidence. Moreover, the ionospheric dynamics is closely tied to the location of various circumpolar features which may vary in location, extent, and intensity in accordance with magnetic activity and/or storm time. Hence a given path may be a canonical midlatitude path under some conditions and may be an auroral path under others.

Real-time knowledge of the geophysical regime is critical for determination of the path characteristics. Certainly, overhead images of the oval would be helpful in this type of scenario, provided the images may translate efficiently into HF communication products which may be utilized by the network manager. Without this information, we have opted to develop a strategy based upon oblique sounding over the region of interest, thereby determining the HF communication properties directly. The availability of auroral images would be useful to us in understanding the nature of HF disturbance "maps" we develop, especially from a broader view, and as an aid to forecasting future events. It would be useful to compare information obtained by the U.S. Air Force and/or NOAA with our database of ionograms to exploit any relationships which may be of value. See section 5 on Dynacast®.

3.2.1. Midlatitude implications. The characteristics and principles described above will lead to performance of an HFDL system approaching 100% for midlatitude circuits provided the following are true: that four service providers are potentially available to each aircraft; that all 11 aeronautical-mobile bands are accessible by each service provider; that frequency pooling is allowed; and that dynamic frequency management is utilized. This has been shown experimentally for a midlatitude cluster of circuits which exhibited sufficient diversity to overcome the effects of a large magnetic storm. It is clear that the presence of sporadic E will be a major deterrent to communication outage at midlatitudes during ionospheric storms, for which the F region is greatly denuded, and a successful frequency management subsystem must account for E_s dynamically.

3.2.2. High-latitude implications. For high latitudes, the principles which have been identified in the preceding paragraph apply equally well. However, the underlying unavailability statistics for individual links may be unsatisfactory in this environment. While station diversity was certainly useful in increasing the network availability in the midlatitude region, it is clearly essential at high latitudes. Using full-band sounding as a driver for dynamic frequency management decisions, one may derive a solution which approaches the optimum. Unavailabilities based upon four-circuit clusters are generally unacceptable if predictions are used to drive the frequency selections in the face of disturbed conditions. If full-band sounding is employed, worst-case unavailabilities of roughly 5% were observed for high-latitude clusters even though the SPs which were specified do not appear to be optimized.

HFDL availability will exhibit within-hour, hour-to-hour, day-to-day, and month-to-month variations, with greater variability being associated with the shorter reckoning intervals. Within-hour availabilities would exhibit extreme variations were it not for the path and frequency diversity built into the system architecture. Nevertheless, short-term availabilities may occasionally droop during periods of magnetic storm activity, but the frequency of such occurrences is low and the droop is seldom more than 5% under moderately disturbed conditions.

We anticipate that long-term average availabilities approaching, but never reaching, 100% may also be achieved if diversity is used in an optimal fashion and if dynamic station and frequency management strategies are employed (see section 3.3 below).

Sporadic E appears to be a persistent feature of the high-latitude region, and it generally operates as a positive influence on the communication performance. Available models provide only limited guidance in connection with sporadic E presence, and this implies that observation must be employed to take advantage of the phenomenon.

3.3. Long-Term Availability Determinations

The following discussion refers to a consolidation of availability assessments for a period of time between December 1994 through October 1995. We have examined these availabilities at a rate of 300 bits/s, which is the baseline rate we have considered in our analysis. The reader is reminded of the general topology of the Northern Experiment. Figure 1 shows the paths which are involved in the analysis. For present discussions, the five distinct clusters of paths, defined by a clusterhead, are examined in some detail. These clusters represent paths configured in a star-net configuration, and the clusterhead represents an aircraft position. Each cluster of paths connects the clusterhead (i.e., aircraft) to respective ground stations. It is recognized that the operational situation is one in which the clusterhead is in motion, whereas our experiments are undertaken in a frozen environment. Accordingly, we have examined more than one cluster in our analysis, and this partially compensates for the static representation which was necessitated.

The alternative is to install full-band sounders on aircraft and take data over numerous flight trajectories in the regions of interest. While such studies would be a logical next step and might be an important diagnostic tool as the impact of solar activity increases in the next few years, such investigations have not been initiated as of this writing. Plans are currently underway to take data from an aircraft platform during 1997–1998.

We have examined four clusters in some detail. These are represented by clusterheads at Churchill, Iceland, Tors Cove, and North Carolina. From Figure 1 we can see to which four ground stations the clusterheads are connected. We have also examined a set of paths organized into a star-net with a clusterhead at Iqaluit. Equipment difficulties are suspected at the Iqaluit site. Given the fact that both Churchill and Iqaluit are located at roughly the same geomagnetic coordinates, and because Churchill does not suffer from equipment difficulties, we feel justified in the elimination of Iqaluit as a clusterhead site. The four clusterheads which have been selected involve an admixture of paths. For convenience, we may characterize the clusterheads and their associated clusters of paths as polar, auroral, trough, and midlatitude, assignments which are based upon representative geophysical regimes which may be involved. We may assign our selected clusters to these geophysical regimes. Accordingly, Churchill, Iceland, Tors Cove, and North Carolina may represent polar, auroral, trough, and midlatitudes, respectively. It should be noted that association of a specific cluster with a geophysical regime does not imply that all of the paths correspond to that regime, only that the clusterhead is located at a position characterized by that regime.

The average availability is deduced under the following condition: We assert that connectivity is established if any one of the 11 aeronautical-mobile bands will pass the SNR test reckoned at the clusterhead for passage of 300 bits/s messages over any one of the four paths in the star-net or cluster. We are really determining service availability. Figure 4 is a chart showing the monthly average availabilities and composite service availability for each of the selected clusters of paths. We see that the least reliable cluster is Churchill (polar), with gradually improving availability arising for Iceland (auroral), Tors Cove (trough), and North Carolina (midlatitude). There are also certain months with relatively low availabilities for selected sites. For example, the lowest value for Churchill is in December 1994, the lowest value for Iceland is in May, the lowest value for Tors Cove is in October, and the lowest value for North Carolina is in June. Thus we see little seasonal consistency in the database.

Despite the fact that there appears to be no seasonal pattern in the database, it is reassuring to see that the network or cluster-average service availabilities obey a simple rule of monotonic improvement with decreasing geomagnetic latitude. Still, one might have expected a cluster labeled "auroral" to exhibit somewhat poorer performance than a cluster labeled "polar." However, a major reason that the Churchill cluster has a lower availability than the Iceland cluster is that the former generally consists of three transauroral and one polar-polar path, whereas the Iceland cluster consists of two midlatitude and two transauroral paths. The Tors Cove cluster is generally represented by a trough-auroral path, a trough-trough path, a transauroral path, and a midlatitude path. The North Carolina cluster is generally represented by three midlatitude paths and one transauroral path. Again, we must emphasize that the geophysical regime representations depend upon time of day, magnetic activity, and other factors which relate to the dynamic nature of the various circumpolar features.

We observe that the Churchill cluster never exhibits a month in which the service availability is 100%. Iceland exhibits 3 months out of the 11 analyzed for which the availability is 100%. Tors Cove exhibits 4 months having 100% availability out of 9 analyzed, and North Carolina exhibits 5 months with 100% availability out of 10 analyzed. It is noteworthy that August provided the highest composite availability: 100% for North Carolina, Tors Cove, and Iceland, and the highest computed monthly value for

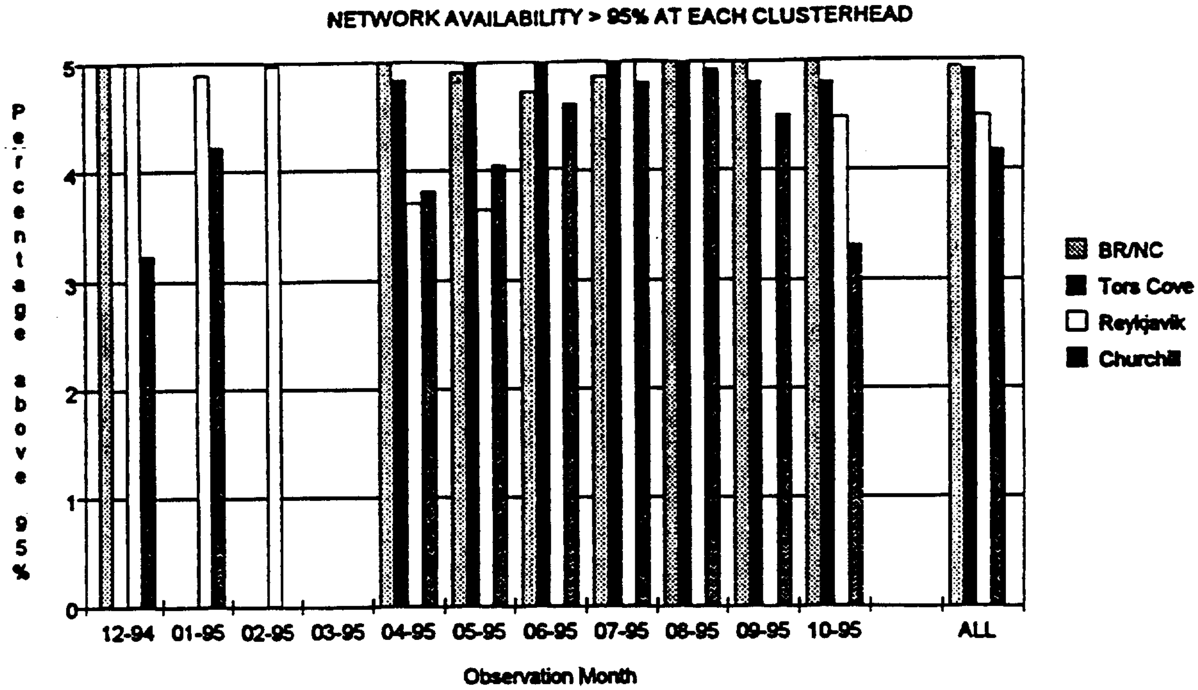

Figure 4. Graphs of the link cluster availabilities for the Northern Experiment. The clusterheads represent aircraft positions but, in fact, are locations of Chirpsounder® receivers. At these locations, we obtain data from four paths representing air-to-ground links. The clusterheads we have considered in this study are (1) a site in northeastern North Carolina (BR/NC), (2) a site near St. Johns, Newfoundland (Tors Cove), (3) a site at Reykjavik, Iceland, and (4) a site located at Churchill, Canada. The links to each clusterhead may be determined from Figure 1. Churchill is connected to Iqaluit, Wainwright, St. Johns, and Reykjavik. Reykjavik is connected to Jan Mayen, Iqaluit, St. Johns, and Churchill. St. Johns is connected to Iqaluit, Reykjavik, Puerto Rico, and Wainwright. BR/NC is connected to Puerto Rico, St. Johns, Wainwright, and Iqaluit. Other possible clusterheads include Iqaluit, Stockholm, San Francisco, and Fairbanks, but these four have not been considered in the current study. We have selected Churchill, Reykjavik, St. Johns, and BR/NC, respectively, as clusterheads for nonredundant representation of polar, auroral, trough, and midlatitude regimes, where these terms are based upon climatological average (i.e., not precise) positions. "All" corresponds to a composite average availability for the entire period of observation for each cluster of links. The reader should note that the plotted availability must be added to 95% to get the total value; thus a plotted value of 4% corresponds to 95 + 4, or 99%.

Churchill, which was 0.9993. The overall composite availability for August for all four sites was 0.9998.

Given the low values for unavailability (i.e., 1-A), we have examined the individual outages. At this stage of our analysis, it is apparent that the outage distribution is largely organized by local time rather than universal time. This would be expected. What was not expected was the extent of this dependence. Almost all the outages were in the 0500–1300 LMT sector (reckoned at the clusterhead, or aircraft position). In fact, there were only five outages in all of the data collection interval for the period 0500–1300 LMT. We have determined that the availability in the 16-hour period 1300–0500 is approximately 0.99993 based upon the number of possibilities for failure during this temporal epoch. On the other hand, the composite average availability for the 8-hour period 0500–1300 LMT is reduced to about 0.988. Clearly, this will have important implications for frequency management for the ultimate HFDL system.

4. Discussion

Many workers have described ionospheric effects on HF communication systems. A number of studies have stood the test of time, especially those studies

TCI/BR is studying this synergistic relationship in the context of high latitude and the equatorial regions where it is suspected that the correlation of unavailabilities will be least.

7. Conclusions

A study of link and network availability has been carried out based upon oblique sounder observations over an extensive region in the northern hemisphere for approximately a year. We have applied the measured propagation conditions in an analysis of HFDL performance based upon a specific system design specification. Nevertheless, the general conclusions will not change. We have concluded that space and frequency diversity will enable the normally unsatisfactory ensemble of HF channels to be utilized effectively to provide an HFDL service with long-term average availabilities approaching 100%. We observe that average availabilities decrease as the network clusters migrate to higher geomagnetic latitudes. Daily and monthly variations are observed as well. There is also a striking diurnal influence on average availability, with very little limit on the performance for netted HFDL service between 1400 and 0400 LMT at the clusterhead (i.e., aircraft) position.

It is emphasized that this result represents the very best that may be achieved under conditions for which full-band sounding is available to drive a dynamic nowcasting and forecasting subsystem for resource management. Frequency sharing and dynamic reallocation is a requisite condition, but it may not be sufficient. A full suite of frequencies populating all of the aeronautical-mobile bands is needed to exploit the dynamic forecasting capability. The reader is also reminded that these data sets were obtained during a period of low solar activity, with only a few episodes of enhanced magnetic substorms. The resource management challenges will become more daunting as the period of solar activity increases in the next few years, and this will surely necessitate some greater consideration of real-time failure mode assessment and mitigation.

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