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A MULTIPLE-ACCESS SATELLITE RELAY SYSTEM FOR LOW DATA RATE USERS

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SUMMARY

Recent Studies in the area of Tracking Data Relay Satellite (TDRS) system design have indicated that a number of basic TDRS support services can be implemented most effectively in terms of fixed-gain to fixed-gain RF links at VHF or low UHF frequencies. The candidate support services are all characterized by low data rates and include emergency voice, command and telemetry, and range and range-rate tracking. They do not include high data rate transmissions such as television or earth resources type data, which would be implemented more efficiently in fixed-aperture to fixed-aperture links at S-band or higher frequencies.

This paper presents preliminary design concepts for a typical broad-beam TDRS implementation using synchronous relays to support multiple manned and automated low-orbiting spacecraft in the conventional VHF bands. Spread-spectrum signalling techniques are employed to provide common-channel multiple-access and to combat multipath and RFI from earth-based sources. System performance is presented in parametric form in terms of system loading and the relative severity of multipath and RFI signals.

Antenna and transponder requirements for both synchronous relay and user spacecraft are discussed along with possible alternative implementations. Problem areas identified include compatibility with existing frequency allocations and usage, antenna design for small unstabilized user spacecraft, synchronization, and relay-to-relay handover procedures.

INTRODUCTION

Existing space research and applications satellites require support from an extensive network of ground tracking and telemetry gathering stations. There are currently over one hundred such ground stations operated by the United States alone. Many of these stations, however, have specialized capabilities which constrain their use to particular tracking and telemetry data transmission schemes. Thus the tracking and telemetry coverage afforded an earth orbiting spacecraft is obtained by means of a series of relatively short observations and despite the large number of ground stations many tracking and communications gaps exist. This has led to the requirement for orbit computations based on sequential tracking by multiple ground stations, the "dumping" of on-board recorded data at opportune times, and in the manned spacecraft case, the augmenting of fixed-site ground stations with RF equipped ships and airplanes.

While the possibility of using synchronous Tracking Data Relay Satellites (TDRS) to supplement and perhaps replace ground based facilities was pointed out as early as 1963 by F.O. Vonbun of the Goddard Space Flight Center, the early state of communications satellite technology necessarily precluded any immediate implementation. Subsequently, both NASA and the Air Force have conducted extensive studies in the TDRS area[1-5]. These studies have shown that a properly instrumented network of synchronous relay satellites can provide complete data acquisition and tracking coverage for a wide range of missions including manned and automated space research and applications vehicles. Potentially, such a system could reduce the present number of ground stations and at the same time provide significantly increased capabilities in the areas of tracking and communications.

The emphasis in these early studies has generally centered on system concepts for relatively wideband communications links between TDRS and user spacecraft. It is known that such links are implemented most readily between fixed-aperture or pointing antennas at high frequencies. This has led to studies and development of large-scale multiple-beam reflector and phased-array antenna techniques for TDRS applications at S-band and above[6-8]. These implied that user spacecraft would be equipped with suitably directive steerable antennas for high data rate communications with the possibility of back-up omni-type antennas for low data rate functions and/or operations under emergency conditions. Support services operable through the low gain back-up antenna would presumably include voice, command, housekeeping telemetry, and two-way range and range-rate tracking. Each of these requires an RF link with an available signal power to noise density ratio (S/N_0) of the order of 40 to 50 dB-Hz or less, and can be implemented with moderate transmit power largely independent of the specifics of system frequencies because of the frequency independent nature of the effective fixed-aperture (TDRS) to fixed-gain (user) RF link (see Figure 1).

More recent TDRS studies[9-11] addressing in detail the problem of providing fundamental TDRS support services to multiple simultaneous users have indicated the desirability of implementing <u>all</u> essentially low data rate TDRS/user RF links at either VHF or low UHF rather than at the

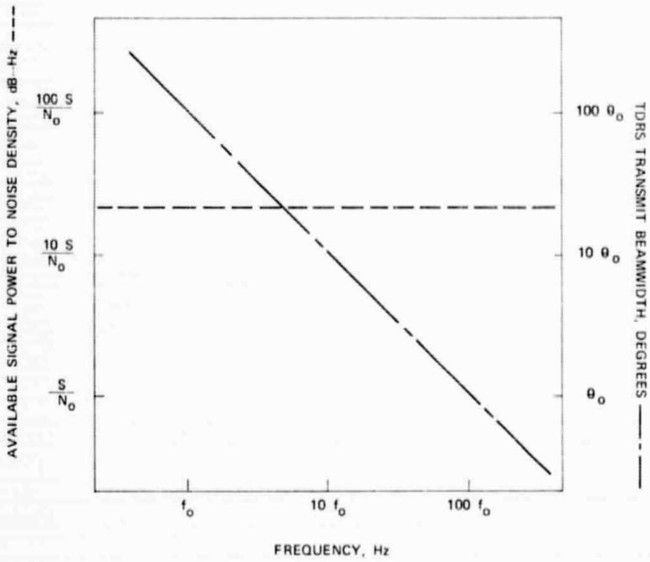

Figure 1. Illustration of frequency dependence of signal/noise density and TDRS antenna beamwidth in links to fixed-gain user spacecraft.

higher frequencies for high data rate links involving directive user antennas. Thus, while a given TDRS would have perhaps several directive steerable antenna beams for wideband links with spacecraft at S-band or above, basic support services for multiple users would be provided using a single broad-beam antenna at low frequencies. The rationale for using low frequencies is clear from Figure 1. Under the operational constraint that user spacecraft must be able to use omni-type antennas for vital support functions such as tracking, command, and emergency voice, the S/N_0 achievable in links with a fixed-aperture TDRS is essentially independent of frequency, while the required TDRS antenna beamwidth goes as the inverse of the frequency.

Thus, at some specified frequency, a given fixed-aperture TDRS is in principle able to support all low orbiting users using a single antenna beam with no penalty in individual user S/N_0 ratios relative to those which might be obtained with the same TDRS using the same transmit power with multiple steered beams at higher frequencies. The advantages of the single broad-beam approach are obvious. They include:

- the number of users provided fundamental TDRS support can be independent of the number of high gain steered antenna beams available on the TDRS;
- the user omni-antenna implementation problem is generally simplified by operations at lower frequencies;
- RF component design, implementation, and reliability all tend to benefit from the choice of lower rather than higher frequencies.

A number of specific disadvantages may be identified as follows:

- multipath propagation effects due to sea-water reflections tend to be more severe at lower frequencies[12];
- because of its broad-beam antenna, the TDRS receiver is relatively more susceptible to RFI from earth based sources than it would be at higher frequencies using multiple narrow antenna beams;
- since each user spacecraft will be illuminated by a multiplicity of signals intended for other users, there will tend to be a "self-noise" limit on communications independent of system thermal noise and RFI power levels.

It is the purpose of this paper to present an introductory illustrative design of a TDRS system providing low data rate support services to multiple users using the low frequency broad-beam approach. Of the class of multiple-access signalling techniques available for this application, spread-spectrum pseudo-noise is selected because it provides a specific mechanism for rejection of RFI and multipath while meeting all system requirements for communications and tracking. Because of its availability as an international resource, the 136-138 MHz telemetry band is designated for the user/TDRS RF link. In keeping with current NASA/ESSA usage, frequencies in the 148-150 MHz band are designated for the TDRS/user link. While it is recognized that implementation of wideband signalling in these bands is at variance with existing international radio regulations, the fact that present regulations make no specific allocations for spacecraft-to-spacecraft communications in any band suggests that the present designations are entirely reasonable for purposes of exploratory system design.

VHF TDRS SYSTEM DESCRIPTION

Summary of Postulated Requirements

On the basis of providing basic low data rate support services to the majority of anticipated NASA launches in the post-1975 time frame, preliminary mission studies indicate the overall TDRS system should be capable of handling between 60 and 75 manned and automated user spacecraft in orbits ranging from equatorial to polar out to 3000 km. Future lunar, planetary, and deep-space missions are excluded because there is no particular advantage in TDRS support of missions which can be tracked for long times by a relatively few highly sensitive ground stations such as those of the present DSN and MSFN. Assuming a random distribution of user orbits and a network of three or four TDRS spacecraft in synchronous orbits, and single TDRS may be required to support as many as 40 simultaneous users.

To the extent possible, the proposed TDRS support will utilize the existing allocations for ground based telemetry, tracking, and command as shown in Figure 2. All users are assumed to have omni-type antennas providing a maximum of 0 dB directivity with arbitrary polarization. Each TDRS is constrained to service all users using a single broad-beam antenna, and provision must be made for TDRS-to-TDRS handover of individual users to assure continuity of coverage.

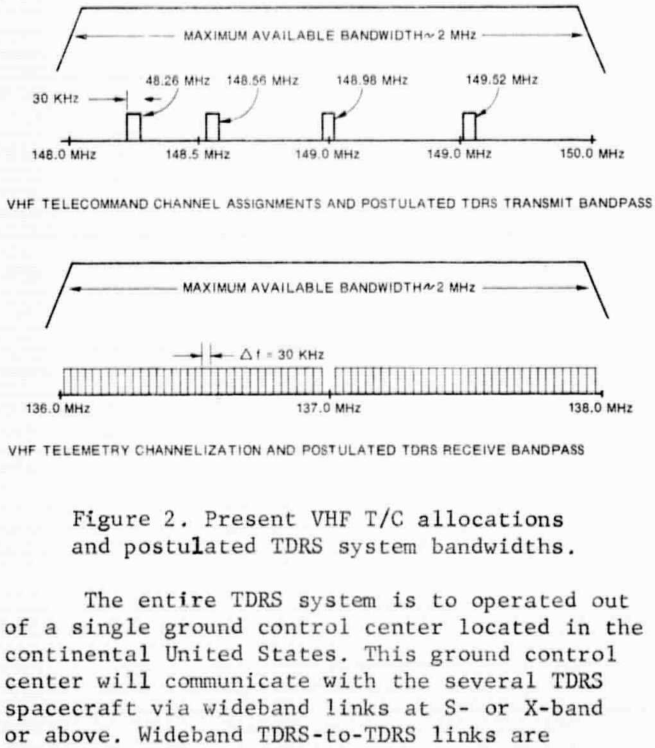

Figure 2. Present VHF T/C allocations and postulated TDRS system bandwidths.

The entire TDRS system is to operated out of a single ground control center located in the continental United States. This ground control center will communicate with the several TDRS spacecraft via wideband links at S- or X-band or above. Wideband TDRS-to-TDRS links are available where required in the event that orbital spacing does not permit direct RF links between a given TDRS and the ground control center.

TDRS Broad-beam Antenna Implementation

The requirement to service users in orbits out to 3000 km means that the TDRS antenna pattern should cover a 25.70 circular sector centered about the local vertical. An appropriate criterion for pattern optimization in the present case is maximation of off-axis gain at the 12.85° point. Figure 3 shows the beam patterns of various circular beam antennas and the boundary curve or envelope of maximum obtainable gain at any off-axis angle. At 12.85°, the maximum gain is about 14 dB with a peak on-axis gain some 3 dB higher. These values are considerably greater than those feasible with electrically despun VHF antennas of the type developed and demonstrated in the ATS program, effectively establishing the requirement that the TDRS VHF antenna be mounted on a stable platform. This indicates the need for either a fully stabilized spacecraft or a spin-stabilized TDRS capable of supporting a large scale despun platform.

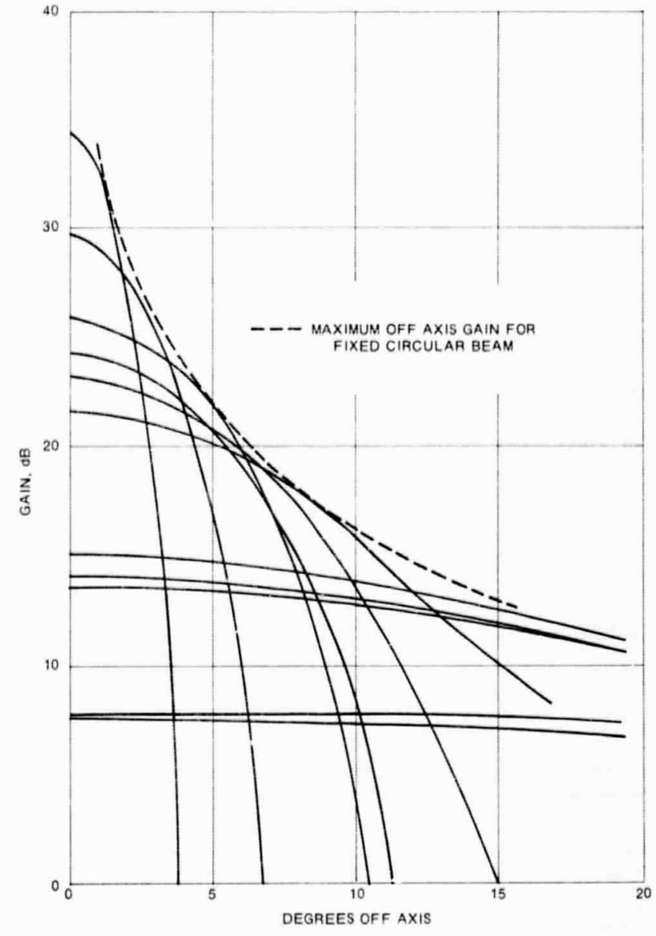

Figure 3. Off-axis gain characteristics of typical circular beam antennas.

In either case, physical implementation of the VHF antenna presents a number of problems because of the relatively large wavelengths involved (λ = 7 ft.) A horn antenna would be the most efficient type at this gain level, but would probably be inconveniently large. More attractive alternatives include a single end fire antenna (disc on rod or cigar type) and arrays of smaller elements such as helices or yagis. Examination of Figure 3 indicates that off-axis gain at the 12.85° point is relatively insensitive to changes in on-axis gain, suggesting that near optimum off-axis gain can be obtained with antennas providing on-axis gain 3 or more dB below the optimum on-axis value of 17 dB. Trade-offs of this type indicate that when all factors are taken into consideration (including antenna noise temperature, size, and weight), the preferred TDRS VHF antenna will be somewhat more broad-beam in nature than that required to service spacecraft out to 3000 km, and will probably have an on-axis gain of the order of 15 dB.

Because of the requirement to work with users having arbitrary antenna polarizations, the TDRS antenna should be able to handle either screw-sense of circular polarization or any other circular set of polarizations. Combinations of signals from crossed linear elements appears to be the best choice for this purpose, and can be readily implemented in either the end fire antenna or the multiple-element array approach.

Spread-spectrum Signal Design

The signalling techniques presently used to provide active VHF tracking, telemetry, and command to NASA's earth orbiting spacecraft do not appear to be directly applicable in the TDRS case. With reference to Figure 2, a very few 30 kHz wide slots in the 148-150 MHz band are available to provide up-links to a relatively large number of spacecraft. Any single ground site, of course, does not in general command or track more than one VHF spacecraft at a time because of the antenna logistics problem. Spacecraft low data rate telemetry and tracking and down-link tracking signals are transmitted to the ground in one or more of a total of sixty-six 30 kHz wide bands stacked side be side in the 136-138 MHz band. As in the up-link case, individual ground sites are generally constrained to serving only one spacecraft at a time.

The telemetry, command, and tracking signal structures now in use are all narrowband and possess no specific mechanism for discriminating against RFI and multipath in either the up-link or the down-link. The active tracking[13] signalling scheme used at VHF (Goddard Range and Range-rate - GRARR) is a coherent-carrier multiple side-tone system which would be particularly sensitive to multipath if used in TDRS/user links.

Existing ground systems do not require true multiple-access signalling since the presence of more than one spacecraft in the ground antenna beam is relatively rare (although mutual spacecraft RFI is observed from time to time in routine system operations[14]. Systematic multipath problems are non-existent in ground based systems, and RFI can be combatted by brute force power in the up-link and narrow ground antenna beams in the down-link.

In contrast, the tracking, command, and telemetry signal structure for the TDRS system must be capable of supporting multiple simultaneous users in the presence of systematic multipath which may involve reflected specular signal strengths equal to or greater than direct signal strengths and RFI which may be many dB greater than either. Because of the great distances involved, basic spacecraft prime power limitations, and the use of broad-beam antennas, brute force cannot be considered a candidate approach for fighting RFI in either the TDRS/user or the user/TDRS link. In the multipath case, since reflected signal strength is proportional to transmitted power level, direct to multipath signal power ratios are independent of transmit level, negating brute force approaches to combatting multipath. To meet the three-fold requirement of multiple-access capability and freedom from RFI and multipath, it is necessary to turn to solutions in the area of RF signal design and system synthesis.

Of the class of multiple-access signalling techniques which might be considered, the digital spread-spectrum pseudo-noise (PN) approach appears most attractive. In the past, PN systems have been used to provide multiple-access and addressing[15], range and range-rate tracking[16], and to combat multipath fading and RFI[17,18]. These closely match the requirements of the VHF TDRS system, suggesting that a properly designed PN signal structure can provide a solution to many of the problems associated with implementation of the overall system.

The principles of PN systems are available in detail in the literature and will not be gone into in any depth here. The defining parameters of a given system may be identified as the clock rate, the code structure and the processing gain. The clock (sometimes termed chip) rate establishes the system RF bandwidth, the code structure determines the lock-up, addressing, and ranging properties of the system, and the processing gain, in the case of a communications application, relates information bandwidth to RF bandwidth and in general defines the anti-RFI and anti-multipath properties of the PN system. Selection of a PN signal structure for the TDRS application thus involves determination of clock/chip rates, code structures, and processing gains which optimize system performance and operations. These and related PN system parameters are discussed below.

Choice of PN Parameters

On the basis of assumed spectrum availability, both the TDRS/user and user/TDRS link must be restricted to a 2 MHz system bandwidth. As many as 40 simultaneous users must share these bands, and each user must be uniquely identifiable in some sense. User identification could possibly be handled with unique PN codes, clock frequencies, or carrier frequencies. Given overall system requirements on code performance, there may not be enough suitable PN codes available. Different clock frequencies might be a good possibility; however, some interference could be encountered as the codes slide through one another. It appears convenient to make all the PN codes the same, use a single system clock rate, and provide user identification on the basis of unique carrier frequencies. Minimum carrier separation in the present case can be readily established on the basis of avoiding overlapping dopplers. Since system doppler ranges will be on the order of ± 4 kHz and some allowance should be made for VCO uncertainties, nominal channel separation is selected as 10 kHz.

Figure 4 shows a frequency plan for the TDRS/user link. The composite spectrum fills the 148-150 MHz band. The middle of the band is taken up by 40 carriers spaced at 10 kHz intervals. The user/TDRS link, not shown, is similiar, having 40 carriers centered about 137 MHz and spaced at intervals of 10 kHz, modified by the nominal user transponder "turn-around" ratio of 137/149.

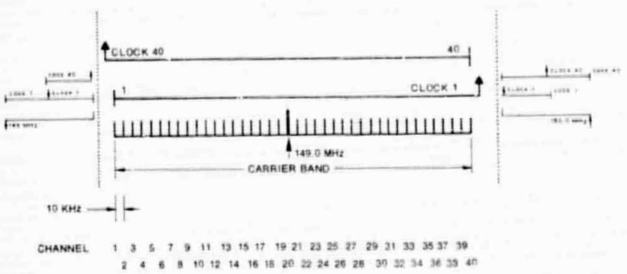

Figure 4. Frequency plan for TDRS/user RF link.

The system clock rate and code length are design parameters which cannot be chosen arbitrarily but are closely tied to other system parameters.

The clock rate directly affects the bandwidth of the transmitted spectrum; therefore the available bandwidth of 2 MHz limits this to no more than 500 kHz. It is also related to the amount of spectrum reserved for the RF carrier assignments which, as noted above, is in turn limited by the anticipated dopplers and frequency drifts. Having assigned 10 kHz carrier separations, a total of 400 kHz is required for the 40 carriers (see Figure 4). It is desirable to make the clock sideband space outside of this center spectral zone to prevent accidental system self interference if momentary code correlation is accomplished between other users' signals. This requires that the clock rate be larger than 400 kHz. The clock rate must also be high enough so that the differential time delay over the physical surface area causing the multipath interference signal will be large in comparison to the clock period. The rates indicated have been calculated to be satisfactorily large.

The code length must be sufficiently long that the range ambiguity caused by it will be sufficiently large so as to not cause difficulties in orbit determination. Since orbit determination can be done to a great extent on the basis of range-rate (i.e., doppler) alone[10,11], the range ambiguity associated with code length can easily be of the order of hundreds of kilometers without causing difficulties. Code lengths also cause the system synchronization time to increase in proportion to their length. With PN system loop bandwidths of the order of 10 Hz and range ambiguities of about 200 km, this will be a matter of several minutes using the proposed mechanization.

User Transponder Characteristics

A functional block diagram of the proposed VHF user transponder in shown in Figure 5. This transponder is of the type which may be termed "coherent regenerative", in that it locks up not only to the carrier component of the input RF signal but also locks up to and regenerates the PN code for transmission back to the TDRS. In the latter respect it differs considerably from simpler coherent PN transponders of the type presently in use in the Apollo USB system, which go through a carrier acquisition procedure but do not actually detect the code, merely remodulating the received code sidebands on the return link carrier. Code and clock regeneration in the user transponder is mandatory in the present case because of multipath and RFI in the TDRS/user RF link.

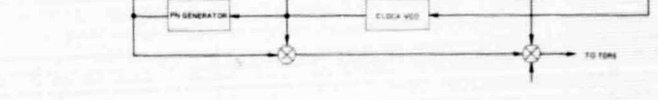

Figure 5. User transponder block diagram.

Operation of the transponder may be described as follows. The input RF signal is a carrier biphase modulated with a code/clock combination which may or may not have up-link data superposed. Only a virtual carrier component exists, i.e. the modulation is controlled to be a full ± 90°. The incoming signal is mixed with a locally generated clock/code modulated signal with a carrier component constrained a priori to be within ± 5 kHz of the input virtual carrier. Under conditions of perfect synchronization, the filtered signal in the narrow IF will be a pure sinusoid which when mixed with the divide-by 2 version of the carrier VCO produces a DC steady state error signal for the carrier VCO. Initial RF carrier lock-up can be accomplished whenever there is partial correlation between the incoming code/clock modulated signal and the locally generated version. This partial correlation occurs when the system is in a search mode and the code/clock drifts into a state where it is anywhere within the period of perfect synchronization. This produces a coherent carrier component in the IF to which the carrier tracking loop can lock on.

A second tracking loop is required for the code/clock function. Assuming carrier synchronization has been accomplished as described, multiplication of the unfiltered version of the IF signal by the divide-by 2 version of the carrier VCO removes the carrier and leaves the clock. This is mixed with a phase-shifted version of the clock VCO to produce an error signal for the clock VCO, thus completing the PN transponder.

Up-link data (commands, emergency voice, etc.) appear as modulation of the carrier in the transponder IF and can be detected with conventional techniques. Down-link data can be superposed on the code/clock modulated carrier and will be recovered when the signal is processed in the ground receiving equipment.

Other user signals, multipath signals, and RFI at the input to the transponder will be beat with the code/clock function along with the desired input signal. Since this will be a non-coherent operation for all except the desired user signal, spectral spreading will result. As a consequence, the complex of direct and multipath signals and RFI will be converted to a broadband process essentially equivalent to a white noise spectral density within the passband of the transponder IF. For discrete CW type signals, the band spreading is essentially equal to the RF bandwidth of the PN system, i.e. 2 MHz. The spectrum spreading of modulated signals is given by the convolution of the code/clock spectrum and the input spectrum, and will generally be greater than 2 MHz. These relationships permit gross parametric analysis of PN system performance without regard for the specifics of multipath and RFI signal characteristics (see Anticipated System Performance below).

Bent Pipe TDRS Repeater

The preferred approach to implementation of the TDRS repeater is the so-called "bent pipe" or two-way frequency translation transponder. A block diagram of a typical implementation is shown in Figure 6. All frequency conversions are under the control of a single mas-

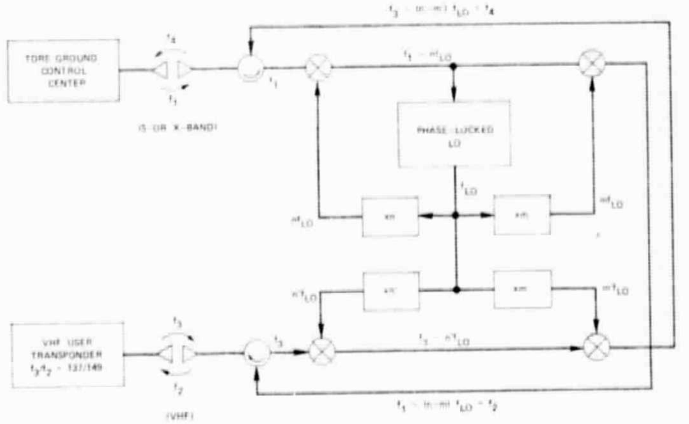

Figure 6. TDRS Dual Frequency Translation Repeater concept showing system frequency relationships.

ter oscillator phase-locked to a signal referenced to the frequency standard of the ground control center. This is necessary for preservation of carrier coherency, required for range-rate tracking based on measurement of carrier doppler. Doppler coherency relationships and processing algorithms for this type of TDRS repeater working with a coherent regenerative user transponder have been derived and are documented elsewhere[10]. Beyond use of a phase-locked oscillator, the proposed TDRS repeater differs from more conventional communication satellite repeaters in two particulars, linearity and VHF transmit power level.

Because of the severe RFI levels anticipated at the input to the TDRS VHF receiver, it may not be desirable to implement the repeater as a bandpass limiter of the type generally discussed in connection with wideband PN multiple-access systems[15]. Rather, it appears advantageous to design the repeater to have a large region of linear operation. Preliminary analysis has shown that the system power penalty associated with linear retransmission of the entire 136-138 MHz RF spectrum as seen by the TDRS need not be particularly severe[10].

The fact that the TDRS must maintain two-way links with up to 40 user spacecraft suggests that a relatively high power VHF transmitter may be required. On the basis of individual transmit carrier levels in the 1 to 10 watt range, mean power levels of up to 400 watts would be required. Since the peak power associated with a complex of 40 independent RF carriers is in the kilowatt range, implementation of the output stage as a class A linear amplifier seems impractical. Possible alternatives include use of class B linear or hard limiting (here feasible because of controlled carrier levels and freedom from RFI) or use of a phase-modulated up-link signal design with the 40 carriers appearing as individual sidebands of of a single RF carrier, with filtering of the residual carrier and undesired sidebands after class C power amplification in the TDRS.

Anticipated System Performance

The results of a gross parametric analysis of system performance are shown in Figures 7 - 10. These curves plot available signal power to equivalent noise density ratios, S/N_o, vs. transmit power level P_{tr} for various values of N equal power user links with relative RFI power as a parameter. The available signal power S is computed as the transmit power P_{tr} less nominal system propogation losses (i.e., VHF spreading loss, transmit and receive antenna gains, polarization loss allowance, etc.). The equivalent noise density N_o is computed as the sum of the intrinsic receiver thermal noise KT_s, the code noise due to N-1 equal power competing signals, $k_s(N-1)S$, a multipath noise density $k_s k_m NS$ produced by N reflected signals, and RFI noise $k_s P_{rfi}$. The intrinsic system noise temperature is taken to be 1000^o Kelvin. This includes receiver noise, antenna noise, etc. and is considered conservative. The k_s factor represents the 2 MHz minimum spreading of undesired signals and is taken to be - 63 dB. The k_m factor is the ratio of total reflected signal power to direct signal power and is taken to be unity.

Because the transponder turn-around ratio of 137/149 is essentially unity, receive and transmit links are reciprocal for all practical purposes and the curves thus apply to both the TDRS/user link and the user/TDRS link, with the proviso that P_{tr} is interpreted as the transmit power per user in the former case.

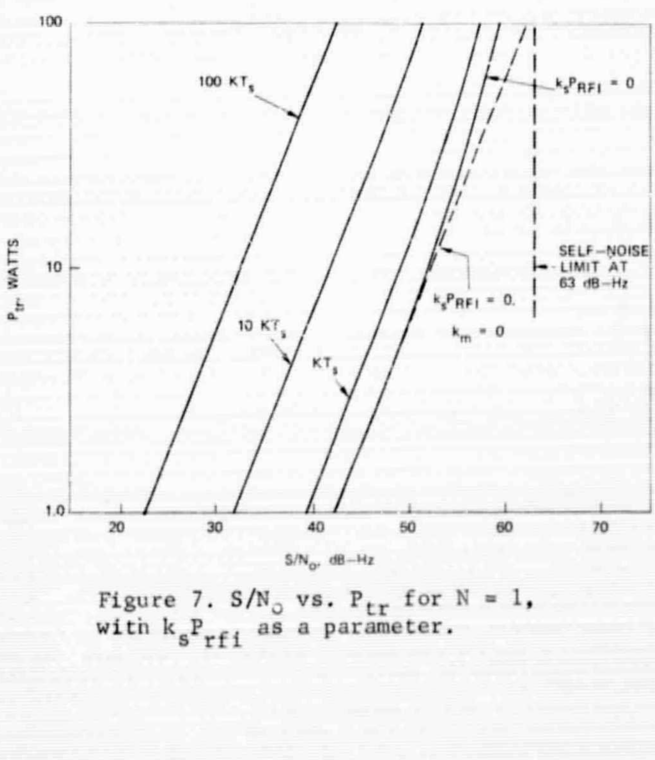

Figure 7. S/N_o vs. P_{tr} for N = 1, with $k_s P_{rfi}$ as a parameter.

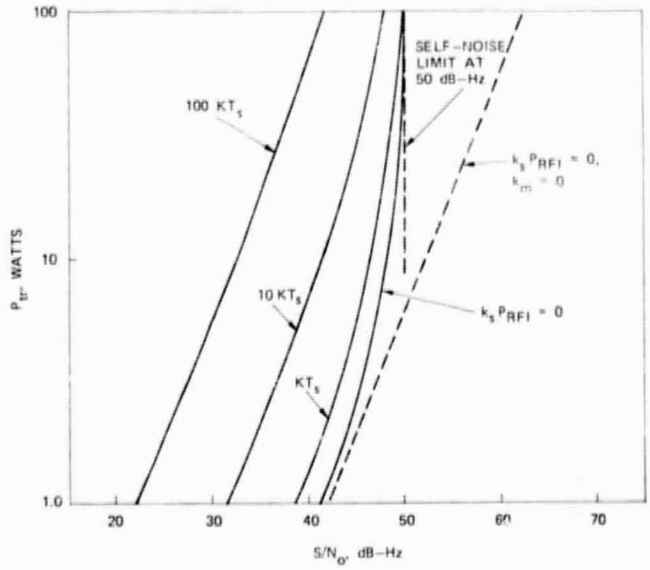

Figure 8. S/N_o vs. P_{tr} for N = 10, with $k_s P_{rfi}$ as a parameter.

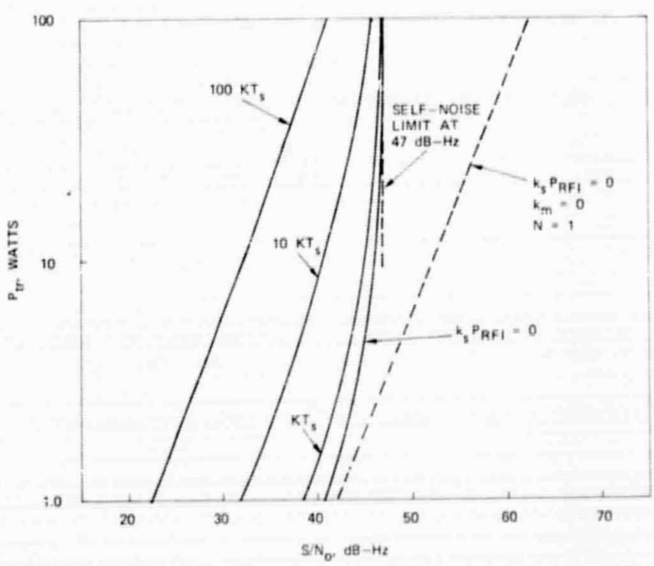

Figure 9. S/N_o vs. P_{tr} for N = 20, with $k_s P_{rfi}$ as a parameter.

The N = 1, k_m = 0, P_{rfi} = 0 case is shown as a reference asymptote in each figure. For any N, the system has a self-noise limit at

$$[S/N_o]_{max} = 10\log_{10}k_s - 10\log_{10}(N-1) - 10\log_{10}k_m N$$

For large N and k_m = 1, this simplifies to

$$[S/N_o]_{max} = 10\log_{10}k_s - 10\log_{10}2N$$

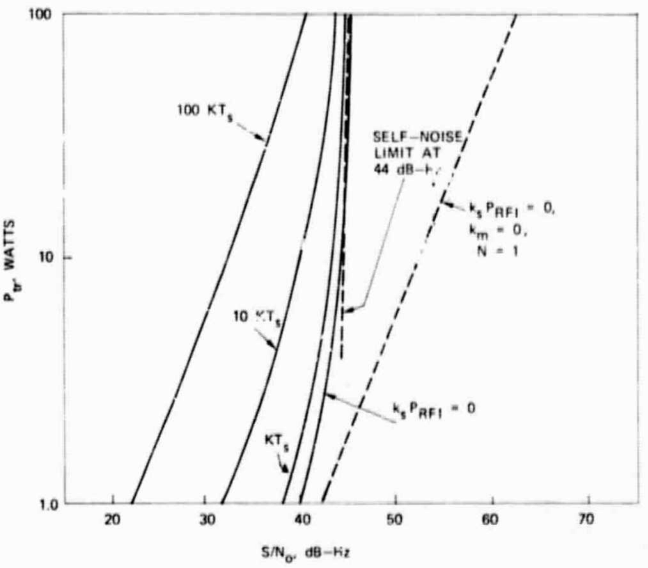

Figure 10. S/N_o vs. P_{tr} for N = 40, with $k_s P_{rfi}$ as a parameter.

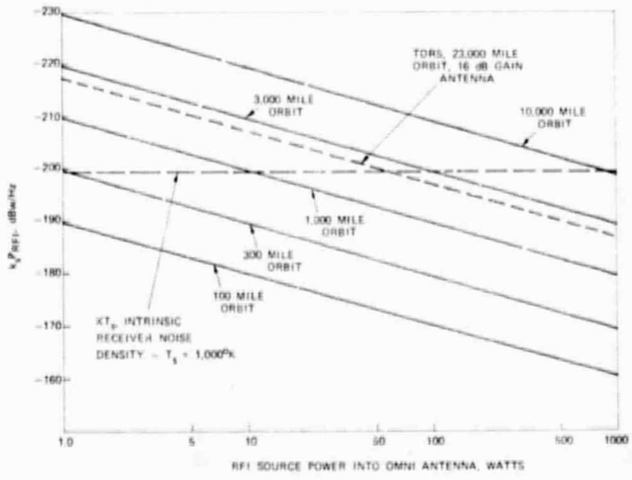

Figure 11. RFI equivalent noise density in spacecraft receiver with spacecraft orbital altitude as a parameter.

which is plotted as a vertical asymptote.

It is clear that under the pessimistic assumption that $k_m = 1$, S/N_o ratios well in excess of 40 dB-Hz can be obtained with transmit powers well under 10 watts even in the N = 40 case. This indicates that self-noise will not be the limiting factor in links called upon to support only emergency voice, digital data at less than kilobit rates, and PN range and range-rate tracking.

RFI noise densities substantially greater than the intrinsic system thermal noise density can seriously limit communications. The RFI power level received at a spacecraft depends on the location, power level, and antenna characteristics of the source(s), the orbital geometry, and the spacecraft antenna characteristics. Figure 12 plots maximum equivalent RFI noise densities vs. RFI source transmit power levels assuming omni-type source antenna characteristics for both the synchronous TDRS and users in orbits from 100 to 10,000 nm. It is clear that while substantial RFI sources are required to produce serious equivalent noise densities in the TDRS receiver, relatively low power RFI sources can seriously degrade the available S/N_o ratios in links to low altitude users. This suggests that of the two links, the TDRS/user link will be more likely to be the limiting one in actual system implementation.

Identification of Problem Areas

RFI. Preliminary surveys of current frequency usages in the VHF bands considered herein indicate that implementation of the TDRS system as proposed will be difficult if not impossible. Existing RFI environments, particularly in the case of the 148-150 MHz link, would produce equivalent RFI noise densities of the order of 10 dB greater than the basic thermal noise, on the average, as a bare minimum; maximum RFI noise could easily exceed intrinisic thermal noise by as much as 20 to 30 dB. Possible solutions include search for "cleaner" bands or a re-allocation of the present bands on a space-exclusive basis.

User Antenna Design. The user antenna question has been largely ignored in this basic paper. The ideal user antenna, in the case of unstabilized spacecraft which can take on any attitude with respect to the TDRS, is one with zero directivity in all directions and a single specified polarization. This can only be approximated by practical antennas such as the classical turnstile. As a result, omni-type antennas tend to have deep nulls and polarizations which are a function of orientation. This can be overcome by the use of brute force power where available, but does present design problems for spacecraft which will use the VHF TDRS system for prime or back-up support.

Synchronization. The codes which appear optimum for the VHF TDRS application involve lock-up times which appear undesirably long. Further study is required to firmly establish the minimum possible code lengths consistent with system requirements and acquisition procedures which minimize lock-up times.

TDRS-to-TDRS Handover Procedures. Assuming system synchronization times can be reduced to the order of seconds, the handover problem is trivial. However, with code lock-up times of several minutes, there will be a requirement for user handover procedures to assure continuity of coverage. This is an area requiring further study.

ACKNOWLEDGEMENT

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