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Recommendations for Digital Radio Common Tactical/Long-Haul Standards

J.E. Farrow
L.G. Hause

U.S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

Dale N. Hatfield, Acting Assistant Secretary
for Communications and Information

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RECOMMENDATIONS FOR DIGITAL RADIO COMMON TACTICAL/LONG-HAUL STANDARDS

J. E. Farrow and L. G. Hause*

This report is the sum of a three-part effort by the Institute for Telecommunication Sciences (ITS) to provide technical recommendations for the DCS Long-Haul Tactical Common system, subsystem, and equipment technical standards for digital radio. The work was sponsored by the Defense Communications Engineering Center, Reston, VA.

Primary recommendations for the system standards include suggested reference circuit and channel distances within a common overseas DCS terrestrial segment; the suggestion that only digital subsystems be included in the global reference circuit; and the statement that only parameters directly measurable in digital systems (such as bit-error-rate) be used in defining performance. The main recommendations for subsystems standards include a recommended scope for subsystem standards; suggestions for specific content in which appropriate standards and subsystem parameters are identified; and exclusion of all reference to FDM/FM parameters from new drafts. Some important guidelines for the equipment standards include an outline for the equipment standards; recommendations on the realism and practicality of design parameters; and recommendations on possible techniques to be included in the standard for upgrading existing facilities.

Key words: digital microwave; equipment standard; radio system standard; subsystem standards; tactical communication

*The authors are with the Institute for Telecommunication Sciences, National Telecommunications and Information Administration, U.S. Department of Commerce, Boulder, CO 80303.

1. DIGITAL RADIO ISSUES GERMANE TO A COMMON TACTICAL/LONG-HAUL SYSTEM STANDARD

1.1 Introduction to System Standards

1.1.1 Purpose of the Common System Standard

The purpose of developing a military communication system technical standard common to both long-haul and tactical applications, besides the usual purposes of a system standard, is to improve interoperation of long-haul and tactical communication systems of the Department of Defense as agreed to by USAEC and DCA in a memorandum of understanding.

Some of the usual purposes of communication system standards are to provide the following types of information:

1. Channel characteristics for the establishment of interconnecting circuits between users. (See MIL-STD-188-100, 15 Nov. 1972, page 1.)
2. User-to-user requirements and hypothetical reference circuits which are essential for developing overall system plans and subsystem standards. (See MIL-STD-188-100, 15 Nov. 1972, page 9; and Draft MIL-STD-188-200, 1 June 1978, page 3.) These requirements include adequate quality and availability of service values.
3. Performance parameters, definitions, and values without specifying the technology that is used to obtain the required performance. (See Draft MIL-STD-188-200, 1 June 1978, page 4.)
4. Requirements for commonality of equipment and reasons to discourage proliferation of equipment types serving the same or similar function. (See Draft MIL-STD-188-200, page 4.)

The purpose of this report is to examine issues germane to the digital radio portions of the military communication system technical standard common to both long-haul and tactical applications (hereafter referred to as the common system standard).

1.1.2. Scope of Report

The three-part effort to provide technical recommendations for the DCS Long-Haul Tactical Common standards was done in three major subtasks corresponding to system, subsystem, and equipment standards. The three major subsections of this report correspond to the three subtasks. This work was sponsored by the Defense Communications Agency, Defense Communications Engineering Center, 1860 Wiehle Avenue, Reston, VA

22090. The subtask one section covers the digital radio aspects of the common system standard. The range of radio system issues covered by this report are those which lie in the following categories:

a. Radio system transmission bit rates.

b. LOS microwave system carrier frequencies.

c. Beyond-the-horizon, "Tropo" system carrier frequencies.

d. Type IV tactical systems (less maneuverable) as described in MIL-STD-188-200 (1978).

The tactical/long haul interface is a hierarchy/multiplex issue and not primarily a radio issue. The level of hierarchy at which the interface occurs does affect radio equipment so this issue is discussed briefly but no recommendations are made.

1.1.3 Approach

The general approach to the problem of improving and encouraging the interoperability of long-haul and tactical digital communication systems has been to define a reference circuit which approximates a typical connection which could be made through the total communication system. Such reference circuits, which have been very important elements in all standards to date, provide a convenient technique for allocating particular technical requirements to each of the subsystems which support the reference circuit.

1.1.3.1 Reference Circuit

A recent report (Kirk and Osterholz, 1976) has proposed a global Defense Communications System reference circuit which is shown diagrammatically in Figure 1. The development of this reference circuit was based on studies of actual segments of the DCS, so it may be expected to reflect closely the actual subsystems traversed by a typical connection. Furthermore, the Kirk and Osterholz report suggests a complete technique for allocating circuit quality degradation (which is a result of short-term channel impairments) and circuit unavailability (which is the total duration of channel impairments each of which last more than one minute). They further suggest an unavailability of 1% for the full length of the DCS reference circuit. This value is based on the requirement for the efficiency of data channels (Kirk and Osterholz (1976), p. 18). This value is also in good general agreement with various CCIR studies and recommendations. (CCIR (1978) Vol. IV, Recommend. 522, p. 61; CCIR (1978) Vol. IX, Recommend. 556, p. 20, and

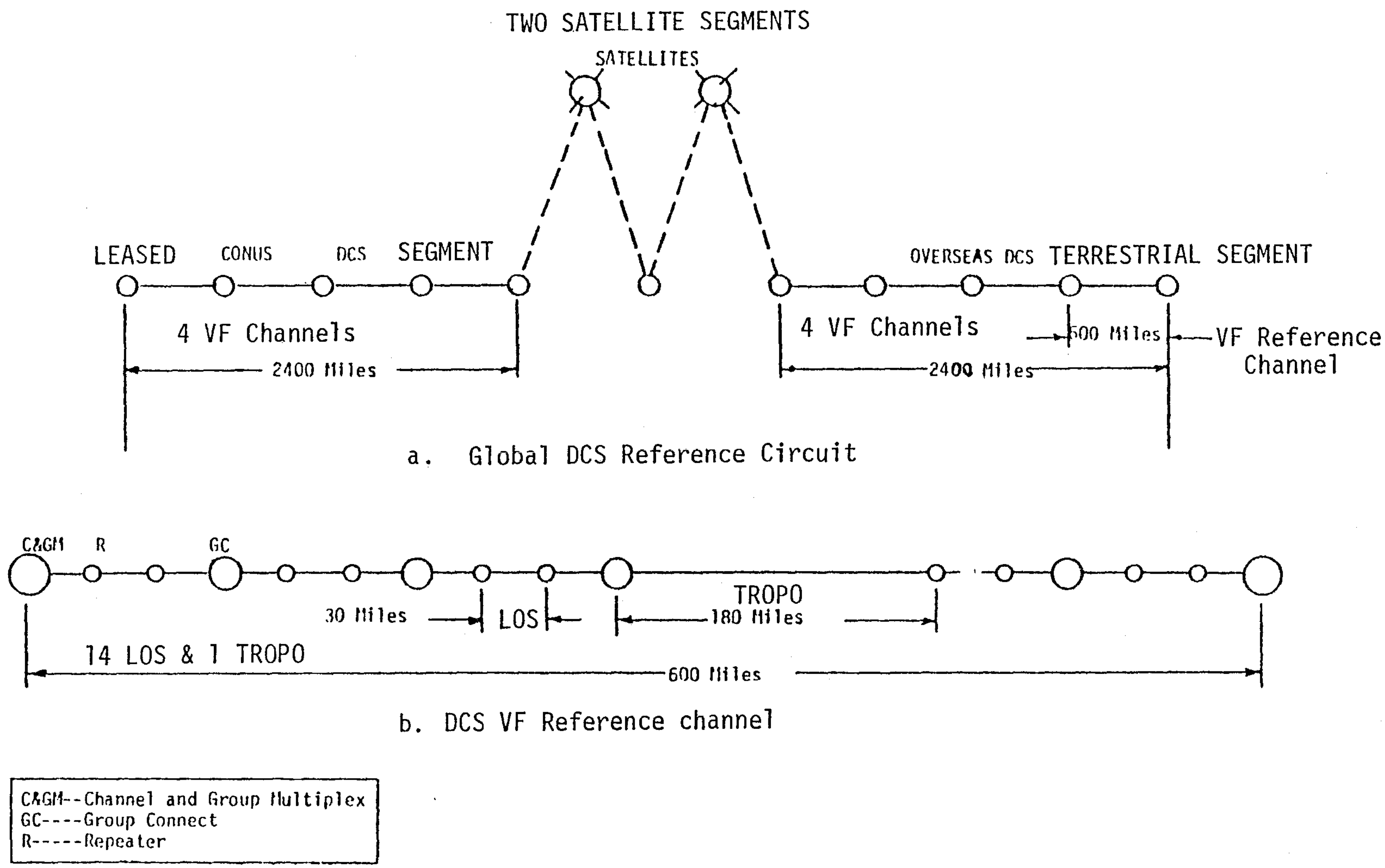

Figure 1. DCS reference configurations (from draft MIL STD 188-XXX, March 1980).

557, p. 43.) The acceptance of these ideas as a working basis for the new standard are reflected in such documents as the new draft of the DCS Digital Transmission Performance Standard, dated March 1980.

1.1.3.2 Transmission Medium versus Equipment Effects

As is carefully pointed out in the Kirk and Osterholz report, a complete description of the various causes of channel disturbance on a system must consider the effects both of the medium and of equipment failures. These authors allocate outages due to equipment failure of all kinds on a VF reference channel of 965-km (600-mile) length to be four times greater than the radio propagation outages the same reference channel. This is a strong indication of the relative importance of these two effects in system availability considerations. Equipment reliability and ease of restoral must be given very careful attention in developing system and subsystem standards. Various studies, CCIR (1978) Report 445-2; OT Tech Memo 77-238 (private communication), FKV Pilot Digital System Evaluation, have shown that the allocation value suggested by Kirk and Osterholz is in good general agreement with measured results on both military and nonmilitary systems.

1.2 Basic Issues

The review of the current draft standards and of comments by various interested parties has surfaced a number of basic issues which have not been totally resolved. In the following sections, these issues are discussed and an attempt is made to suggest technically sound resolutions.

1.2.1 Common Reference Circuit

As was mentioned previously, the principal reason for developing a system standard is to allocate the unavailability to various system components so that these components can be specified in such a way that an economically feasible system can be built. In the current instance, the development of a common tactical/long-haul communication system standard must give due consideration to the effects of both the tactical and long-haul parts of the system on either voice or data signals. The most reasonable approach is to define a reference circuit that contains both tactical and long-haul elements. The main problems with such an approach are that different reference channels (Kirk and Osterholz, p. 6; MIL-STD-188-200, 1 June 1978) are used in tactical and long-haul standards, that different assumptions are made about the composition of the channels, and that the channels are described in different units of measure. The reconciliation of these differences is not an impossible task but it will require some adjustment of both tactical and long-haul standards and ways of thinking.

Our suggested approach is to establish a single VF reference channel applicable both to tactical and to long-haul systems. This reference channel, shown in Figure 2, would be 1000 km long and would consist of one tropospheric scatter link 300 km long and fourteen line-of-sight links, each 50 km long. Note that two changes from the DCS VF reference channel are being proposed and one change from the tactical reference channel. The unit of measure of the DCS VF reference channel is to be kilometers instead of miles, and in order to work in even increments of length, the lengths of the reference channel and its component links are increased by about 3%. The tactical circuit was already specified in kilometers but the composition of the VF reference channel is made identical to the suggested revision of the DCS reference channel. If these changes are accepted, two beneficial results would accrue. First, the global reference circuit could include one (or more) tactical VF reference channels without the need of changing the analysis of subsystem availability requirements. This should not be a problem because the critical nature of tactical traffic requires that it be carried on links as good as or better than required for the long-haul traffic. Some of the techniques for providing high-quality tactical links are discussed in Section 1.2.7 of the report. This is reflected in MIL-STD-188-200 where, in Section 4.1.2, the less maneuverable tactical systems are described as being well sited and carefully installed. Second, expressing the units of linear measurement in metric units would bring the standards into conformance with Presidential policy as stated in Public Law 19-168 which is the Metric Conversion Act of 1975.

A realignment of thinking of the tactical and long-haul communities in regard to the specification of the systems is necessary. As Kirk and Osterholz (1976) note on page 8 (in a reference to DCEC TR 3-74), the transfer response and noise quality of each individual channel of 64 kb/s PCM exceeds the quality of an equivalent analog channel. This means, again in the words of Kirk and Osterholtz, that no detailed allocation of circuit characteristics associated with the voice A/D process (such as idle noise, loaded noise, and amplitude and phase distortion) is considered necessary. These authors suggest that a more usable measure of system performance (and hence voice and data channel performance) is the probability that the mission bit stream error rate is above some specified threshold value. Their suggested value for this parameter is one error in 10^6 bits or an error rate of 10^{-6}. They further show that the system performance predicted for a given configuration is not a strong function of the error rate chosen.

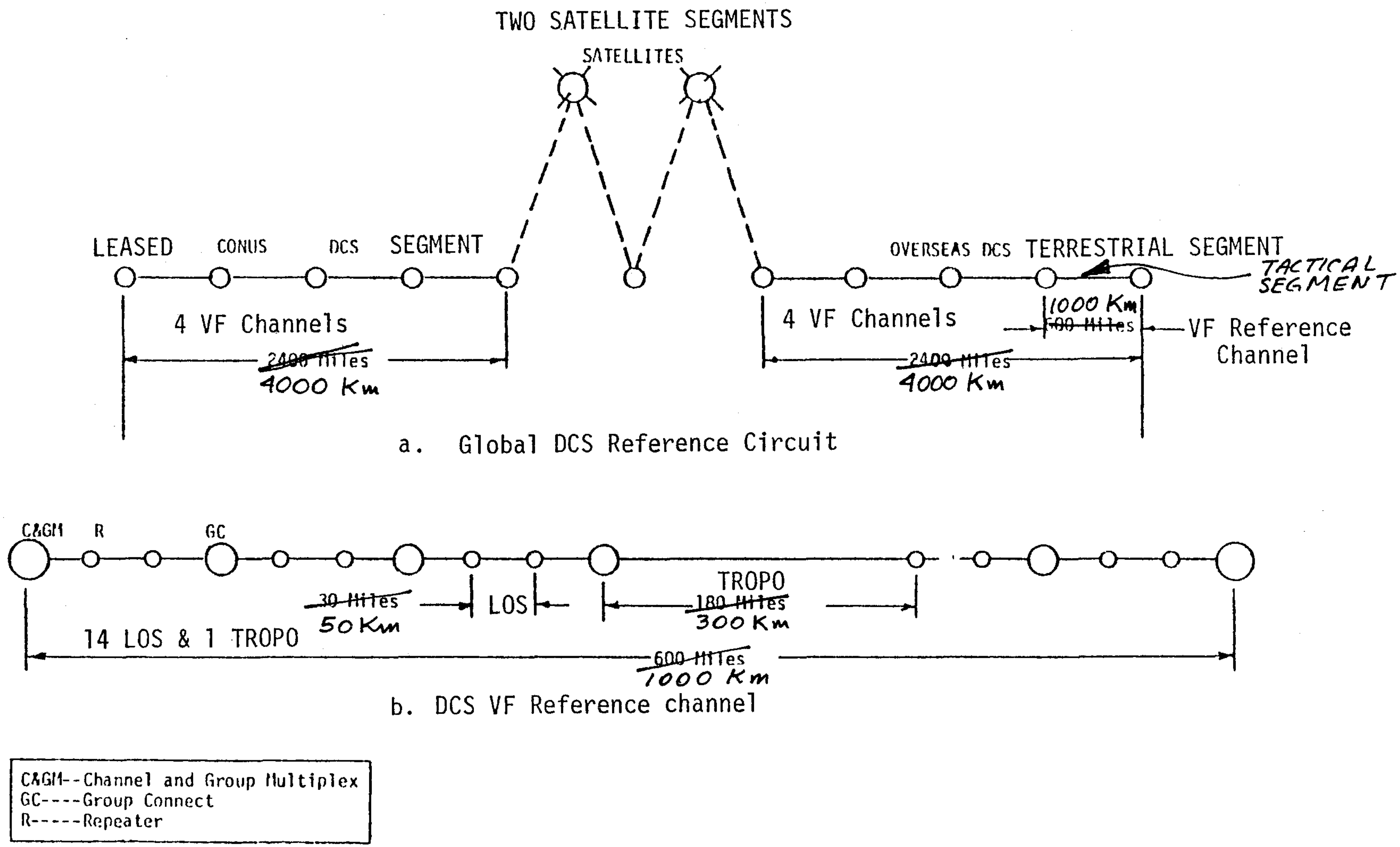

Figure 2. Suggested combined tactical/long-haul reference circuit and channel.

To summarize the foregoing discussion, we recommend that a common tactical/long-haul digital VF reference channel be adopted and that it be as illustrated in Figure 2. We recommend that for the all-digital global combined reference circuit, no detailed allocation of voice circuit characteristics associated with the voice A/D and D/A process be considered. We recommend that the performance of the radio links which support the reference channel be described in terms of the probability that the bit error rate is above a threshold value as suggested in Kirk and Osterholz (1976).

1.2.2 Mixed Analog-Digital Reference Circuit

In establishing a reference circuit for the combined tactical/long-haul standard, a basic issue which remains unresolved is whether to permit analog radio links to be part of the DCS global reference circuit. In favor of this idea is the important consideration that much of the Defense Communication System will be composed largely of analog radio links for several more years at least, and may have analog radio links in some places far into the future. Thus a reference circuit which includes both analog and digital transmission subsystems would be a more accurate reflection of the current situation. The rapid pace of replacement of analog radio links by digital ones decreases the strength of this argument, however.

The most important reason for not considering a hybrid reference circuit is that these circuits are affected differently by transmission impairments. This difference is clearly pointed out in the Kirk and Osterholz report on page 2, and is reflected in the description in CCIR (1978), Recommendation 556 of an all digital reference circuit. We recommend that a digital-only combined global reference circuit be established.

1.2.3 Combined Global Reference Circuit Quality

As was previously cited in this report, Kirk and Osterholz (1976) consider the quality of a voice channel in terms of the probability of short duration disturbances occurring during a 5-minute telephone conversation. The approach these authors took in their analysis involved examining the probability that any of the radio links making up the reference circuit would fade deeply enough to cause an error burst in the digital baseband data stream. Although Kirk and Osterholz have done a much more detailed analysis of reference channel quality than has been referenced in the CCIR documents, their approach is quite similar to that outlined in CCIR (1978) Report 378-3 in which the channel disturbances are characterized as high error rate (fairly long) periods and short error bursts. The CCIR (1978) report further discusses the duration and severity of error bursts with reference to the probability of call dropout due to the effects of error bursts on automatic switching systems. While Kirk and Osterholz have considered the effects of customer patience instead of automatic switching systems on the likelihood of call abandonment or dropout, their analysis may more closely reflect the conditions to be found on the DCS or on tactical systems. For this reason, we recommend that the Kirk and Osterholz approach be used while bearing in mind that on page 19 of TR 12-76, the authors encourage further study of the precise numerical values to be used in describing channel quality. It is interesting to note that the CCIR (1978) report referenced above makes a similar recommendation.

1.2.4 Combined Global Reference Circuit Availability

One of the most important aspects of system operation is the availability of service. This importance is reflected in various CCIR Reports and Recommendations for civilian systems; for military command and control systems, the availability is of critical importance. Kirk and Osterholz have proposed a value of 0.99 for end-to-end reference circuit availability and have considered the factors affecting availability. Their analysis allocates an unavailability of 0.004 for the overseas terrestrial segment (see Figure 2.) which is in very good general agreement with measured values of circuit availability given in CCIR (1978) Report 445-2. We recommend that the values of allocated unavailability suggested by Kirk and Osterholz be retained as working standards until experience provides an even better basis for selecting these numerical values.

1.2.5 Inclusion of Multichannel Radio Links Only

The development of a common tactical/long-haul reference circuit must be preceded by a decision as to what sorts of equipment will be considered suitable to support the reference circuit. A first part of this decision would be to include only equipment which carries interswitch trunks. The reason for doing this would be to exclude single-channel or small-capacity radio links which will likely carry dedicated circuits. These narrowband radios should be considered part of the subscriber loop and beyond the scope of the reference circuit standard. Other considerations are that single-channel radio links are highly mobile, and their operating frequency is outside of the range of consideration as stated in Section 1.2.7. For these reasons, we recommend that only radio links whose mission bit stream is at a rate equal to or greater than that output by the first level multiplex be considered as supporting the combined global reference circuit.

1.2.6 Equipment Reliability Considerations

In discussing the availability of the reference circuit, Kirk and Osterholz allocate one-fifth of the outage time on the overseas segment to propagation problems and four-fifths of the outage time to equipment failure outages. This proportion indicates that efforts to improve subsystem availability will pay off four to one if the effort is made to improve equipment reliability rather than propagation reliability. This should not be taken to imply that efforts to improve radio propagation reliability are not valuable but rather to indicate that there is a much more useful and cost effective effort to be made in a currently neglected area.

At this point, we disagree with Kirk and Osterholz on system reliability. On page 25, these authors state:

> "The major factors which affect equipment-related unavailability are (1) the degree of equipment redundancy in the system, (2) the efficiency of performance monitoring techniques to detect and switch to standby equipment when failures occur, and (3) the logistics approach that is used to effect the restoral of failed equipments. Of these factors, the most important is the degree of redundancy. Effectively used redundancy allows nearly uninterrupted service when a single equipment fails.
>
> The next most important factor in optimizing availability is the selected logistics approach. An adequate supply of spare modules or assemblies must be available on-site to avoid excessive downtime after a failure occurs. Also, personnel must be available to make the corrective action. Also, travel time is a very important factor in determining the mean-time-to-service-restoral (MTSR). (Note the difference between MTTR which addresses only the time required to repair a unit, given that both personnel and parts are available, and MTSR which includes travel time and time to locate the appropriate part, plus the basic MTTR.)
>
> The third major factor affecting unavailability is performance monitoring effectiveness. Performance monitors must be capable of detecting the failure of on-line redundant units and switching to the off-line unit but, even more importantly, they must be capable of detecting failures in an off-line unit so that it can be repaired before it is needed. Inability to detect an on-line equipment failure can be rectified by manually activated switchover to a standby equipment (hence a very short time-to-restore) when the on-line unit subsequently fails. This occurence results in the need to dispatch a maintenance man to physically repair the equipment before service is restored.
>
> The above factors result in equipment-related availability being described in terms of four parameters:
>
> (1) the mean-time-between-outages (MTBO) which can be restored by manual redundancy switching,
>
> (2) the mean-time-between-outages (MTBO) which require equipment repair to accomplish service,

(3) the mean time-to-service-restoral (MTSR) when an operational redundant unit is available, and

(4) the mean-time-to-service-restoral (MTSR) when actual equipment repair is required.

Of the above four factors, (3) can be assumed to be trivial relative to (4), and hence (1) is also trivial. In summary, the major factors which affect the unavailability of a system such as the DCS which widely uses redundancy are the percentage of undetected off-line equipment failures which nullify the advantage of redundancy, the manning density of the maintenance function which determines the travel time component of MTSR, and the adequacy of spare parts support."

While such an analysis can be expressed in a closed mathematical form, it ignores the realities of life on the DCS. It is not in agreement with the analyses given in CCIR (1978), Report 445-2, which shows five outage types. These categories are equipment failure, propagation, loss of primary power, maintenance, human error, and all other occurrences for which no cause could be isolated. The authors' personal experiences are that equipment failures are not independent random events but, rather, they tend to cluster. This clustering is usually due to human factors which are not considered in the foregoing analysis. For instance, if a technician attempts to restore to service some equipment with which he is unfamiliar, there is a great likelihood that he will do more harm than good. This is not an unknown occurrence to the authors' certain knowledge. This is discussed in FKV Pilot Digital System Evaluation, Volume 1, page 4 (private communication).

A second serious flaw in the Kirk and Osterholz analysis ignores design and installation errors which cause clustered outages. Such things as antennas falling off towers, waveguide systems which must be repeatedly replaced, and power distribution systems that pull a site down when the operator attempts to switch from commercial to stand-by power contribute a major portion of system unavailability. Furthermore, the time to restore a failed antenna system for instance can be as long as 6 months.

These remarks are intended to convey a sense of urgency regarding the contribution of equipment failure to reference circuit unavailability and to inject a note of reality into the calculation of unavailability related to equipment failure. Serious engineering design flaws and installation errors are both due to human factors which need to be controlled. The statement in the last line from the Kirk and Osterholz quote concerning "the manning density of the maintenance function" demands correction to "the skill density of the maintenance function".

It is a total fallacy to assume that all military personnel of a certain Military Occupational Specialty (MOS) will have the same level of training, native intelligence, motor skills, or motivation, and any analysis based on such an assumption will provide very little guidance for system improvement. It is further a misuse of reliability analysis to ignore the most important contributor to the unreliability of the DCS, namely the human factor. In this same vein, another aspect of the human-factor problem must be mentioned, namely the system management function. Even the most elaborate scheme of fault detection and reporting which could be devised is worthless unless human operators respond to the information provided. It is a management function to ensure that the fault-detection information reaches the right people, that the proper interpretation of the information is made, that appropriate corrective action is undertaken in a timely manner and that follow-up insures that correction is made. Management must respond to the failure of any one of these activities with improved training, improved motivation, or improved operating procedures. This is the only way to reduce system unavailability to projected levels. Management must also support their lower echelon maintenance personnel to the extent that if a problem keeps recurring, higher level maintenance efforts can be promptly called upon to correct the equipment problem.

The authors are of two minds on including this material in this report. The reference circuit is an intellectual tool to be used as an aid in system conception, design, and implementation, while this diatribe on reliability relates to the lowest level of the physical equipment and operation. However, if the reference circuit standard does not reflect fairly closely the actual conditions on the subsystems which will carry the reference circuit, then its development becomes a sterile mental exercise which will in no way contribute to improved communication service for DCS customers. It is recommended that the assumptions made about system management and skill levels required to validate the use of the reference circuit be stated clearly and explicitly in the documentation describing the global reference circuit.

1.2.7 Range of Major Radio Types to be Covered by the Standard

Important among the issues are the ranges of digital radio types which should be covered by the standard for the common system. As an example, radio systems using carrier frequencies below 0.3 GHz should not be covered because these bands do not have the required capacity due to crowded spectrum conditions and many are primarily designated for other services by international agreement.

The ranges of digital radio types that are within the scope of the common system standard are defined by:

a. Carrier frequency range

b. Radio transmission bit rate range

c. Path types which are line of sight (LOS) and beyond the horizon (Tropo).

The carrier frequency range for LOS paths is from 0.4 GHz to about 9.0 GHz. The upper end of the 7.125 - 8.400 GHz band should be the upper frequency limit because the major cause of channel outage changes from multipath outage to rain-attenuation effects fairly rapidly within the 7.1-8.4 GHz band. This is shown by examples of theoretical calculations for a 48-km path in Maryland (Figures 3 and 4). The 15 GHz band was selected for the example in Figure 4 because this band is the next available Government band above 8.4 GHz. The system standards for both tactical and long-haul links operating at frequencies above 8.4 GHz will require special attention to the rain attenuation effect. The calculation results shown here were obtained from the models in Hause and Wortendyke (1979) pages 33-50.

At 8 and 15 GHz, the multipath predictions are the same because the multipath occurrence factor is greater than 1. For severe multipath fading, a Rayleigh distribution through the long-term median does, indeed, seem to be close to the limiting case. An example of such data is shown in Hause and Wortendyke (1979), page 35.

At 8 GHz, rain-attenuation and multipath outage time are about equal for this 48-km path when diversity improvement is considered. At 15 GHz, rain attenuation is seen to dominate the outage statistics totally, at least for this path in Maryland.

The range of carrier frequencies for tropo paths has been well established and should not be at issue. This range is 0.4 to 5 GHz (draft MIL-STD-188-XXX, March 1980). Carrier frequency ranges should be the same for both tactical and long-haul system standards because the equipment state-of-the-art and propagation limitations are approximately the same for both kinds of systems.

Limitations on the upper and lower radio transmission bit rates for systems covered by the common system standard are determined by the multiplex hierarchy on the low end (1.5 Mb/s) and the multipath caused distortion on the upper end.

The maximum bit rate covered in the common system standard should be nominally 50 Mb/s based on hierarchy requirements and the finding that, up to the 50 Mb/s range, digital microwave links are not sensitive to frequency selective fading

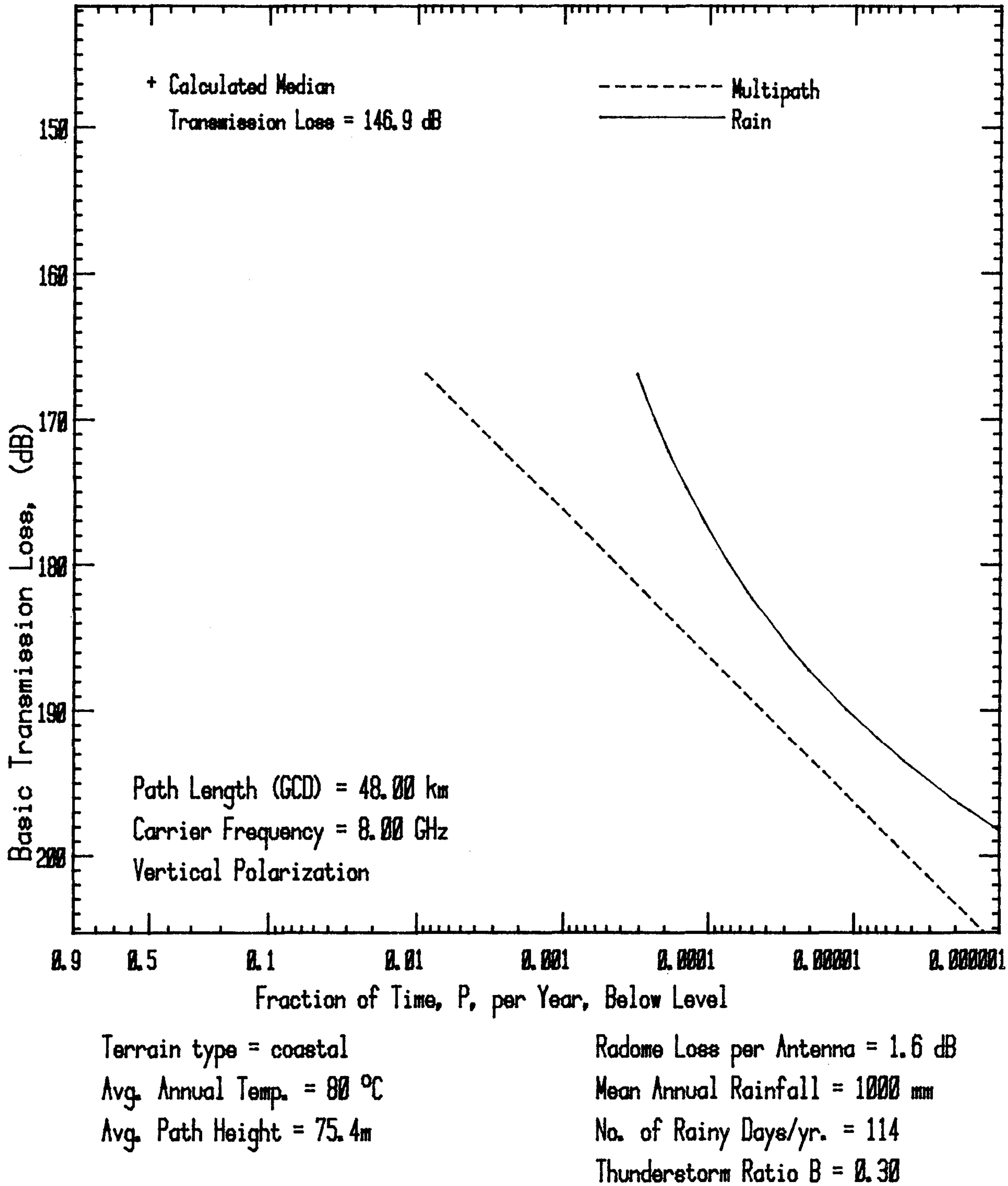

Figure 3. Multipath and rain loss variability for the path from Carney to northeast Maryland.

Technical Concepts of Access Area Mapping and Gateway Interfacing of Digital Communication Systems, pp. 46-59), the only rate which the tactical and long-haul systems have in common is 1.544 Mb/s, so that careful consideration should be given to interfacing at this data rate. We have not considered the problems of voice channel digitizing rate or format changes. If equipment designed to change channel rates and formats between tactical and long-haul hierarchies becomes widely available, then interoperability would be greatly facilitiated even to the extent that tactical and long-haul radio links could be interspersed to support the reference channel. ITS offers no recommendation on this matter.

1.3 Recommendations for System Standards

This section of the report contains a list of all recommendations made in the various preceding sections. The recommendation number corresponds to the sub-paragraph number where the issues are discussed in Section 1.2.

1a. It is recommended that a common tactical/long haul digital VF reference channel be adopted and that it be as illustrated in Figure 2 of this report.

1b. It is recommended that for the all-digital global combined reference circuit, no detailed allocation of voice circuit characteristics associated with the voice A/D and D/A process be considered.

1c. It is recommended that the performance of the radio links which support the reference channel be described in terms of the probability that the bit error rate is above a threshold value as suggested in DCEC TR 12-76.

2. It is recommended that a digital-only combined global reference circuit be established.

3. It is recommended that the Kirk and Osterholz approach (to describing combined global reference circuit quality) be used while bearing in mind that on p. 19 of TR 12-76, the authors encourage further study of the precise numerical values to be used in describing channel quality.

4. It is recommended that the values of allocated unavailability suggested by Kirk and Osterholz be retained as working standards until experience provides an even better basis for selecting these numerical values.

5. It is recommended that only radio links whose mission bit stream is at a rate equal to or higher than the output of the first level multiplex be considered as supporting the combined global reference circuit.

6. It is recommended that the assumptions made about system management and skill levels required to validate the use of the combined global reference circuit be clearly and explicitly stated in the documentation describing the reference circuit.
7. It is recommended that the global reference circuit system standards cover only terrestrial radio equipment of the following characteristics: Line-of-sight radio sets with a carrier frequency between 0.4 and 9 GHz with a mission bit stream capability of 1.5 to 50 Mb/s and tropospheric scatter radio sets with a carrier frequency of 0.3 to 5 GHz and a mission bit stream capability of 1.5 to 12.5 Mb/s.
8. It is recommended that the 1972 edition of MIL STD 188-100 be retained as a standard for analog systems.
9. ITS offers no recommendation on the matter of the location in the multiplex hierarchy of the long-haul/tactical interface.

2. RECOMMENDATIONS FOR DIGITAL RADIO LINK SUBSYSTEM STANDARDS

2.1 Introduction

This report on subtask 2 will concern itself with a review of the common tactical/long-haul line-of-sight subsystem design standard, MIL STD 188-145 DRAFT 24 April 1977, and the common long-haul tactical troposcatter subsystem design standard, MIL STD 188-144 DRAFT January 1980. There is no draft of MIL STD 188-141 on high-frequency digital subsystems available so the contribution to this subject will be to discuss the key subsystem parameters in Sections 2.1 and 2.2 of this section which apply generally to all modes of propagation.

2.1.1 Basic Concept

While reviewing the two available subsystem standards, it was observed that the purpose of both documents is ". . . to provide technical standards for (tropospheric scatter or microwave) radio links . . ." and that the documents are ". . . to be used in the design and engineering of new (tropospheric scatter or microwave) communication links . . . ." The emphasis in the subsystem standards is on the establishment and continuity of radio communication which will meet the quality requirements of the global circuit standards and will make use of hardware which meets the equipment technical standards. Thus, the subsystem design standards should describe the methods of using standard hardware and should provide a common ground between the global circuit requirements and the characteristics of standard equipment. The primary concerns of the subsystem standards should be factors affecting link performance. These are first, radio propagation effects, and second, radio-site infrastructure and support facilities.

A discussion and development of these two topics will form the major part of this report.

2.1.2 Limitations of Subsystem Standards

Subsystem standards are intended to fill the gap between equipment and global circuit standards and must meet each of these other standards at their interfaces. Some of the material in the global circuit standard will need to appear in the subsystem standard as will some equipment characteristics and parameters, but the subsystem standard should not contain any detailed discussion or consideration of these other subjects. For instance, a simplified block diagram of a radio terminal may be included to clarify a point, but no detailed equipment descriptions or standards should be included nor should any operating parameters or circuit details. These topics must be covered in the equipment standards and may be included by reference, but they should not be repeated in the subsystem standard. Similarly, the subsystem standard may include a brief statement of global standard performance goals and the maximum degradation of service to be permitted in each part of the global circuit but lengthy descriptions of global circuit quality and the rationale for the development of such standards should be completely avoided although, again, they could be included by reference. Specific recommendations of sections of the draft subsystem standards to be eliminated will be made in later sections.

To summarize, we recommend that the global digital reference circuit standard and the digital equipment technical standards be accepted as having been established in the preparation of the subsystem standards and that the subsystem standards concentrate on radio link propagation effects and radio site infrastructure and support facilities. Each of these areas will be dealt with in subsequent sections of this report.

We further recommend that the required single radio link availability derived from the global circuit quality standard be set forth explicitly and that the accompanying paragraphs state explicitly what causes of unavailability are to be included in the figure. The possible causes of unavailability as considered by Kirk and Osterholz (1976) are related to propagation and equipment failure

(TR 12-76, pp. 24 and 25), and the explanatory paragraph must show what fraction of the allowed unavailability will be properly charged to each cause.

2.2 Subsystem Standard Organization

The subsystem standard should be organized to define and establish standards for those parameters of particular importance to radio link performance. These were previously stated as:

1. Radio propagation effects, and
2. Radio site infrastructure and support facilities.

2.2.1 Radio Propagation Effects

The three modes of electromagnetic communication being considered here occupy different frequency ranges, exploit different basic physical phenomena for their operation, and consequently are subject to interruptions from completely different causes. For instance, rain attenuation and atmospheric refractivity are the basic processes which limit line-of-sight propagation but they have no noticeable effect on HF links. Conversely, the state of the ionosphere is responsible for HF propagation while it has no influence on line-of-sight links. Tropospheric scatter propagation on the other hand is affected by conditions both in the lower atmosphere and, at the lower end of the band, in the ionosphere. Nevertheless, the requirements of traffic sent via any of these propagation modes is described in the same terms, namely, the quality and availability of the communication channel. The global reference circuit is used to allocate unavailability among the component links which make it up and the equipment standards give performance parameters which are to be used to meet the availability requirements. The subsystem standards should direct the selection of appropriate equipment to provide communication service of the desired quality in the most economical way.

2.2.1.1 Basic Transmission Loss

One of the most important concepts developed which permits an engineering estimate of radio link performance to be made is that of basic transmission loss. Basic transmission loss is defined as 10 times the logarithm to the base 10 of the ratio of the power fed directly to a loss-free isotropic antenna (located where the operating antenna will be placed) to the power received at the terminals of a loss-free isotropic antenna at the distant terminal (again located at the position of the operating antenna). Thus, basic transmission loss, L_b can be expressed as

$$L_b = 10 \log \frac{P_t}{P_r} .$$

The value of this concept is that it allows the radio path loss to be calculated without reference to such variable factors as antenna gain, transmission line loss, or absolute power levels involved. In fact, this concept is applicable to any frequency range or mode of transmission.

The signal received over any radio path will vary in time and usually over a very wide range. The prediction techniques which permit estimates of the time distribution of transmission loss (and hence received signal level) are quite different for each of the three modes of transmission discussed, and this leads naturally to having a separate standard for each propagation mode. We recommend that the digital subsystem standard establish the propagation models to be employed in designing radio links, and establish the format in which the results of the calculations are to be presented and used to determine the necessary equipment operating parameters (such as transmitter power, receiver sensitivity, and antenna size).

2.2.1.2 Path Clearance Criteria

One of the most important ideas with regard to the operating parameters of a tropospheric communication circuit (that is, line-of-sight or troposcatter) is the necessity of determining what mode of propagation any particular radio link will operate in. This is primarily a function of the radio path terrain clearance which is in turn influenced by local climatic conditions. The reason for the importance attached to this decision is that a normally line-of-sight link which operates in a diffraction or troposcatter mode for any perceptible fraction of the time will not be able to meet the availability requirements derived from the global reference circuit. Recall that this derived unavailability for a microwave path is about 2.6 minutes per year so that the fraction of time per year that a path is obstructed must be considerably shorter than this for a radio link to be considered line of sight. Recent work on the amount of clearance required has provided values based on measured data (CCIR 1978, Report 338-3, p. 186). We recommend that the value given in this reference, namely 0.6 Fresnel zone clearance at a k-value of 0.7, should be included in the line-of-sight subsystem standard as a limiting value to determine whether a link is line or sight or not.

2.2.2 Radio Site Infrastructure and Support Facilities

2.2.2.1 Radio Site Infrastructure

As important as radio propagation effects are in providing communication channels of the desired quality and availability, it is acknowledged (Kirk and Osterholz, 1976) that on a typical segment of the DCS, equipment failure contributes about four times more unavailability than does propagation outage. As the authors stated in their report on subtask one of this project, the analysis in 12-76 is incomplete and ignores many of the failure modes which result in interruptions of radio traffic. In view of this, the subsystem standard should address the various site support functions such as building integrity, environmental controls, power generation and distribution techniques, tower, waveguide and antenna installation, and intrasite signal cabling. To the best of the authors' knowledge, none of the subjects mentioned are discussed in sufficient detail in any of the referenced documents in the draft standards. It would seem that the place for such references would be in the standards which define and describe link and site installation. If no military standards exist covering these subjects, then commercial architectural and electrical standards should be used. We recommend that the common tactical/long-haul digital subsystem standards be changed to include by reference recognized standards for site infrastructure elements as discussed above.

2.2.2.2 Site Support Facilities

Referring again to Kirk and Osterholz (1976), those authors state the three most important factors which affect equipment related unavailability in their order of importance:

1. The degree of equipment redundancy in the system,
2. The logistics approach used to restore failed equipment, and
3. The efficiency of performance monitoring techniques in detecting failures and switching to standby equipment, and in detecting failures in the standby equipment.

The first factor is concerned more with radio link design and equipment but in view of its importance, we recommend that no tropospheric radio link (that is, one which operates in the line of sight, diffraction, or tropospheric scatter modes) which does not employ a diversity scheme be considered as supporting the global digital reference circuit.

The logistic approach used to restore failed equipment has many facets which should be addressed in the standard. The standard should require a minimum set of test instrumentation for locating faulty modules to be used on manned and unmanned sites and include schemes for repairing and calibrating these instruments. The standard should require a minimum level of spare inventory for manned and unmanned sites. Mention should be made in the standard of the test equipment and spares to be available to the mobile maintenance team. The items mentioned are a part of a general maintenance philosophy which should be outlined in the standard. The other aspect of the maintenance philosophy is the direction given for the less tangible aspects such as records and operation logs and the requirements for intersite rapport and coordination. Site logs are important since the information they contain should give an accurate picture of how well the radio links terminating at a site are performing compared to the standards and to the design specifications. Also, slow degradation of link performance would be apparent if a good site log is kept. This is a proper subject for the standard since, as was discovered on the FKV system in Germany, a site log can easily degenerate into no more than a visitor sign-in sheet (Skerjanec and Farrow, 1977, private communication, FKV Pilot Digital System Evaluation Vol. 1, p. 6, NTIA Tech. Memo). To summarize, we recommend that a basic maintenance standard be established and included in the digital subsystem standards either in total or by reference to a stand-alone maintenance standard.

As more and more sites are unmanned, the need for an advanced Transmission Status Monitoring and Control (TSMC) function becomes more pressing. Although the two initial DCS long-haul digital segments (FKV and DEB Phase I) were installed with a fairly rudimentary TSMC, it soon became obvious that more thought and engineering would be necessary if such a TSMC were to be at all useful (Skerjanec and Farrow, 1977, private communication, Vol II, pp. 40 and 41). In view of this, we recommend that the digital subsystem standards contain a carefully chosen set of functional requirements for a TSMC. Consideration should be given to standardizing the monitoring module interface parameters, both electrical and mechanical as well as communication line rates, line format, and data communication protocols. While such a standard would stifle initiative to some extent, the market for TSMC equipment is both broad enough and mature enough that an adequate system can be specified which would serve well into the future. In addition, such a standard would permit the interconnection of the TSMC equipment between and among subsystems installed at different times and by different contractors using TSMC hardware provided by a number of different vendors.

The provision of TSMC remote units (that is, units which interface with the alarm and control points within the communication equipment) will make data about equipment operation at many remote sites available to TSMC master units located at key nodes in the various DCS segments. The way that these data are manipulated at these master nodes has not been fully thought out but various studies are continuing [the ATEC project and the EFAS (Enhanced Fault Alarm System) used on Digital European Backbone Phase I]. While it may be too early to establish standards for the way in which the TSMC data will be processed, presented to the operator, and stored for further analysis, it should be possible to establish a set of design objectives which could provide interim guidance for subsystem design and procurement of this essential element. We recommend that a study be made of ATEC and EFAS field experience with a view toward establishing design objectives for the master node data processing hardware and software.

2.3 A Critique of the Tropospheric Radio Circuit Subsystem Standards

The current draft of MIL-STD-188-144 dated January 4, 1980, and the current draft of MIL-STD-188-145 dated April 25, 1977, were reviewed on the basis of the analysis and recommendations of the foregoing sections of this report and those in the reports on subtasks 1 and 3. The remarks in the following sections will be specific comments directed at particular features of the current draft standards.

2.3.1 Critique of MIL-STD-188-144 (Tropospheric Scatter)

A commendable tendency toward brevity is shown in MIL-STD-188-144. This increases the utility of a standard by making the application of its provisions easier to check. However, the standard still contains too much tutorial material on the global circuit quality and availability derivation. As we stated previously in this report, tutorial material extracted from global circuit standards should not appear in MIL-STD-188-144. We recommend that with reference to paragraph 1.5, only paragraph 1.5 itself and sub-paragraphs 1.5.6, 1.5.7.1, 1.5.7.8, and the last five sentences of 1.5.8 be retained. This would provide sufficient explanation of the concept and would give some numerical values for threshold BER and data channel efficiency. Since section one is primarily introduction and background, it should be kept short and to the point.

Section 2 contains a list of referenced documents which "form a part of this standard to the extent specified herein:". Two of the references MIL-STD-188-340 and MIL-STD-188-311 are standards for FDM/FM equipment which should be removed from a digital standard as inapplicable. Two others, MIL-STD-461 and MIL-STD-462, refer to equipment functional aspects and should appear in the equipment standards only. One, MIL-STD-962, seems to have little relevance to the subject of subsystem standards. We recommend that these five reference documents be deleted from the digital troposcatter subsystem design standard. In the list of other publications, note that the Office of Telecommunications has now become the National Telecommunications and Information Administration.

In Section 4, titled General Requirements, all reference to FDM/FM subsystems should be deleted. Any interfacing between FDM/FM subsystems and those using TDM/DM (Time Division Multiplex/Digital Modulation) will be made at voice frequency and the parameters of this interface are well covered in MIL-STD-188-100.

In line with the previous suggestion, paragraph 4.1 should be changed to refer to performance standards for TDM/DM tropospheric scatter or diffraction radio links. The discussion should be based on the concept of the global reference circuit as developed in detail by Kirk and Osterholz (1976) and revised in the section on subtask one in this series. One of the most important items to be included in this paragraph is an explicit statement of the availability that the radio link must provide (as is now indicated in paragraphs 4.2.2 and 4.2.3) and an explicit statement as to the causes of outage to be covered by the standard. As 4.2.2 and 4.2.3 now read, there is no indication as to how the long-term propagation unavailability is to be allocated on a per-unit-distance basis nor how the equipment unavailability will be allocated among the line-of-sight and troposcatter links which make up a segment. We recommend that the allocation of radio link unavailability due to all causes be decided upon and made a clearly-worded, explicit part of the standard.

The next subject in the draft standard is propagation analysis and performance calculation. It would be well to separate these two issues in the standard. This will allow the basic transmission loss concept discussed earlier to be introduced for the propagation analysis. It would be well for the standard to specify the form in which the propagation analysis is to be presented and used for performance calculations. The format which is most easily obtained from MIL HDBK 417 is a distribution of expected transmission loss for all hours of the year for service probabilities of 0.5 and 0.95. A convenient format for graphical presentation of such a distribution is on normal probability graph paper with end points at 0.0001 and 0.9999 and a linear ordinate scale. As link design progresses, transmission loss in dB can be plotted as an ordinate on one side of the page and received signal level in dBm on the other. A graph such as this is extremely useful in testing a transhorizon radio link since values of measured received signal level can be compared with predicted values. Such a presentation is shown in MIL HDBK 417, Figure 4.4-38, page 4-187. The standard now properly specifies the fraction of time and service probability values to be considered as well as the standard deviation and climatic factor to be used in calculating the prediction uncertainty.

The path intermodulation distortion calculation applies only to FDM/FM systems so it should be dropped from the digital subsystem standard. The antenna multipath coupling loss and diversity paragraphs apply more to determining the overall transfer characteristic of the system than the propagation area alone. These items should be placed under Section 4.2 which specifies subsystem availability and its calculation.

The summation rules for summing multiple link characteristics in tandem as defined in MIL-STD-188-100 are inapplicable to TDM/DM transmission techniques. The methods given in Kirk and Osterholz (1976) should be referred to for this calculation. Note that the propagation analysis for FDM/FM or TDM/DM transmission systems will be identical; only the performance analysis will change.

To summarize, we recommend that all reference to FDM/FM transmission be deleted from this subsystem standard, but that the current reference to MIL HDBK 417 as updated by CCIR report 238 be retained. We further recommend that a format for presenting the results of a propagation analysis be developed (such as MIL HDBK 417, Figure 4.4-38) and required from the system engineer. We also recommend that a technique for analyzing the performance of a digital system (as is outlined in Kirk and Osterholz, 1976) be formalized and included in the subsystem standard by reference.

Section 4.2 should be deleted in its entirety and replaced as was suggested above with a simple statement of the link requirements and a reference to a method of calcualting performance. Since the short-term within-the-hour signal-to-noise ratio will be the dominant factor in determining link performance, this section must either contain or reference a technique (the digital equivalent of Brennan's work on diversity combining for FDM/FM systems) of using the digital troposcatter equipment standards to select radio equipment which will permit the installation of a radio link to meet the stated availability and channel quality requirements.

In addition, the material in Sections 5.2.1 and 5.2.2 of the standard should be relocated to Section 4.2. This section would also be the appropriate place for the antenna multipath coupling loss and diversity discussion.

Section 4.3 should be expanded to include all of the site infrastructure standards or references as discussed in Section 2.2.1 of this report. Section 5.1.1 of the standard contains a number of subsections which are concerned primarily or solely with equipment standards and should be either deleted or condensed into a single paragraph or table. Section 5.1.2 contains important material on system timing which should be retained and even expanded. Section 5.1.3 contains descriptions of various configurations which should be retained but may need to be edited somewhat to remove equipment standards. Section 5.2.1 and 5.2.2 should be relocated to Section 4.2 and should be rewritten to describe exactly what is covered in the subsystem availability specification. Sections 5.2.3 through 5.2.6 are equipment specifications and should be removed from this subsystem standard.

One subject which is covered in MIL-STD-188-145 but not in MIL-STD-188-144 is some reference to frequency coordination and spectrum use. As a minimum, the standard should direct the user to the military agency which arranges for frequency assignments.

2.3.2 Critique of MIL-STD-188-145

The document which we have available for review is a marked-up copy of a draft dated April 25, 1977. The draft has numerous notes in the margin some of which indicate that material is to be deleted. This may make some of the comments made in this section unnecessary but in general, the marginal notes will be ignored.

First, we recommend that all equipment standards be removed from MIL-STD-188-145 and be included only by reference. Secondly, we recommend, in consonance with our recommendations in the section on subtask 1, that only digital microwave radio links be considered as supporting the global digital reference circuit, and that all reference to FDM/FM transmission be eliminated from MIL-STD-188-145.

In particular, Section 4 of the standard should be rewritten to contain the description of the global reference circuit and the microwave link availability derived from the requirements placed on the global reference circuit. This is also the place where the total availability of a microwave link should be stated and where the listing of causes of unavailability should be given. Section 4 should also contain the description of radio propagation analysis which is to be done and the form in which the results of the analysis is to be presented. In this regard, we recommend that the methods given in MIL HDBK 416 for line-of-sight radio link analysis be updated by the material in NTIA-Report-79-18 (Hause and Wortendyke, 1979) and that the propagation analysis be presented in the form shown in Figures 4-3 and 5-3 of the report for basic transmission loss and received signal level, respectively. The path-loss data should be tabulated as shown in Table 4-1, and the link equipment gain parameters should be summarized as shown in Table 5-1 of the same report. The report itself describes the propagation models which were programmed for a desk-top computer. The link analysis and design model is the only one available which combines the latest information about multipath and rain attenuation in a concise, manageable form. If the line-of-sight radio link design technique described in NTIA-Report-79-18 is used, it permits the propagation analysis and radio link equipment selection to be done by a design engineer using a desk-top calculator in an interactive mode. The radio link analysis has since been updated to include consideration of digital transmission techniques. Section 4 of the standard should also contain the specific technique by which it is determined whether or not a radio path is line of sight in terms of terrain clearance. We recommend a value of 0.6 Fresnel zone clearance at a k-value of 0.7 in Section 2.1.2 of this report.

Section 5 of MIL-STD-188-145 contains a great deal of repetitious material on FDM/FM transmission and equipment standards which, as was mentioned previously, should be deleted.

Nowhere in the standard is there a mention of the site infrastructure elements nor of necessary support facilities. These critical elements of a system are discussed in Section 2.2 of this report and again, it is strongly recommended that recognized electrical, architectural, and civil engineering standards be included in the subsystem standard by reference at least. The same strong recommendation concerning standards for site support facilities as was made in Section 2.2.2 of this report is reiterated here and the comments in that section concerning a TSMC system apply to line-of-sight as well as beyond-the-horizon subsystem standards.

The summation rules for analyzing the performance of radio links in tandem given in MIL-STD-188-100 are inapplicable to TDM/DM transmission techniques. The methods given in DCEC TR-12-76 should be referred to for this calculation.

The subject of subsystem synchronization is not treated in the current draft of MIL-STD-188-145. We suggest that a section be devoted to this subject even though many of the operating parameters may have to be determined and standardized later.

The material regarding transmitter frequency coordination and transmitter receiver frequency separation is useful and appropriate, as is the very brief paragraph on radio regulations. We recommend that this information (updated if necessary) be retained as an appendix to the standard.

3. DIGITAL LOS MICROWAVE RADIO EQUIPMENT STANDARDS UPGRADE RECOMMENDATIONS

3.1 Introduction to Equipment Standards

ITS has performed a study to determine what improvements can be made to the equipment technical design portion of MIL-STD-188-322, November 1, 1976. This study included the following tasks:

1. Review appropriate documents and current studies which will lead to improvements in the standard.
2. Attempt to determine whether all aspects of the equipment are adequately covered.
3. Determine whether design parameters and techniques are realistic and whether they might be improved in terms of the performance-cost tradeoff. Keep in mind the DoD commitment to procure under DRAMA and TRI-TAC specifications.
4. Look for possible techniques in the standard which could be subsequently used in upgrading DCS equipment by field modification.
5. Answer the following questions:
   a. Are interfaces specified and described so as to minimize problems when the equipment is used with other equipment?
   b. Do any parts of the standard discourage innovation?
   c. Are values specified in the standard directly measurable?
   d. Are design objectives provided and stated as such?
   e. Can design objective performance be improved?
   f. Should additional design objectives be added?
   g. Is there a good probability that the design objectives could become standards in the next 5 years?

This report includes recommendations and answers to the various questions and provides rationale on which the recommendations and answers are based.

3.2 Review Appropriate Documents

In pursuing this part of subtask 3, MIL-STD-188-322, November 1, 1976, was reviewed in detail. In addition, the DRAMA radio specifications and TRI-TAC microwave and tropo-scatter radio specifications were studied. Specifications for commercial and other military digital radios such as the DCS Standard Radio (FRC-162) were considered. In our effort to answer questions raised in these researches, current

CCIR documents were reviewed and other military and nonmilitary standards were consulted. Primary references germane to the completion of subtask 3 are included in the bibliography.

3.3 Aspects of Equipment Covered

Many aspects of equipment operation in the November 1, 1976 issue of MIL-STD-188-322 are noted "to be supplied later". These, of course, must be decided before it could be a complete standard.

One important omission is the antenna system performance standards. Failures of the antenna, antenna mounts, or transmission lines have been observed to contribute a major portion of system unavailability. Such outages have been observed on the Scope Com system in Germany, the ETA system in Germany, the Phil-Tai-Oki system in Taiwan and most recently, on the DEB Phase I in Italy. Many of these failures do not result from "infant mortality" syndromes but affect antenna systems which have been installed for years. Sufficient engineering consideration has not been given within the applicable standards for this critical area in terms of dynamic wind and ice loading of both antennas and transmission lines, ice-fall from towers onto antenna system components, and protection for horizontal transmission line runs.

One weakness observed in many installations is that the quality of the antenna mounting hardware is so poor as to compromise the installation. For instance, the use of galvanized instead of stainless steel bolts and threaded adjustment hardware makes it almost impossible for the installer to do quality work. Furthermore, the antenna and transmission line system is the one place where no redundancy is currently required by the standard. In view of the problems with antennas that have been pointed out, it would seem reasonable to connect one transmitter to each of the diversity antennas and have the standby transmitter switched into a termination. This would not only provide redundancy in a critical area but would also permit much more rapid and complete fault isolation of the radio equipment and radio link.

Another deficiency in the current standard is the failure to provide a mechanical specification for the rf, digital, monitor and control, and prime power interfaces. The standard should require the use of specific waveguide and coaxial fitting types for the rf interface for each frequency band, specific coaxial or triaxial fitting types for the digital mission bit stream, service channel bit stream, and clock signal digital interfaces, and specific military standard multipin connectors for monitor/control and power interfaces. This is the only way to provide easy interconnection between equipments and to provide standard interfaces for test equipment. This is a very important consideration with regard to equipping the sites and the mobile teams to perform normal maintenance.

Another serious fault in the current standard is the lack of specification of test and maintenance access points. Examples of such access points are receiver signal input test ports and decoupled transmitter output test ports. When an on-site or mobile maintenance team is attempting to correct an equipment fault, their most critical need is to isolate the problem to as small an area of the equipment as possible. Since it is often difficult to isolate a problem to one end or the other of a radio link, a very important series of tests to perform initially are loop-back tests at rf, at IF (if transmit and receive IF's are used), and at mission digital baseband. Since dual diversity is used at all levels above the first level multiplex, provision should be made to separate completely one side of the diversity system and connect it back-to-back (using the necessary pads, amplifiers, and translation oscillators) to facilitate fault isolation through the high-level multiplex transmitter, the radio transmitter, the radio receiver, and through the high-level multiplex receiver.

3.4 Improved Design Parameters

The major categories of design parameters in MIL-STD-188-322, with a number of suggested additional categories are shown in Table 1. At the right of each parameter are columns which discuss the realism, cost performance tradeoff, evaluation, present value, and recommended value of the various parameters. A numerical value has been assigned to the cost and performance columns of the table to indicate the relative importance of the parameter and the relative cost of meeting the standard. The scale ranges from 1 to 10 with lower numbers indicating the more desirable or more important condition. For instance, a performance weight of 10 would indicate that the value of the particular parameter would have little influence on the performance of the radio system. Similarly, a cost weight of 1 would indicate that the value required of the parameter could have a major cost impact on the radio system. A realism score of 1 indicates a realistic and realizable value and a score of 10 indicates that the parameter value is over-specified or should not be specified.

The following paragraphs further discuss some of the remarks in the Comments column of some parameters in Table 1. The parameters will be dealt with in the same order as they appear in the table.

Table 1. LOS Microwave Radio Equipment Parameter/Attribute Evaluation

Parameters & Attributes	Is Parameter Realistic	Cost Performance Trade-off: Performance Weight	Cost Performance Trade-off: Cost Weight	How is Parameter Evaluated? Calculated Measured Estimated	Value Provided in MIL-STD-188-322	Recommended Parameter Value	Can Parameter Be Measured with Link in Service?	Comments
MIL-STD-188-322 Parameters								
Transmitter								
Output Power	1	3	3	Meas.	1 & 10W	Same	No	Standard should be pwr. meas. at ant.
RF Interface Return Loss	1	7	7	Meas.	26dB	Same	No	Leave alone.
RF Trans. Line Ret. Loss	1	7	10	Meas.	14dB	20dB	No	Std. commercial practice.
Emission Limitations	1	8	5	Meas.	NTIA std.	Same	Yes	Leave alone.
Randomized Signal		6	10	Meas.	Spec. comp. -30dBc		Yes	Requires further study
Clock Recovery from MBS Alternative	3	1	3	Obsv.	Para. 5.1	N/A	No	Leave alone.
Receiver								
Noise Figure	1	1	5	Meas.	10,14dB	Same	No	Leave alone.
Dynamic Range	1	2	9	Meas.	50dB	Same	No	Reword standard.
Adjacent Channel Interference Sensitivity	3	4	5	Meas.	*TBD			Study CCIR Report 779.
Co-Channel Interference Sensitivity	3	3	7	Meas.	20,25dB	Same	No	Change design obj. to std.; see CCIR Report 779.
Carrier and Clock Recovery	10	1	3	Obsv.	*TBD			Not needed. Std. might stifle initiative.
Return Loss In	1	7	7	Meas.	26dB	26dB	No	Std. Commcl. Prac.
Return Loss Out	1	7	10	Meas.	14dB	20dB	No	Std. Commcl. Prac.
Regeneration	2	2	2	Meas.	10% jitter	Same	No	Leave alone.
BER Threshold	1	1	3	Meas.	TBD	Modulation dependent	No	Provide a minimum std.

*TBD means To Be Determined

Table 1. (cont.) LOS Microwave Radio Equipment Parameter/Attribute Evaluation

Parameters & Attributes	Is Parameter Realistic	Cost Performance Trade-off: Performance Weight	Cost Performance Trade-off: Cost Weight	How is Parameter Evaluated? Calculated Measured Estimated	Value Provided in MIL-STD-188-322	Recommended Parameter Value	Can Parameter Be Measured with Link in Service?	Comments
Miscellaneous								
Transmitter & Receiver Frequency Accuracy	1	4	6	Meas.	5 ppm	Same	No	Exceeds NTIA std.
Transmitter & Receiver Frequency Stability	1	4	6	Meas.	5 ppm	Same	Yes	Should be specified more completely.
Data Sampling in Receiver	10	1	5	meas.	On + to - of clock. ± 25% nom. data intvl.			Not needed in std.
Sensitivity to Timing Jitter	1	1	3	Meas.	12.5% abs. 25% rel.	Same	No	May need slew rate standard.
Modulation	10	5	9	Obsv.	No Technique required	No recommend.	--	Not needed in std.
System Gain	10	2	9	Meas.	95dB		No	Not needed.
Terminal Configurations	2	2	7	Obsv.				Move to Xmit Sec.
Transmitter Redundancy and Switching	2	2	2	Obsv.	N/A	N/A	--	Leave alone.
Transmitter Line Build-out	6	4	10	Obsv.	350 ns	Same	Yes	Leave alone.
Receiver Diversity Operation and Switching	1	2	7	Obsv.				Move to Rcvr Sec.
Receiver Line Build-out	2	4	10	Meas.	350 ns	Same	No	Leave alone.
Status Indicators and Alarms	3	2	4	Obsv.	Para. 5.11.1	Same	--	Leave alone.
Performance Monitors	2	2	5	Obsv.	Para. 5.11.2	Same	--	Leave alone.
Input Power (Primary Power)	1	4	10	Obsv.	Para. 5.13	Same	--	Leave alone.

Table 1. (cont.) LOS Microwave Radio Equipment Parameter/Attribute Evaluation

Parameter & Attributes	Is Parameter Realistic	Cost Performance Trade-off		How is Parameter Evaluated? Calculated Measured Estimated	Value Provided in MIL-STD-188-322	Recommended Parameter Value	Can Parameter Be Measured with Link in Service?	Comments
		Performance Weight	Cost Weight					
Reliability								
EMI	---	4	1					MIL STD 461 462 463
Human Engineering	---							MIL STD 472
Environmental Test Methods	---							MIL STD 210
Climatic Extremes	---	5	1					MIL STD 210
Quantitative Reliability	---							MIL STD 781 785
Radio Reliability and Definition of Failure	1	1	5	Calc.	Para. 5.12.5.2	Same	--	Define radio set to incl. ant. & feeder.
Maintainability	---	2	1					MIL STD 470 471
Interface, Digital								
Mission Bit Stream (2)	1	2	6	Meas.	MIL STD 188-114 ref.	Same	No	Need connector std.
Service Channel Bit Stream	1	8	10	Meas.	No value provided	Same as MBS	Yes	Need performance std. Need connector std.
Clock In	1	3	2	Meas.	MIL-STD-188-114	Same	No	Need connector std.
Clock Out	1	2	6	Meas.	MIL STD 188-114 ref.	Same	No	Need connector std.
I/O Signal Characteristics	1	2	5	---	---	---	No	MIL STD 188 114
Balanced to Unbalanced Conversion	6	8	8					MIL-STD-188-114
Data-Timing and Phasing	1	2	8	Meas.	+10%	Same	Yes	Leave alone.
Data Rates	1	1	2	Obsv.	Table III	No recommend.	---	Requires further study
Alarm and Control Interfaces	3	2	9	Obsv.	MIL STD 188-114	Same	No	Need connector std.
Service Channel	1	4	9	Meas.	MIL-STD 188-114	Same	No	Need connector std.

Table 1. (cont.) LOS Microwave Radio Equipment Parameter/Attribute Evaluation

Parameter & Attributes	Is Parameter Realistic	Cost Performance Trade-off: Performance Weight	Cost Performance Trade-off: Cost Weight	How is Parameter Evaluated? Calculated Measured Estimated	Value Provided in MIL-STD-188-322	Recommended Parameter Value	Can Parameter Be Measured with Link in Service?	Comments
Additional Categories								
Receiver Bandwidth	1	4	8	Meas.		NTIA STD	No	
Receiver Spurious Emission	1	5	8	Meas.		Same	No	Need connector std.
Use of Equalizer (Static or Dynamic)	---	6	4			To be det.	--	Needs further study
Interface Mechanical Std	---	2	9	Obsv.		Att. para.	--	
Antenna System (Installation and Protection)	---	1	1	Obsv.		See att. para.	--	
Transmission Line (Installation and Protection)	---	1	1	Obsv.		See att. para.	--	
Loop-back and Fault Isolation Test Points	---	2	9	Obsv.		See att. para.	--	

3.4.1 Output Power

The levels of output power specified are consistent both with limits for radiated power and with the capability of available equipment. The minimum power specified is acceptable. The maximum power specified should be referred to the antenna port or expressed in terms of effective radiated power (NTIA, 1979, Section 5.10.4). This will allow transmitter powers higher than 10 watts to be used to overcome the effects of transmission line loss.

3.4.2 Randomized Transmitter Bit Stream

This characteristic of the radio transmitter requires further study. There are two reasons to provide for increasing the randomness of a transmitted signal. One is to provide sufficient data transitions so that a clock signal can be recovered and the other is to prevent the occurrence of high-level spectral components in the radiated microwave signal. It is anticipated that bulk encryption of the digital baseband would provide sufficient randomization for both purposes, but clear transmission might require further randomizing. The usual technique used is a self-synchronizing scrambler at the transmitter and its complementary descrambler at the receiver. The length of the shift registers used influences both the degree of suppression of spectral components and the extent of multiplication of bit errors in the data stream. Balancing the desirability versus cost of these two randomizing results should be used to guide the development of the standard. We offer no recommendation on this subject although CCIR Report 384-3 indicates a method for calculating the intensity of spectral components.

3.4.3 Receiver Dynamic Range

The value of dynamic range in the standard is reasonable, but it should be described as the difference in dB between the receiver input signal level at the threshold of minimum acceptable performance (a bit-error rate of 10^{-6} would agree with DCA's TR-12-76) and the receiver input saturation level at which the bit-error rate begins to increase again. We recommend this definition for receiver dynamic range be adopted for standards purposes.

3.4.4 Adjacent Channel Interference Sensitivity

The value of this parameter in the standard is "to be determined". We recommend that CCIR Report 779 (1978) be studied to arrive at a reasonable value of this parameter.

3.4.5 Carrier and Clock Recovery

This characteristic of the radio receiver is "to be determined" in the current standard. Although the techniques for clock and carrier recovery are very important in receiver operation, we recommend that this particular characteristic not be standardized. To do so would stifle initiative and needlessly limit military radio system performance.

3.4.6 Bit-Error-Rate Threshold

The bit-error-rate (BER) threshold of a microwave radio is a fundamental parameter. The standard should define the BER threshold and should require, by means of some mathematical function which includes the data rate and the spectrum efficiency, a value of received signal level (RSL) at which the BER threshold is to occur. An example of such a function can be found in the DRAMA radio specification, CCC-74049 USACEEIA (1976). We recommend that the BER threshold be defined as the steady RSL at which the BER is 10^{-6} to agree with Kirk and Osterholz (1976).

3.4.7 Transmitter and Receiver Frequency Stability

The stability of the master oscillators which control the transmitter output frequency and the local oscillator frequency are currently required to be "better than 0.0005%". The standard should discuss short-term and long-term stability separately since different effects tend to dominate different time frames. For instance, short-term instabilities are usually noise-like with zero average value but fairly wide rapid excursions while the long-term effect is a slow, steady drift or permanent change in frequency. We recommend that the standard be written to acknowledge both of these types of instability.

3.4.8 Data Sampling in Receiver

The description of how the data stream is sampled in a microwave receiver and the statement of the accuracy of the sampling are not needed in the standard. To include this material may stifle initiative and needlessly restrict the performance of military radios.

3.4.9 Modulation

The specification of a particular modulation scheme for digital radios is ill advised. Further development of various modulation techniques could result in improved performance. It would not seem necessary to deny the benefits of future developments to military system users.

3.4.10 System Gain

The value of system gain which is calculated for any particular radio is a function of transmitter power and receiver BER threshold. Since transmitter power is dictated by radio regulations and the receiver BER threshold can be determined by the formula suggested under BER threshold, system gain is redundant. We recommend removal of system gain from the standard.

3.4.11 Radio Reliability and Definition of Failure

In view of the importance of the antennas and transmission lines to the operation of the radio link, it is suggested that any discussion of the radio set reliability include the antenna-feeder subsystem as an integral part of the radio set for reliability discussion purposes. To do this will have two beneficial results. The first will be to emphasize to system designers the importance of the antenna and feeder, and the second will be that an important contributor to radio link unavailability will be recognized so that a more realistic link availability value can be used. We recommend that the antenna and transmission line subsystem, including their support systems, be considered part of the radio set for purposes of defining and calculating radio link reliability.

3.4.12 Data Rates

The data rates shown in Table III of MIL-STD-188-322 do not include a rate equal to the output of the first level PCM multiplex unit. It is not unlikely that some 24 voice channel links will be required within the DCS. We suggest that further study be done on this issue.

3.4.13 Use of Static or Dynamic Equalizer

The suggestion that this subject be included in the standard is made with the expectation that such a device will not be required on every radio purchased. The use of an equalizer is justified only where very high data rates (over 50 Mb/s) are used or on links which are subject to especially severe multipath effects. The inclusion of this topic in the standard is intended to facilitate the purchase of such a unit if one is needed. We recommend that consideration be given to developing a standard for an rf equalizer.

3.4.14 Interface Mechanical Standards

The problem of interconnection among various equipments produced by various manufacturers and installed in many different configurations could be significantly eased if a small number of mechanical connector standards could be developed. Such a standard should specify:

a. One waveguide flange for each frequency band.
b. A coaxial rf transmission line fitting.
c. A coaxial rf and IF fitting for use inside the radio set.
d. An unbalanced data and clock fitting type for input, output, and internal interconnection.
e. A balanced data and clock fitting type for input, output, and internal interconnection.
f. A standard multipin connector for control input and for alarm, status, and monitor outputs with designated functions for all pins.

It is anticipated that these fittings could be selected from current JAN types which would make further detailed connector design and specification unnecessary. An example of a waveguide mechanical interface table is given in the DRAMA specification, CCC 74049, paragraph 3.5.4.1. We recommend that such a set of mechanical standards be adopted. These standards will tend to stifle innovation somewhat but at an acceptable price.

3.4.15 Antenna and Transmission Line Installation and Protection

As has been stated elsewhere in this report, the problems with transmission line and antenna installation which the authors have observed demand resolution. We have been unable to determine whether the observed problems arise because of inadequate standards or because the standards of installation are not met. If inadequate standards are the problem, we recommend development of standards and their inclusion in the microwave radio standard. If adequate standards exist, we recommend that they become part of the microwave radio standard.

3.4.16 Loop-Back and Fault Isolation Test Points

The operation of a radio system and the prompt restoral of service after a failure require that fault isolation be accomplished very rapidly (Kirk and Osterholz, 1976, pp. 25-6) so that repairs can be carried out. Many problems with modern systems are so complex that merely isolating the station which has a problem is difficult. If all of the equipment at a station could be looped back in-house, much more rapid fault isolation would be possible. We recommend that the standard require that radios be equipped with rf, IF (if possible) and mission bit stream loop-back and fault isolation test ports which can be rapidly accessed without removing the radio from an operational configuration (without opening the waveguide, for instance).

3.5 Field Modification Upgrades

Considerable thought has been given to this subject and a number of suggestions are offered. The possible improvements range from simple additions to equipment, through major changes in radio site organization, and into the organization of support functions. In all cases, the suggestions reflect either common practice in other areas of communication technology or improvements suggested by competent authorities.

3.5.1 Move RF Head Closer to Antenna

This suggestion would involve locating an optional low-noise amplifier, local oscillator multiplier chain (or parts of it), the mixer and an IF amplifier remote from the remainder of the radio and placing them directly at the antenna. This technique is commonly used in satellite earth stations where the rf system is located immediately behind a Cassagranian-fed parabolic reflector. The advantages of such an arrangement are that the receiver line loss is eliminated as are the effects of rf reflections due to poorly matched terminations. The advantage increases markedly as carrier frequency increases. A number of manufacturers produce sealed radio units for outdoor mounting so the technology for such a technique is available. Of course, consideration must be given to providing adequate access to the rf head in case of failure.

3.5.2 Move All Radio Equipment Closer to Antenna

The second suggestion is similar to the first one, but its realization would only be practical on sites where a steel tower is being replaced by a concrete one. It is suggested that, in the future, all such concrete towers be designed to accommodate the radio sets and at least the highest level multiplex inside the tower midway between the vertically spaced diversity antennas. Such an arrangement would eliminate almost all line loss and rf reflection problems and would allow reduced transmitter power to be used in many cases. This arrangement is commonly used by the European telephone administrations and by television broadcast organizations. The savings from doing this would include the cost of purchasing and installing long, expensive waveguide runs. Such a tower would provide better access to and protection for the antennas.

3.5.3 Transmit from Either Diversity Antenna

Another suggestion which would complement the previous two is to transmit from either diversity antenna (only one transmitter would be operating at any one time). The advantage of doing this would be to provide redundancy in the only part of the rf system which is not protected now. This could be done on new installations at very low cost and could be retrofitted at moderate cost since only the transmitter waveguide or coaxial plumbing would need to be changed.

3.5.4 Improve Antenna and Feeder Installation

As has been stated previously, the antenna and transmission line installations on many parts of the DCS have suffered numerous failures from faulty engineering, improper installation, and shoddy materials, as discussed in Section 3.3 of this report. As transmission line systems age, the initial problems whose effects may be only minor can and usually do cause more and more system degradation. A careful review of system test data and performance records would show which links would be most likely to benefit from an upgraded antenna system. The most obvious symptom of antenna system problems would be reduced median received signal level (RSL). Unusual variations in RSL could also be indicative of the same type of problem.

3.5.5 Install Equalizers on Bad Paths

Digital radio links which perform below expected levels of either quality or availability might benefit from the installation of equalizers in the receivers. Before this technique is attempted however, all other possible causes of poor performance such as antenna alignment, transmission line quality, and electronic equipment alignment, should be eliminated by very careful testing. The technique should not be used for mission bit streams less than 12 Mb/s. Furthermore, only radio links which are subject to serious and continuous multipath effects are candidates for this treatment.

3.5.6 Install Transmit and Receiver Test Ports

The preceding discussions have emphasized the necessity of collecting accurate data on various parameters of link operation. To assist in this data collection, transmitter and receiver test ports should be required on new equipment and should be installed on old equipment which lacks them. These installations need not be costly and would permit much more thorough testing than is possible without them. The test ports would allow a milliwatt-level sample of the transmitter signal to be extracted and would allow the injection of a calibrated level into the receiver. This would make it possible to analyze the transmitted signal, to inject a calibrating signal into the receiver, or, using suitable attenuators and translation oscillators, to connect the radio set back-to-back at the rf level for troubleshooting or testing.

3.6 Specific Questions From Statement of Work

The following sections answer the specific questions contained in the statement of work.

5a. Are interfaces specified and described so as to minimize problems when the equipment is used with other equipment?

No. The lack of a complete connector mechanical standard for each of the various interfaces is a serious omission, as has been noted earlier in this report.

5b. Do any parts of the standard discourage innovation?

Yes. However, a standard must freeze technology at some point, particularly in regard to such things as interface connector standards. Some of the standards tend to become too involved with details of function such as those which discuss the orderwire and maintenance coordination circuit voice-channel digitization technique and the specification of details of the receiver data-sampling process. These specifications of what process is to be used to arrive at a result do not belong in a technical standard. Table 3.1 notes in the Comments column which parameters or characteristics should not be standardized.

5c. Are values specified in the standard directly measurable?

Yes. Two different areas of the standard will prove difficult and time-consuming to establish compliance with. One is the radio frequency stability criterion required for the transmitter and receiver and the other is the bit-error rates required. In previous sections of this standard, we have suggested rewriting the frequency stability section and changing the bit-error rate at threshold.

5d. Are design objectives provided and stated as such?

Yes.

5e. Can design objective performance be improved?

No. Most areas where design objectives are stated are either within the state of the art or are construction features which should remain design objectives. See 5g.

5f. Should additional design objectives be added?

No. There are no areas of the standard where the state of the art is changing rapidly enough to require further design objectives to be added.

5g. Is there a good probability that the design objectives could become standards in the next 5 years?

Yes. All design objectives except those involving construction features can be changed to standards at present.

3.7 Conclusions and Recommendations for Equipment Standards

The November 1, 1976 issue of MIL-STD-188-322 was an excellent guide to the specification of radios during its early years, but technology has now made certain changes necessary.

Our primary recommendation under task 2 is that the organization be made more logical and so we have included a suggested outline for the standard as an appendix.

A number of recommendations resulted from our studies made under subtask 3. These recommendations are listed in Section 3 of the report.

Our efforts on task 4 involved determining what techniques could be part of the standard and also be used to upgrade DCS equipment operation by field modifications. These recommendations are covered in detail in Section 3.5.

Task 5 requested the answers to specific questions and Section 3.6 contains these answers and supporting rationale.

4. CONCLUSIONS

The particular conclusions and recommendations dealing with each section of the report are presented at the end of each section and will not be repeated here. Three major conclusions can be stated which apply to the entire subject of the common long-haul/tactical standards.

1. There is a serious need to develop a common long-haul/tactical digital reference circuit which can be described in the terms used in the DCEC TR-12-76 report.*
2. Any new digital standard should exclude consideration of FDM/FM transmission links as part of the common long-haul/tactical global reference circuit and the composition of the standards should reflect this policy.
3. The common long-haul/tactical digital transmission subsystem and equipment standards should be revised and augmented as described in Sections 2 and 3 of this report.

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*Note: The requirements stated in this document are based on engineering judgments which are intended to assure a specified circuit time availability and circuit quality. DCEC TR-12-76, page 19, indicates a need for user subjective evaluation and changes in the requirements. A possible approach to formulating quantitative user criteria is the application of Interim Federal Standard 1033. However, until such criteria are available, the DCEC TR-12-76 report should be used as the basis for the development of the global reference circuit and the long-haul/tactical standards.

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APPENDIX

This appendix consists of an outline for a combined tactical/long-haul standard for microwave radio sets. This outline is our attempt to organize MIL-STD-188-322 in a logical manner. We do not purport to have discovered the only possible organization for the standard but merely suggest it as more logical than the existing format. The outline is shallow, being only four categories deep, but we feel that it would be fairly easy to expand to include all of the material in the current issue of MIL-STD-188-322 and all of the suggested changes mentioned in this report.

Proposed Outline for MIL-STD-188-322

1. Scope
2. Referenced Documents
3. Terms and Definitions
4. General Requirements
    - 4.1 Spectrum Management Standards
    - 4.2 Functional Performance Standards
    - 4.3 Interface Standards
    - 4.4 Reliability Standards

4.1 Spectrum Management Standards

4.1.1 Transmitter

4.1.1.1 Bandwidth Occupancy

4.1.1.2 Out-of-band Levels

4.1.1.3 Frequency Stability

4.1.1.4 Randomized Bit Stream

4.1.1.5 Modulation Efficiency

4.1.2 Receiver

4.1.2.1 Receiver Bandwidth

4.1.2.2 Sensitivity to Spurious Signals

4.1.2.3 Selectivity

4.1.2.4 Local-Oscillator Frequency Stability

4.1.2.5 Receiver Noise Figure

4.1.3 Antenna

4.1.3.1 Gain

4.1.3.2 Pattern

4.1.3.3 Pointing and Stability

4.2 Functional Performance Standards

4.2.1 Transmitter

4.2.1.1 Characteristics

4.2.1.2 Redundant Equipment Operation

4.2.1.3 Multiplex

4.2.2 Receiver

4.2.2.1 Characteristics

4.2.2.2 Diversity Equipment Operation

4.2.2.3 Multiplex

4.2.2.4 Mission-Bit-Stream Performance

4.2.3 Clock

4.2.3.1 Precision

4.2.3.2 Stability, Long-Term

4.2.3.3 Phase Noise & Jitter

4.2.4 RF Transmission Line, Antenna & Tower

4.2.4.1 Antenna Mounting

4.2.4.2 Antenna Protection

4.2.4.3 Transmission Line Installation

4.2.4.4 Transmission Line Protection

4.2.4.5 Transmission Line Pressurization

4.2.4.6 Lightning Protection

4.2.4.7 Tower Grounding

4.2.5 Monitor, Alarm & Control Functions

4.2.5.1 Monitored Parameters

4.2.5.2 Alarm Conditions

4.2.5.3 Remote & Local Controls

4.2.6 Service Channels

4.2.6.1 Local Orderwire

4.2.6.2 Maintenance Coordination Circuit (MCC)

4.3 Interface Standards

- 4.3.1 Mission Baseband
  - 4.3.1.1 Input, Mechanical and Electrical
  - 4.3.1.2 Output, Mechanical and Electrical
  - 4.3.1.3 Cable Length
- 4.3.2 Service Channel Baseband
  - 4.3.2.1 Input, Mechanical and Electrical
  - 4.3.2.2 Output, Mechanical and Electrical
  - 4.3.2.3 Cable Length
- 4.3.3 Clock Signals
  - 4.3.3.1 Input, Mechanical and Electrical
  - 4.3.3.2 Output, Mechanical and Electrical
  - 4.3.3.3 Cable Length
- 4.3.4 Radio Frequency Interface
  - 4.3.4.1 Receiver Input
  - 4.3.4.2 Transmitter Output
  - 4.3.4.3 RF Branching Filters
  - 4.3.4.4 Transmission Line and Antenna Ports
- 4.3.5 Power Interface
  - 4.3.5.1 DC Power
    - 4.3.5.1.1 Reverse Polarity Protection
    - 4.3.5.1.2 Surge Protection
- 4.3.6 Monitor, Alarm & Control Interface
  - 4.3.6.1 Mechanical Interface Parameters
  - 4.3.6.2 Electrical Interface Parameters

4.4 Equipment Reliability Standards

4.4.1 Transmitter

4.4.2 Receiver

4.4.3 Clock

4.4.4 Antenna System

4.4.5 Monitor, Alarm, and Control Circuits

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14. SUPPLEMENTARY NOTES

15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report is the sum of a three-part effort by the Institute for Telecommunication Sciences (ITS) to provide technical recommendations for the DCS Long-Haul Tactical Common system, subsystem, and equipment technical standards for digital radio. The work was sponsored by the Defense Communications Engineering Center, Reston, VA.

Primary recommendations for the system standards include suggested reference circuit and channel distances within a common overseas DCS terrestrial segment; the suggestion that only digital subsystems be included in the global reference circuit; and the statement that only parameters directly measurable in digital systems

(CONTINUED)

16. Key Words *(Alphabetical order, separated by semicolons)*

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(such as bit-error-rate) be used in defining performance. The main recommendations for subsystems standards include a recommended scope for subsystem standards; suggestions for specific content in which appropriate standards and subsystem parameters are identified; and exclusion of all reference to FDM/FM parameters from new drafts. Some important guidelines for the equipment standards include an outline for the equipment standards; recommendations on the realism and practicality of design parameters; and recommendations on possible techniques to be included in the standard for upgrading existing facilities.

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