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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-353

Semiannual Review of

Research and Advanced Development

January 1, 1967 to June 30, 1967

Volume III. Supporting Research and Technology for the Office of Tracking and Data Acquisition (New Systems and Spacecraft Subsystems), National Aeronautics and Space Administration

JET PROPULSION LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA

July 31, 1967

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Approved by:

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JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

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Technical Memorandum 33-353, Vol. III

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PREFACE

This document has been prepared under the direction of the Office of Research and Advanced Development of the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

The Semiannual Review of Research and Advanced Development is published in three volumes directed to the appropriate NASA funding offices:

Volume I	Supporting Research and Technology for the Office of Space Sciences and Applications
Volume II	Supporting Research and Technology for the Office of Advanced Research and Technology
Volume III	Supporting Research and Technology for the Office of Tracking and Data Acquisition (New Systems and Spacecraft Subsystems)

This issue reports progress for the period of January 1 to June 30, 1967, Fiscal Year 1967. Preceding issues were published as follows:

Fiscal year	Calendar period covered	JPL Technical Memorandum No.	Publication date
1965	January 1 to June 30, 1965	33-243	August 15, 1965
1966	July 1 to December 31, 1965	33-272	January 31, 1966
1966	January 1 to June 30, 1966	33-296	July 31, 1966
1967	July 1 to December 31, 1966	33-322	January 31, 1967

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CONTENTS

TRACKING AND DATA ACQUISITION (150)

Tracking and Data Acquisition (150-22)

INTRODUCTION

This volume contains a review of all supporting research and technology in progress at the Jet Propulsion Laboratory during the period January 1 to June 30, 1967, under the direction of the JPL Office of Research and Advanced Development, for the NASA Office of Tracking and Data Acquisition (New Systems and Spacecraft Subsystems).

The work units are arranged in numerical sequence by NASA code in each subject section. To locate a desired unit, refer to the Table of Contents under the appropriate subject heading.

JPL research and advanced development results published as JPL documents and in the open literature during this report period are listed under each work unit.

TRACKING AND DATA ACQUISITION (150)

TRACKING AND DATA ACQUISITION (150-22)

RF TECHNIQUES ENGINEERING

NASA Work Unit 150-22-11-07-55
JPL 350-10700-1-3330
C. T. Stelzried

OBJECTIVE

The objectives of this task are to provide practical fieldworthy techniques for precision attenuation, impedance, and power measurement calibrations. In part, these consist of (1) the ground receiving system antenna RF hardware calibrations required for accurate evaluation and (2) absolute receiving sensitivity, antenna pointing accuracy, and absolute received power level calibrations. These calibrations are necessary to maintain and extend the DSIF receive capabilities to known sensitivity and to establish spacecraft performance. This is especially important in order to reduce the tolerances of the overall communications system.

The objective consists further in the application of these techniques to spacecraft RF hardware. It is desirable to apply these methods to spacecraft systems to reduce, stabilize, and calibrate transmission line losses and other parameters.

X-BAND NOISE TEMPERATURE CALIBRATIONS

A program is presently under way to evaluate the DSIF antennas at frequencies above the standard S-band communication frequency. An X-band RF cone was assembled (Fig. 1) and is adaptable to the Goldstone 85-ft Venus Station and the 210-ft Mars Station antennas. To date, the X-band has been tested on the ground at JPL and on the Venus Station at Goldstone (Fig. 2). Experimental techniques, data reduction methods, and results have been presented (JPL SPS 37-44, Vol. III, pp. 21-85).

The total system temperature of this cone on the antenna is about 38°K. Considerable attention has been given not only to overall system noise temperature but also to calibration of the antenna noise temperature, which requires the use of cryogenically cooled terminations. It is expected that continued improvements of the absolute antenna noise temperature calibrations will ultimately not only improve the estimates of atmospheric noise and antenna back-lobe contributions but will also provide an independent measurement of the cosmic background radiation (Ref. 1). These measurements will provide a lower limit on the obtainable receiving system noise temperature.

TOTAL SYSTEM NOISE TEMPERATURE CALIBRATION

One of the important parameters for the sensitivity of a receiver system is the overall equivalent noise temperature. The multifrequency cones of the Venus Station 85-ft antenna and the Mars Station 210-ft antenna have both been equipped with the same type of noise temperature instrumentation. Daily measurements (JPL SPS 37-42, Vol. III, p. 25) are performed with Y-factor power ratio measurements between an ambient waveguide termination and the antenna. It is shown and demonstrated that this technique provides a very reliable method for overall system temperature measurements. The overall averages for the daily noise temperatures for the period October 20, 1966, to February 9, 1967, are shown in Table 1. Additional system noise temperature data has been reported pertaining to the operation of the Mars Station 210-ft antenna during the Mariner IV superior conjunction (Ref. 2).

THERMALLY ISOLATED MICROWAVE TRANSMISSION LINES

Spacecraft onboard communication systems require microwave transmission lines with high reliability, low loss, and light weight. Microwave transmission lines that provide thermal isolation are used in the construction of thermal calibration terminations ("cold loads"). These thermal terminations provide noise temperature calibration instrumentation for low noise receiving systems. The thermally isolated transmission lines are usually fabricated from thin wall stainless steel. Copper plating is used to reduce the microwave insertion loss.

A lightweight, thermally isolated low loss waveguide section has been fabricated with plastic. Figure 3 shows a photograph of an H-band plastic waveguide test section fabricated by hand-wrapping fiberglass tape to the desired thickness on a steel mandrel and impregnating it with liquid plastic. The measured microwave dissipative loss of this particular section at 8448 MHz was 0.0196 dB. This is in good agreement with a loss of 0.0258 dB measured for a solid aluminum waveguide of the same length, fabricated by EDM (electric discharge method) if account is taken for surface roughness.

The primary advantage of the plastic waveguide fabrication technique over conventional stainless steel sections is reduced cost and fabrication time. Special thin wall stainless steel waveguides require a factory mill run that entails long lead time and user storage problems. The plastic section also has higher rigidity and less total weight than conventional stainless steel sections.

The primary disadvantages are the dimensional instability caused by the higher coefficient of expansion of the material and the thin conductive coating on the flanges. The flanges cannot be lapped due to the thin metal covering.

REFERENCES

1. Dicke, R. H., Peebles, P. J. E., Roll, P. G., and Wilkinson, D. T., "Cosmic Black-Body Radiation," Astrophys. J., Vol. 142, No. 1, pp. 414-419, July 1, 1965.

2. Brown, D. W., Stelzried, C. T., and Bathker, D. A., "System Temperature," JPL TR 32-1092, The Superior Conjunction of Mariner IV, R. M. Goldstein, et al., April 1, 1967.

PUBLICATIONS DURING REPORT PERIOD

Open Literature

1. Stelzried, C. T., and Reid, M. S., "Precision Power Measurements of Spacecraft CW Signal Level with Microwave Noise Standards," IEEE Trans. Instrum. and Measur., Vol. IM-15, No. 4, pp. 318-324, December 1966.

JPL SPS Contributions

1. Otoshi, T. Y., and Stelzried, C. T., "Improved Calibration Techniques: X-Band Noise Temperature Calibrations," SPS 37-44, Vol. III, p. 72, March 1967.

2. Stelzried, C. T., "Improved RF Calibration Techniques: Daily System Noise Temperature Measurements," SPS 37-44, Vol. III, p. 85, March 1967.

3. Stelzried, C. T., and Otoshi, T. Y., "Improved Calibration Techniques: X-Band Cone Built-in Reflectometer System," SPS 37-45, Vol. III, May 1967.

4. Stelzried, C. T., Otoshi, T. Y., and Mullen, D. L., "Thermally Isolated Transmission Lines," SPS 37-45, Vol. IV, June 1967.

5. Stelzried, C. T., and Otoshi, T. Y., "WR 430 Waveguide Precision Rotary Vane Attenuator Calibration," SPS 37-46, Vol. III, July 1967.

JPL Technical Reports

1. Brown, D. W., Stelzried, C. T., and Bathker, D. A., System Temperature, JPL TR 32-1092, The Superior Conjunction of Mariner IV, R. M. Goldstein, et al., April 1, 1967.

ANTICIPATED PUBLICATIONS

None.

Table 1. Summary of the system temperature and maser gain averages and measurement dispersions

DSS	Frequency, MHz	System temperature, °K	Maser gain, dB
Venus	2388.0	22.9 $\pm 3.2\ (pe_i)_D$ $\pm 0.13 (pe)_D$ 33 data points	39.8 $\pm 0.54 (pe_i)_D$ $\pm 0.07 (pe)_D$ 50 data points
	8448.0	37.9 $\pm 1.7\ (pe_i)_D$ $\pm 0.13 (pe)_D$ 17 data points	40.4 $\pm 0.63 (pe_i)_D$ $\pm 0.13 (pe)_D$ 23 data points
Mars	2388.0	27.4 $\pm 3.2\ (pe_i)_D$ $\pm 0.21 (pe)_D$ 15 data points	38.4 $\pm 0.43 (pe_i)_D$ $\pm 0.08 (pe)_D$ 28 data points
	2297.6	28.1 $\pm 2.5\ (pe_i)_D$ $\pm 0.15 (pe)_D$ 19 data points	40.6 $\pm 0.17 (pe_i)_D$ $\pm 0.03 (pe)_D$ 30 data points

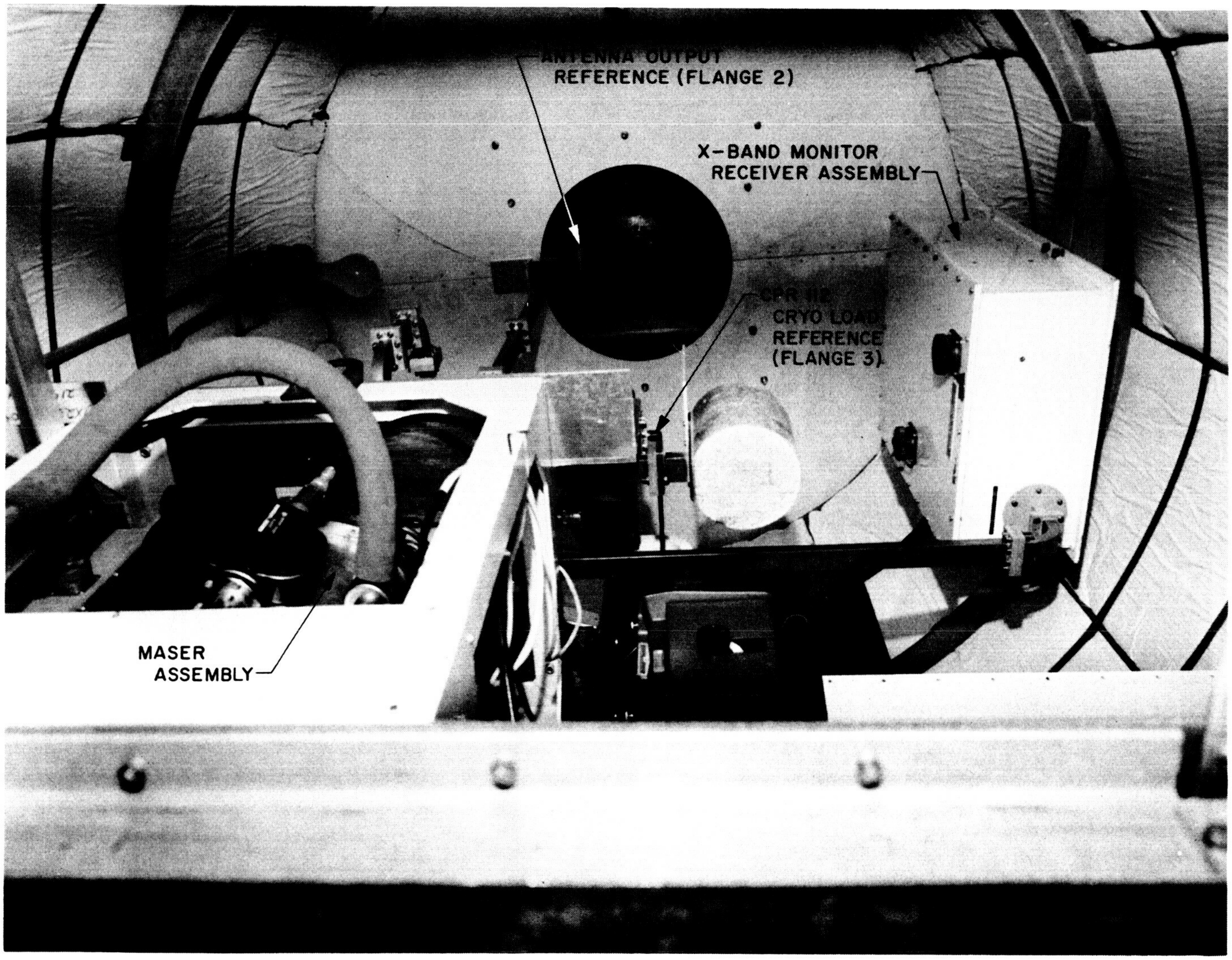

Fig. 1. X-band cone interior

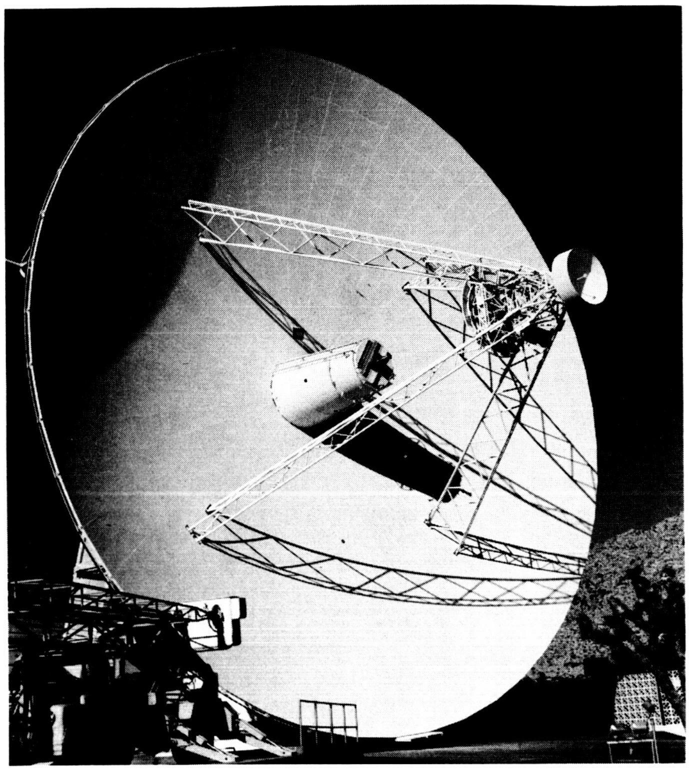

Fig. 2. X-band cone on 85-ft Venus Station antenna

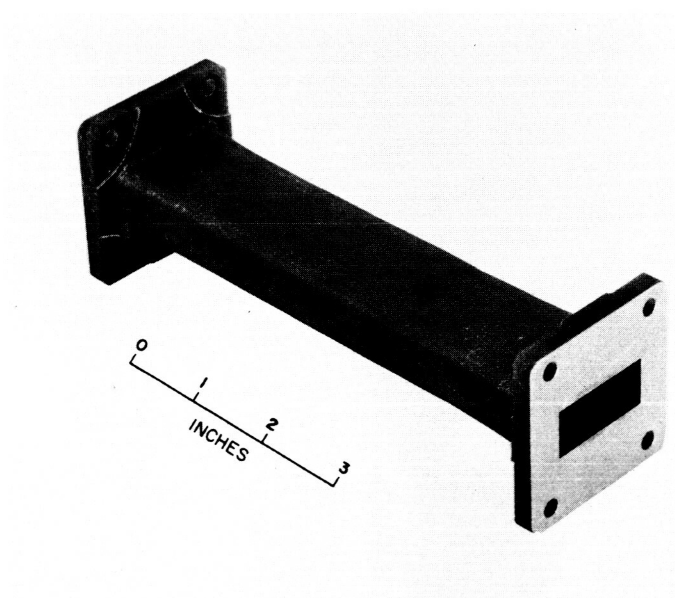

Fig. 3. WR 112 plastic waveguide section

COMMUNICATIONS SYSTEMS DEVELOPMENT
NASA Work Unit 150-22-11-08-55
JPL 350-10800-X-3310

Robert C. Tausworthe

OBJECTIVE

The objective of this effort is the development of techniques needed for future DSN tracking and communications capability. Methods are sought to provide improved tracking and data acquisition, better ranging subsystems operable below present DSIF ranging thresholds, accurate solutions to problems arising in deep space communication and data acquisition systems, and improved telemetry systems operating at higher rates than presently available.

PROGRESS

Phase Tracking Research

A cycle-slipping simulation of a phase-locked loop was implemented on an SDS 930 computer; the results verify a theoretical model with high accuracy. The probability of the mean time to first slip very closely approximated a gamma density. The sample-data loops in the Mariner R&D ranging system have been analyzed theoretically, and the implementation agrees with theoretical results. A set of curves showing the transformation of phase-locked receiver design points appears in JPL SPS 37-46, Vol. III.

Ranging Systems Development

An R&D ranging system for Mariner V has been constructed, tested, and operated on the Lunar Orbiter B spacecraft. This system is an improvement over the DSN Mark I system, as it is capable of ranging spacecraft out to planetary distances. The difference is mainly involved with the code-tracking loop, which allows very narrow bandwidths to be achieved through the use of a digital computer as system controller and signal processor. Actual ranging of the Mariner spacecraft began in late June of CY 1967. As it is an experimental system, refinements in hardware and software will continue as experience with the system is obtained.

Sequential Decoding Research

A program is being developed for the SDS 930 computer which will accommodate rates up to 2 kbits/s at almost negligible error probabilities. There are still many tradeoffs and evaluations to be made, mainly in the areas of efficient synchronization and data handling. However, it now appears that sequential decoding is an outstanding method for obtaining extremely reliable data at data rates below 3 kbits/s. In particular, sequential decoding is envisioned as the system necessary when data compression or other nonredundant data schemes come into existence.

Block-coded telemetry and noisy-reference detection have been moved to NASA Work Unit 125-21-02-03, "Coding and Synchronization Studies." Time synchronization by moon-bounce radar has been delegated to NASA Work Unit 311-03-53-3310, "DSN Telemetry Demodulation Engineering," and mission-independent telemetry to NASA Work Unit 150-22-12-04-33, "Information Systems."

PLANS

In FY 1968, it is planned to implement the sequential decoding scheme into a workable communications system to demonstrate efficient data synchronization at very low error probabilities.

As a continuing part of the phase-locked loop research, characterization of the accuracy with which a loop is able to track a noisy oscillator will be made. Volume II of JPL TR 32-819, Theory and Practical Design of Phase-Locked Receivers, will be completed. This volume will be concerned with data and subcarrier demodulation, cycle slipping, and false lock.

Ranging of the Mariner V spacecraft and validation of the tracking data will continue until encounter (mid-October) and probably extend throughout the useful life of the spacecraft.

PUBLICATIONS DURING REPORT PERIOD

Papers Presented at Symposia

1. Tausworthe, R. C., "Ranging the 1967 Mariner to Venus," 1967 IEEE National Convention, Hilton Hotel, New York City, March 1967.

2. Lindsey, W. C., and Tausworthe, R. C., "A Survey of Phase-Locked Loop Theory," 1967 International Comm. Conf., Minneapolis, Minn., June 12-15, 1967.

Open Literature

1. Tausworthe, R. C., "Cycle-Slipping in Phase-Locked Loops," IEEE Trans. Commun. Technol., Vol. 15-3, June 1967.

2. Tausworthe, R. C., "A Method for Calculating Phase-locked Loop Performance near Threshold," IEEE Trans. Commun. Technol., Vol. 15-4.

3. Tausworthe, R. C., "Ranging the 1967 Mariner to Venus," Proceedings of 1967 IEEE National Convention.

4. Tausworthe, R. C., "Coherent Receiving Systems," Chapter IV in Deep Space Telemetry and Command Systems, by E. Rechtin, et. al., to be published by McGraw-Hill.

JPL SPS Articles

1. Viterbi, A. J.,* "The Effect of Filtering and Quantization on a Coded PSK Communication System," SPS 37-45, Vol. IV.

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*Consultant, UCLA Engineering Dept., PO DH-366315.

2. Tausworthe, R., "Phase Locked Receivers: Specification of Parameters at an Arbitrary Design Point," SPS 37-45, Vol. III.

3. Gray, R., "Analysis of the Tracking Loop of the Mariner V Ranging System," SPS 37-46, Vol. III.

4. Tausworthe, R. C., "Tests on the Mariner V Ranging System," SPS 37-46, Vol. III.

ANTICIPATED PUBLICATIONS

None.

INFORMATION PROCESSING
NASA Work Unit 150-22-11-09-55
JPL 350-10900-X-3310

Eugene R. Rodemich

OBJECTIVE

The objective of this continuing work unit is to use mathematical and statistical reasoning to discover methods for efficient and error-free communication within the DSN. These techniques are pushed to the point at which they can be picked up by companion Advanced Engineering work units ("Error-Free Data Transmission," NASA Work Unit 150-22-15-11-33; "Data Compression Engineering," NASA Work Unit 150-22-15-14-33).

PROGRESS

During the second half of FY 1967, the synchronization of extremely weak binary signals was studied for possible use in a mission-independent telemetry system (A-1).[1] This work was reported on at a professional society meeting (B-1).

A new very simple arithmetic decoding procedure for certain cyclic codes was found (A-2). This procedure generalizes the error-correction method used in the Mariner 1967 high-speed data lines.

A method was discovered (A-3) to extend algebraic decoding procedures so that more errors can be corrected than can be corrected using earlier procedures.

A method of calculating the output of a limiter when the input is both phase and amplitude modulated was found (A-4). The method is being used to find the output of a phase-locked loop when the input is a narrow-band Gaussian process, so that the Mariner IV solar corona occultation experiment can be properly interpreted under NASA Work Unit 125-21-01-01-55, "Propagation Studies." This work was reported on at a professional society meeting (B-2).

A new method was found for computing the derivatives of a band limited function (A-5). This method is useful in obtaining radar brightness maps under NASA Work Unit 150-22-11-10-33, "Astrometrics."

A paper was accepted showing that the use of error-correcting codes with bit-by-bit detection (as opposed to correlation detection) is not indicated on the Gaussian channel if the goal is low threshold (C-1).

PLANS

During FY 1968, a final recommendation will be made to the DSN as to what form a standard DSN correlator should take. A final report on the Teletype Coding

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[1] Numbers in parentheses refer to publications listed at the end of this work unit.

Project will be written, incorporating both the theoretical work done under this work unit and experimental work done under the companion work unit, "Error-Free Data Transmission." Work will be done on the possibility of improving ranging and range-gating by using sequences other than PN sequences. In particular, the possibility of correlating with a sequence different from the one sent will be investigated. The performance of various synchronization methods for weak binary signals will be compared with the optimum performance which will be determined.

CONTRACT

Work was done by a contractor, the University of Southern California, Electrical Engineering Department, under JPL PO 951076. The contract was extended five months in January 1967, to terminate June 1967. The same subcontractor is being asked to propose on what would be a new contract starting September 1, 1967 (PR 472971). The subcontractor works on combinatorial and algebraic problems of importance in space communication (D-1 and D-2).

PUBLICATIONS DURING REPORT PERIOD

A. JPL SPS Articles

1. Eisenberger, I., and Posner, E. C., "Synchronization of Extremely Weak Binary Signals," SPS 37-43, Vol. IV, pp. 327-330.

2. Solomon, G., "Arithmetic Decoding of Cyclic Codes," SPS 37-44, Vol. IV.

3. Berlekamp, E., "Decoding Codes Beyond the Bose-Chaudhuri Bound," SPS 37-44, Vol. IV.

4. Greenhall, C.,* "Signal and Noise in Non-Linear Devices," SPS 37-44, Vol. IV.

5. Zohar, S., "Computation of the Derivatives of a Band-Limited Function," SPS 37-45, Vol. IV.

B. Symposia Papers

1. Eisenberger, I., and Stiffler, J. J., "Synchronization of Extremely Weak Binary Signals," presented to annual meeting of Society of Industrial and Applied Mathematics, Washington, D. C., June 12-15, 1967.

2. Greenhall, C.,* "Output of a Limiter Under Stochastic Input," presented to Southern California Section, Society of Industrial and Applied Mathematics, Los Angeles, April 30, 1967.

C. Journal Articles

1. Posner, E. C., "Properties of Error-Correcting Codes at Low Signal-to-Noise Ratios," to appear in J. Appl. Math. of Society of Industrial and Applied Mathematics, August 1967.

*Resident Research Associate.

D. Contractor Publications (PO 951076)

1. Golomb, S. W., "A Rational Algorithm for Marsh's Cubic Transformation," SPS 37-44, Vol. IV.

2. Golomb, S. W., and Hales, A. W.,* "On Enumerative Equivalence of Group Elements," SPS 37-44, Vol. IV.

ANTICIPATED PUBLICATIONS

None.

*Consultant, Math. Dept., UCLA, PO BZ-419057.

ASTROMETRICS

NASA Work Unit 150-22-11-10-55
JPL 350-11000-X-3310
Eugene R. Rodemich

OBJECTIVE

The purpose of this work unit is to develop theoretical and numerical tools for estimating and analyzing the effects of solar system geometry and physics upon deep space communication and radio navigation systems. These techniques are based in part on work done under the companion work unit (NASA Work Unit 150-22-11-09-55, "Information Processing") and are used in NASA Work Unit 125-21-02-04, "Propagation Studies," as well as in NASA Work Unit 150-22-11-11-33, "Propagation Engineering."

PROGRESS

During the second half of FY 1967, various analytic techniques were developed useful for preparing radar brightness maps of the planets (1), (2).[1] Computer programs were written and run for finding the backscatter function, for removing the effect of noise, for taking into account planetary geometry, for finding the brightness at a point, for averaging several experiments, and for drawing the maps. Some of the programs run on an IBM 1620, and some on an IBM 7094. Radar data obtained in previous Venus radar experiments are being prepared for the programs, and actual Venus maps will be obtained. Several different procedures for obtaining the maps will be used, so that the true effect of the Venus surface can be found. The maps will be furnished to the companion "Propagation Studies" work unit for interpretation.

A method was derived for eliminating the effect of charged electrons on ranging data (3). The method allows present ranging systems to be used even through media containing electrons.

PLANS

During FY 1968 a radar brightness map of Venus will be obtained. This will furnish the first look at the surface of that cloud-obscured planet. Chirp coding will be studied for the purpose of obtaining a new mapping technique. Methods will be developed for finding the variances in estimates of radar scattering laws.

PUBLICATIONS DURING REPORT PERIOD

JPL SPS Contributions

1. Zohar, S., "The Range-Gated Autocorrelation Function," SPS 37-43, Vol. IV, pp. 330-338.

[1] Numbers in parentheses refer to publications at the end of this work unit.

2. Zohar, S., "A New Method for Extracting the Reflectivity Distribution From Planetary Radar Data," SPS 37-44, Vol. IV.

3. Reichley, P., "Elimination of Charged Electron Effects From Ranging Data," SPS 37-44, Vol. IV.

ANTICIPATED PUBLICATIONS

None.

PROPAGATION ENGINEERING

NASA Work Unit 150-22-11-11-55
JPL 350-11100-1-3330
G. S. Levy

OBJECTIVE

The objective of this work unit is to achieve the necessary understanding of the plasma propagation effects encountered by an interplanetary telecommunication link. The plasmas of concern are those due to entry ionization, ion engine exhaust, and solar wind. The most immediate problem is that of communication with a Martian landing capsule during the blackout period.

PROPAGATION ENGINEERING

Upon entry into a planetary atmosphere a vehicle is decelerated by drag effects. In addition to the deceleration the gas is heated above the temperature at which it ionizes. The ionized plasma sheath that is formed perturbs the propagation of the microwave telemetry passing through it.

The ionization is a sensitive function of vehicle entry angle and velocity as well as the physical and chemical composition of the planetary atmosphere. The best data we have on the Martian atmosphere were obtained by the Mariner IV occultation experiment (Refs. 1, 2, 3, 4); therefore it is important to make the best possible analysis of this limited data for application to the blackout problem. The entrance data were obtained on both an open- and a closed-loop receiver. The closed-loop receiver gives an integrated cycle count and permits a higher degree of accuracy than the data processing employed on the open-loop receiver. The open-loop receiver was used to obtain spectral analysis over one-second intervals and therefore yielded only frequency as a function of time rather than the cycle count integral. On the exit from occultation only the loop receiver data were available and so only frequency-vs-time information has been obtained.

A digital computer program has been prepared to obtain cycle integration data from the existing tapes. These data will be used for further refinement to the model of the Martian atmosphere. This data reduction technique will also be applied to the Mariner V radio occultation experiment to determine the atmospheric parameters of the planet Venus.

Proposals have been received in response to an RFP and are being evaluated for a study of propagation phenomena to be expected in a Mariner '71 vehicle landing on Mars. It is anticipated that this contract will be placed in the first half of FY 1968.

Dr. G. Cohn of Quantum Engineering has conducted a study under a JPL contract to determine the effect of entry plasma on the telemetry link of a Voyager Mars lander. The effects of both frequency shift and attenuation were studied, and a report has been issued. The plasma environment model used in this study was adopted from D. Spencer (Ref. 5). It was found that for the model used both attenuation and frequency shift can be significant effects.

As a spacecraft enters the atmosphere of Mars, a plasma column trailing the spacecraft is generated. The strength and frequency of the signal originating from the spacecraft are greatly affected by the presence of this plasma column. The objective of this investigation was to obtain an estimation of the frequency shift as well as the attenuation of the signal passing through the plasma column based on an idealized model (Ref. 1) (see Fig. 1). It is assumed for this model that (1) the plasma is confined to a cylindrical column swept out by the spacecraft, (2) the plasma is uniformly distributed over each circular cross section of the column, and (3) the density of the plasma varies along the column in accordance with the generation rate and the decay rate of the plasma for the nonfrozen flow model. Furthermore, it is assumed that the plasma medium may be adequately described by a cold plasma permittivity constant with loss. The velocity, electron collision frequency, and plasma frequency as functions of altitude are shown in Figs. 2, 3, and 4.

Figure 5 shows the total frequency shift as seen at the earth due to both orbital doppler and to the frequency perturbations due to the media. The calculated plasma attenuation is also presented on the same graph. It can be seen that the frequency shift due to the plasma becomes significant when the attenuation would make tracking high frequency rates most difficult.

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1. Kliore, A., Cain, D. L., Levy, G. S., Eshleman, V. R., Fjeldbo, G., and Drake, F. D., Science, 149, 1243, September 10, 1965.

2. Cain, D. L., Drake, F. D., Eshleman, V. R., Fjeldbo, G., Kliore, A., and Levy, G. S., Proceedings of the Ionospheric Research Committee of the Avionics Panel, A. G. A. R. D., N. A. T. O., Rome, Italy, September 21-25, 1965.

3. Kliore, A., Cain, D. L., Drake, F. D., Eshleman, V. R., Fjeldbo, G., and Levy, G. S., Proceedings Caltech-JPL Lunar and Planetary Conference, Pasadena, California, September 13-18, 1965.

4. Kliore, A., Cain, D. L., and Levy, G. S., Radio Occultation Measurement of the Martian Atmosphere Over Two Regions by the Mariner IV Space Probe, COSPAR, Vienna, Austria, May 11-17, 1966.

5. Spencer, D. F., An Evaluation of the Communication Blackout Problem for a Blunt-Mars-Entry Capsule and a Potential Method for the Elimination of Blackout," JPL TR 32-594, April 15, 1964.

PUBLICATIONS DURING REPORT PERIOD

JPL Technical Report

Levy, G. S., "Polarization Measurement" in The Superior Conjunction of Mariner IV, R. M. Goldstein, et al., TR 32-1092, April 1, 1967.

Contractor Report

Cohn, G. I., Preliminary Estimate of Perturbation in the Mars-Voyager-Mission Entry Vehicle Telecommunication Link Caused by Ionization of the Martian Atmosphere, Quantum Engineering, Pasadena, California, JPL Reorder 67-228, March 1967.

ANTICIPATED PUBLICATIONS

None.

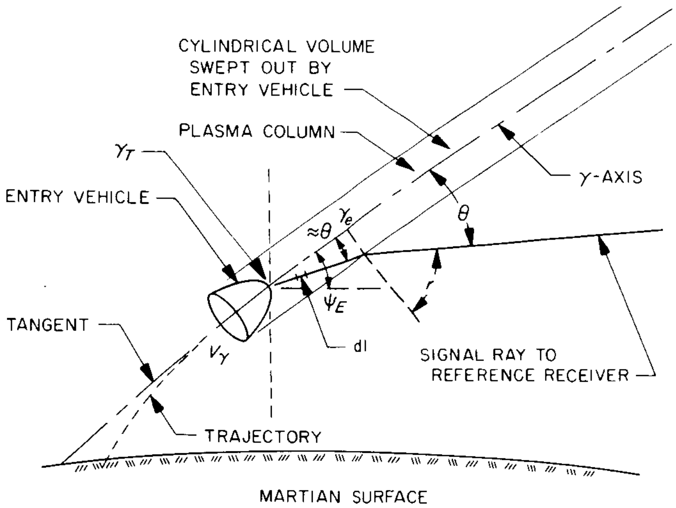

Fig. 1. Entry vehicle, trajectory, and plasma column configuration.

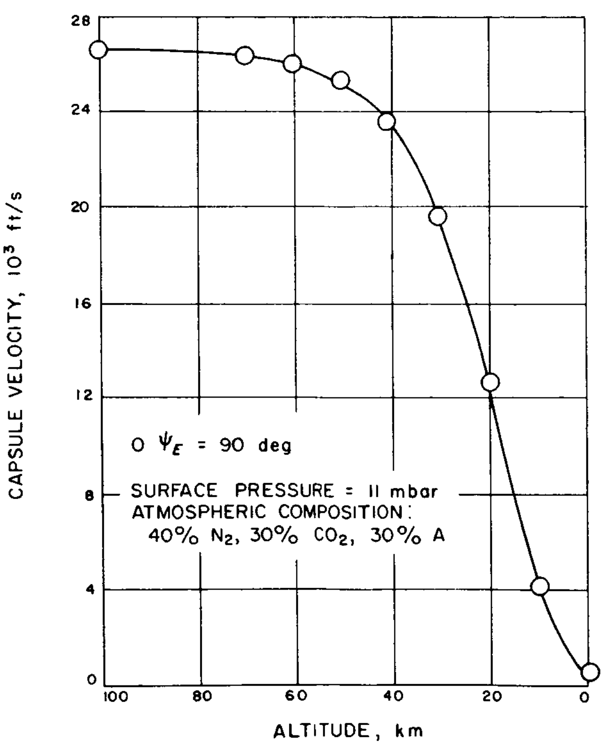

Fig. 2. Velocity vs altitude.

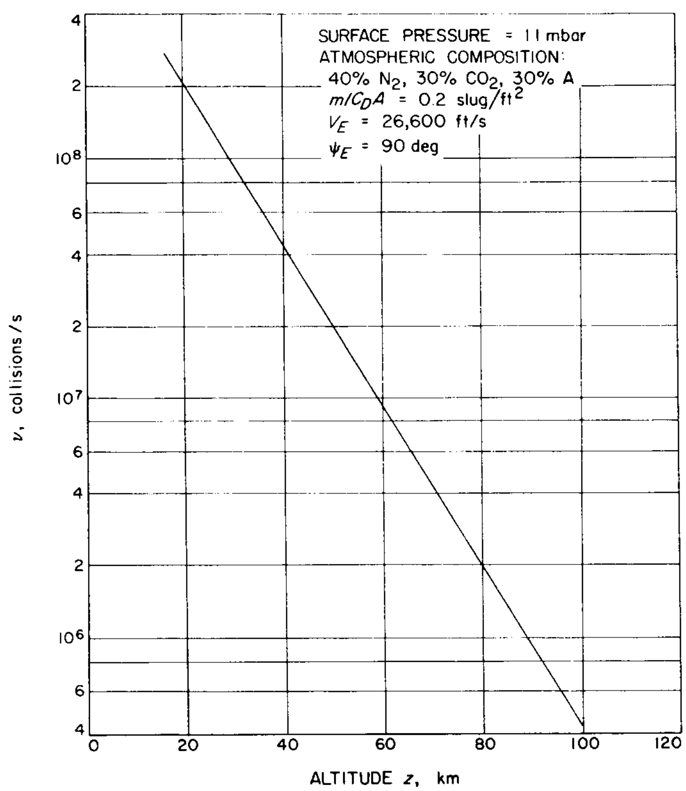

Fig. 3. Electron collision frequency vs altitude.

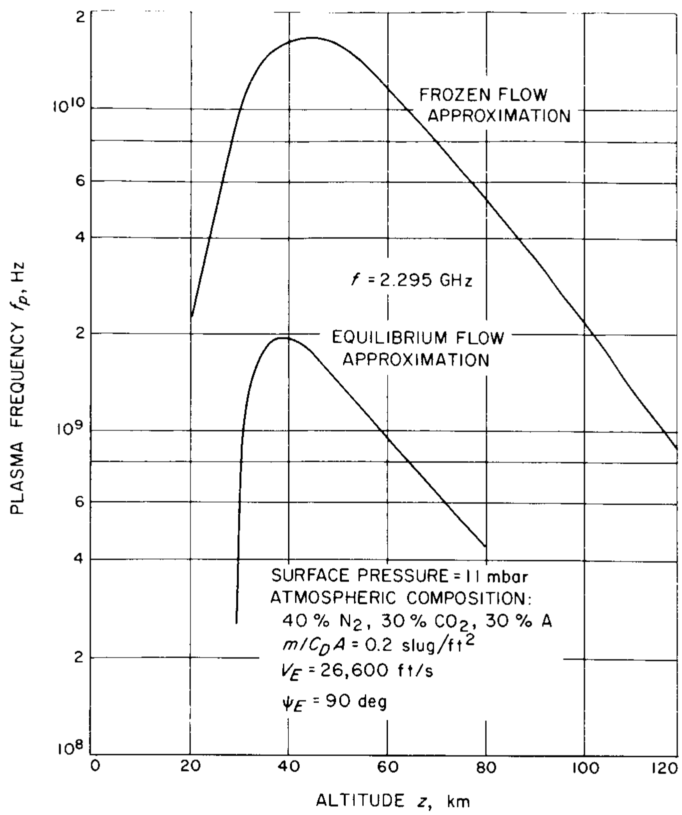

Fig. 4. Plasma frequency vs altitude

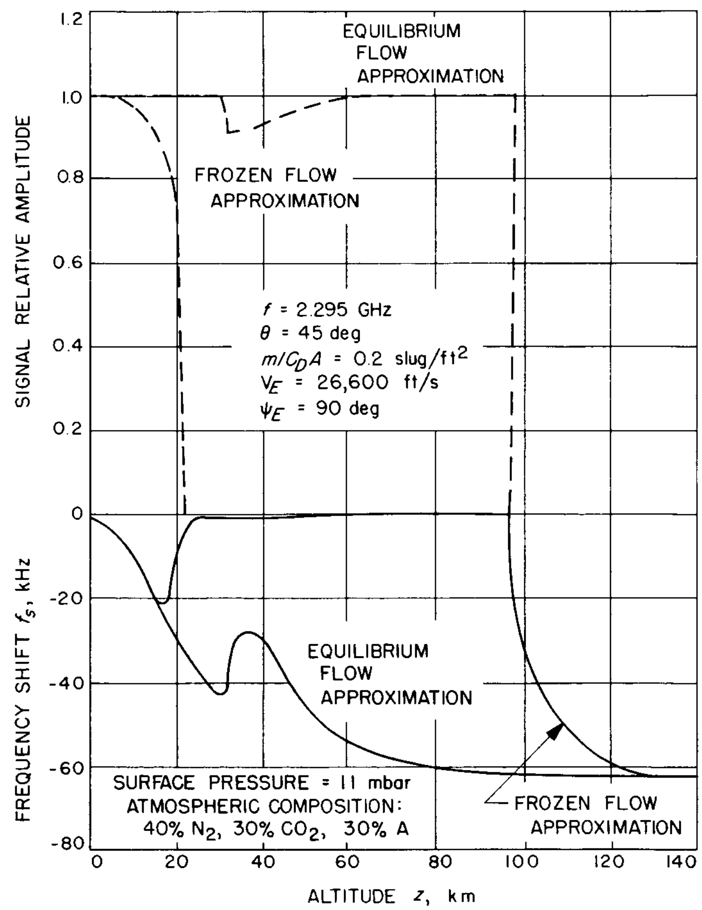

Fig. 5. Frequency shift and signal relative amplitude vs altitude

LOW NOISE TRANSPONDER PREAMPLIFIER DEVELOPMENT

NASA Work Unit 150-22-17-01-55
JPL 350-70100-1-3330

W. Higa
S. Petty

OBJECTIVE

The objective of this task is to study and develop low noise technology for spacecraft receiver front ends. The goal will be to minimize noise figure, size, and input power while maximizing reliability.

LOW NOISE TRANSPONDER PREAMPLIFIER DEVELOPMENT

A tunnel diode amplifier is currently being evaluated. These devices are very promising from the point of view of dc power requirement. Typically 10 to 20 mW of power is required. However, the bias regulating circuit usually dissipates a lot more power than this, and the power requirement is increased to approximately 1/2 W. Thus, an area of investigation shall be the development of more efficient bias regulating circuitry. The noise figure of tunnel diode amplifiers is in the order of 4 dB and the power gain around 20 dB.

A parametric amplifier with solid-state pump source will be delivered shortly and will be compared with the tunnel diode amplifier. A procurement has been initiated for a transistor amplifier which will meet spacecraft requirements.

Analyses (JPL SPS 37-45, Vol. III) indicate that a preamplifier with a noise figure of 4 to 5 dB with a gain of around 17 dB is required to provide a 3 dB improvement in the noise figure (8 dB) of the mixer currently being used on spacecrafts.

Future plans, in addition to testing manufactured devices, include studies of efficient power supplies (for tunnel-diode amplifiers) and efficient solid state frequency multipliers (for paramps).

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

RANGING TRANSPONDER
NASA Work Unit 150-22-17-03-55*
JPL 350-70300-X-3360

L. M. Hershey

OBJECTIVE

The objectives of this work unit are (1) to complete the development of the Mariner S-Band, turnaround ranging transponder in order that the technique may be confidently employed by advanced projects and (2) to modify the Mariner transponder for multiple project utility and to extend its ranging capability beyond lunar distances.

PROGRESS

The improvement of the Mariner C transponder design was originally defined as a two-phase task. The first phase consists of a study of the existing transponder circuitry, the recommending of design changes to the transponder, and the demonstration of the performance improvement capability of selected design changes by modifying an existing Mariner C transponder. The second phase was to be the fabrication of a complete engineering model transponder based on selected results of phase I.

Both phases were funded. The statement of work for phase I was written and approved, and procurement action was completed. Upon evaluation of the proposals, Philco-Ford SRS, was selected as the contractor and a contract for phase I only was signed on February 28, 1966 (JPL Contract 951290). The contract for phase II was not signed but funds were held for it, pending completion of phase I.

Because of the number of problems that were uncovered under phase I, and because of the limitations of available resources, both manpower and funds, phase II was redefined. Funds that were being held for phase II were added to phase I by contract modification. Emphasis was placed on the measurement of ranging time delay variations with temperature.

Final results of the redefined testing program are expected early in the next reporting period.

Instead of developing a complete improved transponder in one step, development contracts will be let for improved modules, a few modules at a time. This improvement process will be continued until the entire transponder has been improved and upgraded. Module interface responsibility will be retained in-house.

DESCRIPTION OF TRANSPONDER

The S-band transponder provides the functions of a double superheterodyne command receiver, a phase-coherent transponder, a turnaround ranging transponder, and a telemetry transmitter. It employs three loops as shown on the block

*Jointly funded under NASA Work Unit 186-68-04-20-55.

diagram of Fig. 1. These loops are the ranging, automatic gain control (AGC), and automatic phase control (APC) loops. In the absence of a received signal from the DSIF, the spacecraft telemetry information is modulated on a signal whose frequency is controlled by an auxiliary oscillator. When a signal from the DSIF is present in the transponder receiver at a level of about -150 dB or higher, the APC loop will lock to it, and AGC voltage is developed in the AGC loop. This voltage, besides controlling the receiver gain for proper operation, also produces a command voltage that turns off the auxiliary oscillator and causes the 19.125-MHz VCO to be switched to the transmitter input in its place. In this manner, closing the APC loop provides an exact ratio of 240/221 between the transmitted and received frequencies. In addition, the AGC voltage is telemetered to provide received signal strength information.

The signal received from the DSIF may have either ranging information or command information phase-modulated on it. The second mixer provides two outputs, one to the 9.56-MHz narrow-band command and APC channel and another to the broad-band 9.56-MHz ranging channel. The ranging code is demodulated by the phase detector in the ranging channel, amplified, and remodulated onto the transmitted signal along with the telemetry. The command information is demodulated by the phase detector in the narrow-band channel.

TRANSPONDER PROBLEMS

Because of the tight Mariner C schedule, some design problems had to be allowed to remain in the transponder. In order to correct them, and to bring the transponder closer to the present state of the art, the transponder improvement program was begun.

The problems which remained in the transponder were system problems and problems peculiar to individual modules.

Three main system problems were found to exist. Solutions to two--the self-lock and AGC problems--were reported previously. The turnaround ranging delay problem is being studied now, and results obtained to date will be described.

Module performance parameters were unstable with temperature and voltage fluctuations; the modules were not readily reproducible; test and adjustment was a long and tedious process.

The ranging improvements are directed toward reducing the turnaround ranging time delay variations through the transponder and increasing the ranging modulation bandwidth.

The time delay through the Mariner C transponder varies with temperature by as much as 200 ns. The DSIF specifies a maximum variation of 100 ns, but future programs are expected to require a reduction of at least one order soon, and eventually two orders. A 3-h stability of 0.7 ms is required for calibration of charged particle effects on Voyager.

Delay measurements are being made with each module subjected individually to temperature tests in order to isolate the causes of the variations, and analysis of these effects is carried on simultaneously. Ranging modulation bandwidth improvements have been designed and tested. They are being applied on the Mariner 69 transponder, based upon results of this study.

Analysis and breadboard tests of partial and whole modules resulted in improvement of nine of the fourteen modules in the transponder. Ranging tests, now under way, indicate the need for further improvement of modules.

STUDY PROGRAM

Under the study program, as reported six months ago, seven modules were analyzed, three were breadboarded, and partial breadboards were built of four more. Since that report, the frequency divider was analyzed, and an improved video amplifier breadboard was built. This module is being tested at present. Additional analytical work was done on the ranging system and on the mixer preamplifier, second IF amplifier, and isolation amplifier. Some of the results of this study are being incorporated in the Mariner 69 transponder and modules will be available for test from that program soon.

RANGING TESTS

The ranging test plan starts with overall tests of an old transponder. Ranging and S-band phase delay variations are taken with the transponder at 8 different temperatures and at 5 different input levels. Next, the same tests are repeated with each six-pack alone subjected to the temperature range; then each individual module is subjected to environment. Certain diagnostic checks are made to aid in the analysis of the results. Available new improved modules will be tested next individually, then in six-packs, and finally a complete transponder using all available new modules will be tested. The results of these tests to date will be described now.

First, the entire transponder was placed in a temperature chamber, and ranging phase delay variations were measured at up-link signal levels of -70, -90, and -110 dBm over the temperature range of -10 to +75°C. The -90-dBm measurements were approximately the same as -70 dBm. Measured performance data at -70 and -110 dBm are shown in Fig. 2. Then similar measurements were made with each six-pack subjected to temperature variations by itself, while the remainder of the transponder was held at room temperature.

The 498-kHz phase delay variation of the entire transponder measured about 15 deg over the type approval temperature range.

However, when individual six-packs were subjected to temperature variations it was found that receiver package 1 (preselector, mixer-preamplifier, 47.8-MHz IF, 9.56-MHz IF, and X36 multiplier) produced a phase shift of 38 deg over the temperature range as shown in Fig. 3. Receiver package 2 (phase detector, frequency divider, VCO, isolation amplifier, and video amplifier) produced a phase shift of 8.5 deg in the opposite direction shown in Fig. 4. The transmitter package (auxiliary oscillator and X30 multiplier) produced a phase shift of 11 deg shown in Fig. 5, also opposing the shift of receiver package 1. In order to further isolate and identify the causes of phase variations, individual modules are being subjected to temperature variations as the next step.

To date, only the 9.56-MHz IF amplifier has been evaluated in this manner. Its effect on ranging delay, when it was placed in the temperature chamber alone, is shown in Fig. 6. The effect is much greater than that observed with its entire six-pack in the oven.

The 9.56-MHz amplifier is not directly continued in the turnaround ranging loop; it is a part of the APC loop that furnishes the reference signal for the ranging phase detector. It was therefore hypothesized that a change in the phase of the signal at the APC loop detector, caused by temperature variations, was affecting the ranging delay at the ranging phase detector by changing the phase of the reference signal.

To determine if this hypothesis was tenable, a measurement was made of the effect of ranging detector reference signal phase on the ranging delay through the transponder. A strong effect was found to exist.

To further test the validity of the hypothesis, the measured RF phase shift through the IF amplifier as a function of temperature and the measured effect of ranging detector reference phase upon ranging delay were used to calculate the effect of second IF temperature on ranging delay. The results were entered as points on Fig. 6. Fairly good agreement is demonstrated between -10 and +40°C, but the results deviate sharply at higher temperatures. The tentative conclusion was that the hypothesis is partially correct, but that some other mechanism was also contributing, and that the effect of the other mechanism was predominant at higher temperatures.

It should be noted that the 9.56-MHz IF amplifier used in these tests exhibits phase shifts in excess of the limits specified for this module, although it had been tested previously (and passed) to these specifications. The specified limit of ±15-deg phase variation through the IF would result in 10-deg overall ranging delay variation, which is still a major contribution to the total.

The effect of the reference phase on ranging delay could not be explained by the analytical model commonly used for a phase detector, so some further investigation was undertaken.

The partial schematic diagram in Fig. 7 shows the principal ways in which the second IF amplifier module can affect the ranging signal. The command and ranging circuits are partially isolated from each other by the 18-Ω resistors in a Y configuration at the second mixer output. The input impedance to the second IF amplifier is 50 Ω resistive through a narrow frequency band of about 4.5 kHz centered on 9.56 MHz. The ranging signal occupies about 3 MHz bandwidth.

The reference voltage to the ranging phase detector is supplied from the VCO through the frequency divider, so its phase varies with phase variations from the second IF input to its limited output. Therefore, it appears that the ranging signal could be affected by a phase variation in the IF, VCO, or frequency divider. It could also be affected by the crystal filter's input impedance in a somewhat different manner. Here, impedance variations across the broad spectrum of the ranging signal causes phase and amplitude distortion of the ranging signal. The distorted signal is affected by phase variations in the ranging detector's reference voltage.

To investigate the crystal filter's effect, the amplitude and phase characteristics of the ranging channel from the second mixer to the isolation amplifier input range centered about 9.56 MHz using the normal circuit. The result seen in Fig. 8 showed over 6 dB amplitude and over 50 deg of phase variation over the frequency range.

The addition of 20 dB 08 isolation in the crystal filter input circuit reduced its effect upon the ranging signal to about 1 dB of amplitude and 10 deg of phase nonlinearity in the ranging bandwidth.

In the Mariner 69 transponder, the addition is being considered of an isolation amplifier in the 47.8-MHz IF amplifier module to provide the necessary isolation.

An additional contribution to ranging phase delay variations was found in the frequency divider. When tuned in the usual manner, its output spectrum contained a substantial amount of VCO frequency divided by four and its odd multiples in addition to the desired VCO frequency divided by two. Careful tuning of the divider input circuit while observing the module's output on a spectrum analyzer resulted in virtual elimination of the undesired spectrum components, and a reduction of the effect of ranging delay on reference phase by about 1/3. The module specification is being changed to require the use of a spectrum analyzer for proper tuning.

The effect of reference phase error on overall ranging delay is shown in Fig. 9. When the frequency divider is properly tuned for a clean spectral output the slope of the curve is reduced by about one third. When, in addition, the crystal filter is isolated from the ranging channel, the effect of detector reference phase variations is reduced as shown in Fig. 9. The specified phase variation limit through the 9.56-MHz IF is ±15 deg over the temperature range. This should produce less than ±3 deg variation in the ranging signal, with the modified circuit.

VIDEO AMPLIFIER

The old video amplifier was analyzed and recommendations made for its improvement during the early part of the transponder study. Problems of particular concern to Mariner 69 were the variation in output level with temperature and time delay variations with input signal level.

A breadboard has been built of a new video amplifier using differential transistor limiters instead of the back-to-back diode limiters used in the old video amplifier. Tests of the new breadboard indicate superior performance in critical areas as shown in Table 1. The output level vs temperature performance has been improved by nearly four to one. The output variation with input level of the new module is too small to measure over ±10 dB input range. The time delay of the new module varies about half as much as the old over the temperature range. Time delay over ±10 dB input change is improved. The greater frequency response of the new amplifier resulted in a decrease in rise time from 80 to 55 ns, and improved filter characteristics reduced under and overshoots to negligible amounts. The new video amplifier will be used in Mariner 69.

Table 1. Video amplifier performance

	Old	New
Δ Output vs temperature (-10, +75°C)	1.9 dB	0.5 dB
Δ Output vs Input (±10 dB)	0.5 dB	<0.1 dB
Δ Delay vs temperature (-10, +75°C)	20 ns	10 ns
Δ Delay vs input (±10 dB)	20 ns	15 ns
Rise time	86 ns	55 ns
Overshoot/undershoot	5/10%	0/0%

OTHER MODULES

Some minor improvements have been made in the performance of certain other modules during this period. The mixer performance has been improved still more than the 1-dB worst case noise figure improvement reported last period. It was found that a selected low-noise version of the new hot-carrier diode used in the redesigned mixer can be substituted directly with a resultant transponder noise figure improvement of another 1/2 dB.

The 9.56-MHz IF amplifier tuned circuits was temperature-compensated to reduce reference signal phase effects upon ranging time delay. This change was applied to the Mariner 69 transponder.

PUBLICATIONS DURING REPORT PERIOD

JPL SPS Contributions

1. Hershey, L. M., "Mariner S-Band Turnaround Ranging Transponder Improvement Program," SPS 37-43, Vol. IV.

2. Hershey, L. M., "Mariner S-Band Turnaround Ranging Transponder Improvement Program," SPS 37-44, Vol. IV.

Contractor Reports

1. Philco-Ford SRS Monthly Progress Reports for the months of January through June 1967 (JPL Contract 951290).

ANTICIPATED PUBLICATIONS

JPL SPS Contribution

1. Hershey, L. M., "Mariner S-Band Turnaround Ranging Transponder Improvement Program."

Contractor Reports

1. Philco-Ford SRS Monthly Progress Reports.

2. Philco-Ford SRS Design Study of the JPL S-Band Turnaround Ranging Transponder--Final Engineering Report (JPL Contract 951290).

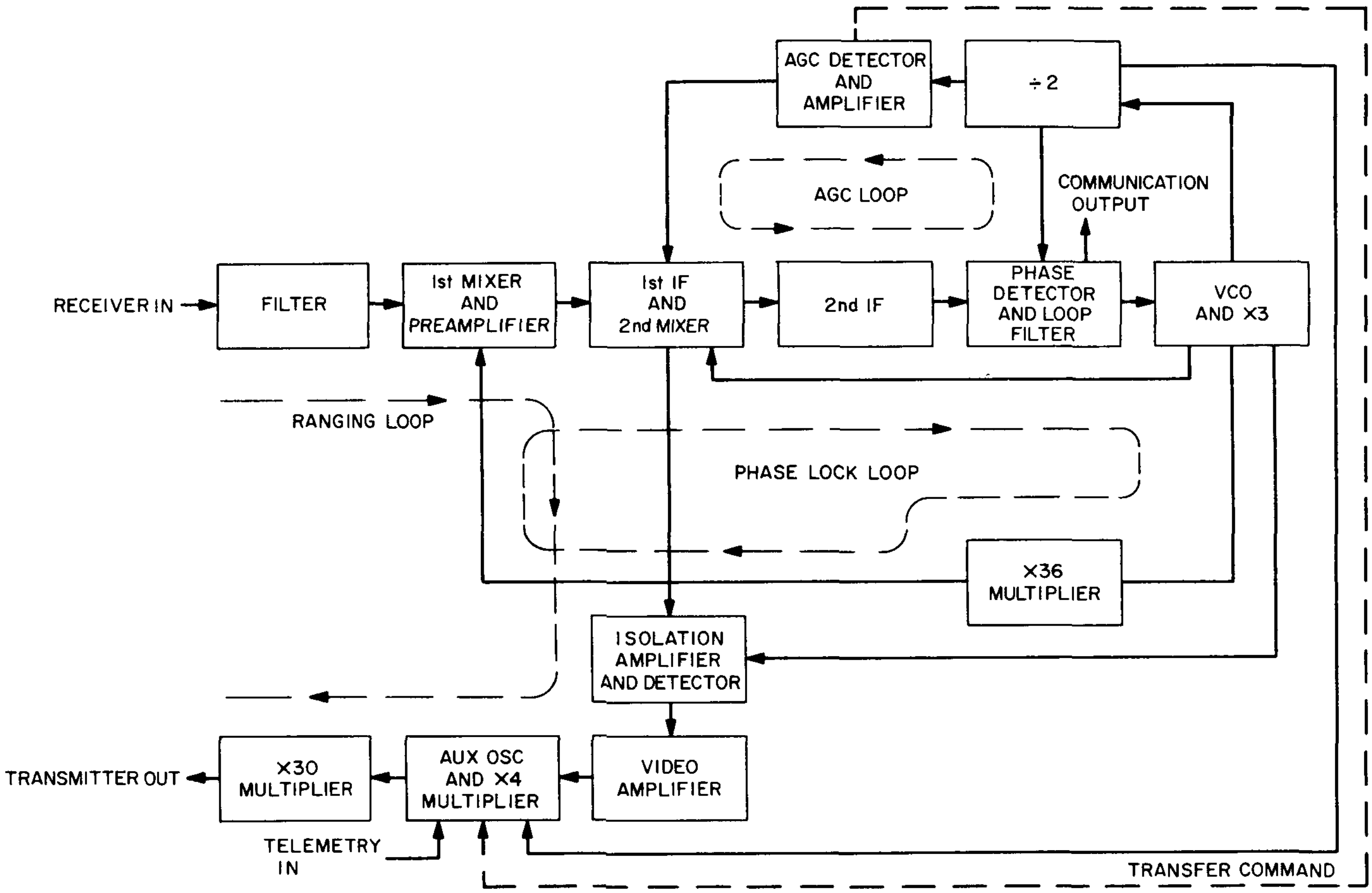

Fig. 1. S-band ranging transponder

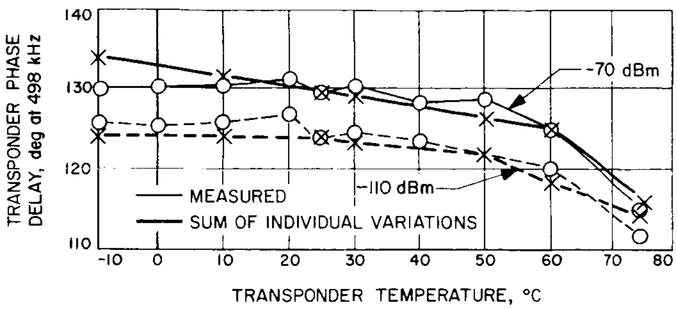

Fig. 2. Mariner C transponder ranging delay variations

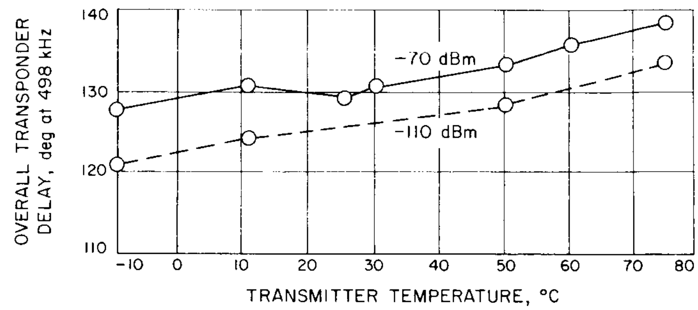

Fig. 5. Ranging delay variations vs transmitter peak temperature

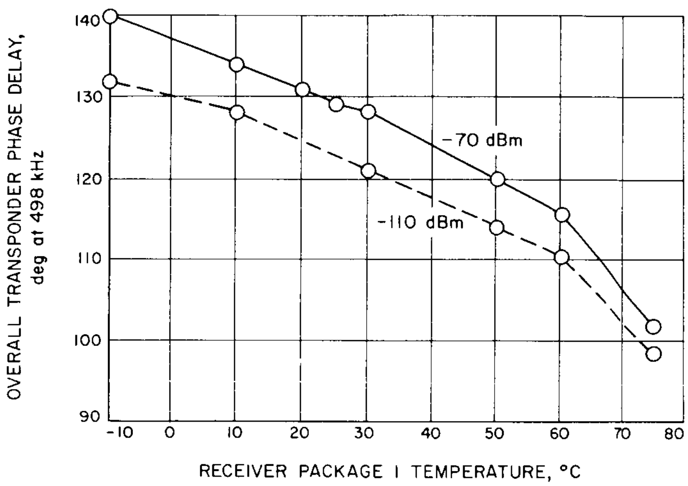

Fig. 3. Ranging delay variations vs receiver package 1 temperature

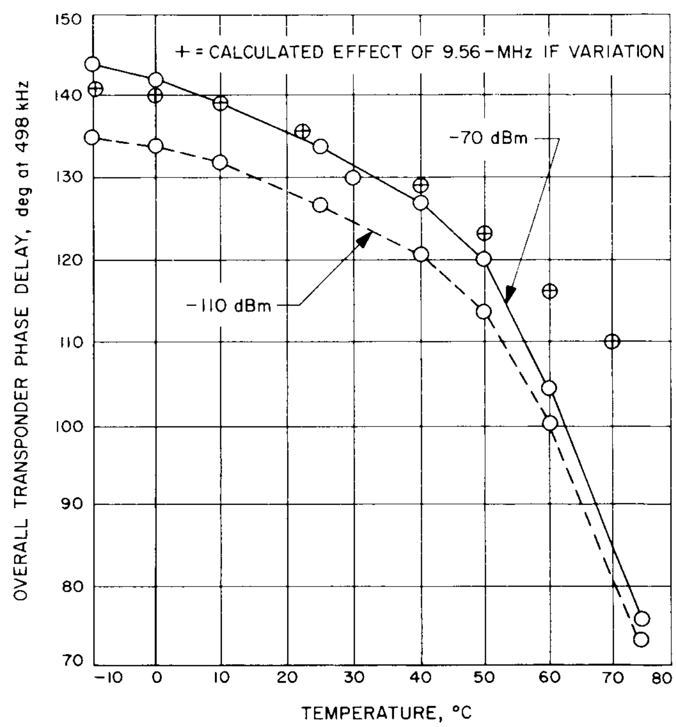

Fig. 6. Ranging delay variation, 9.56 MHz IF

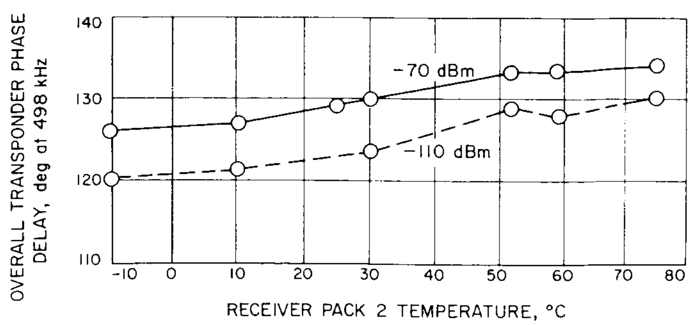

Fig. 4. Ranging delay variations vs receiver package 2 temperature

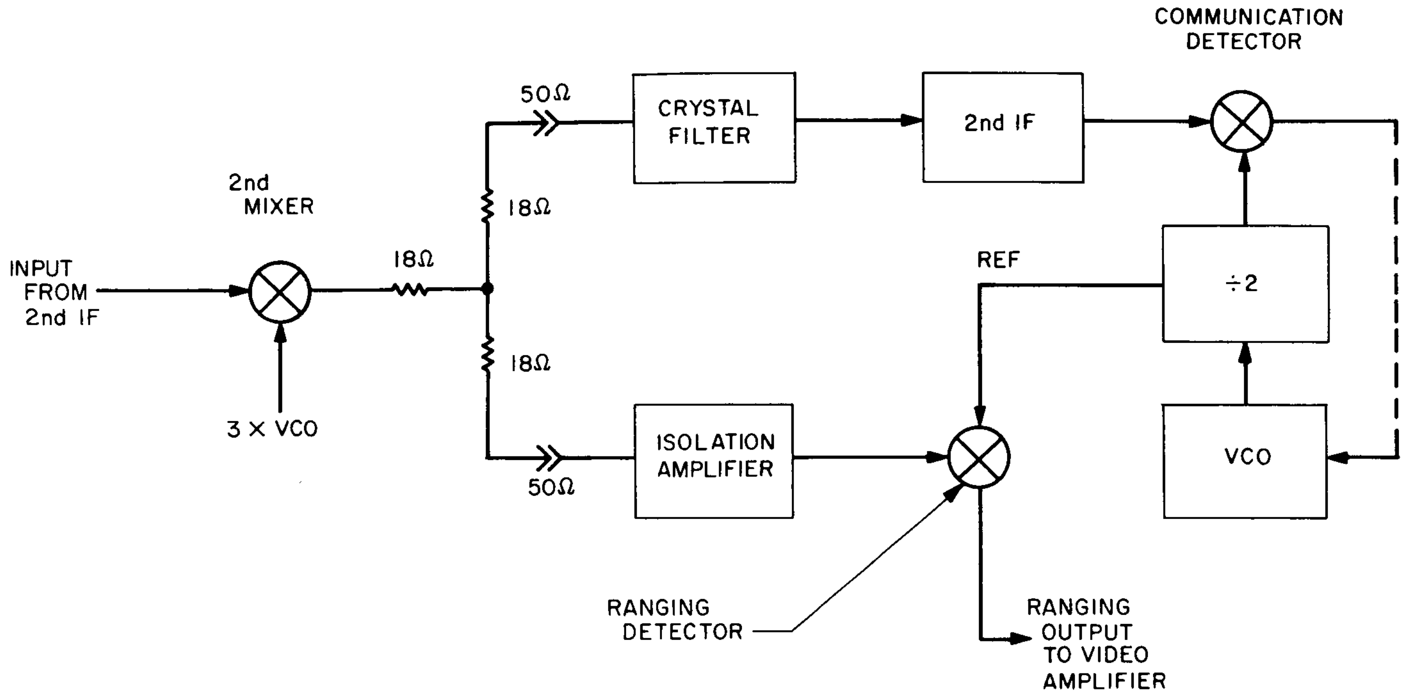

Fig. 7. Partial ranging diagram

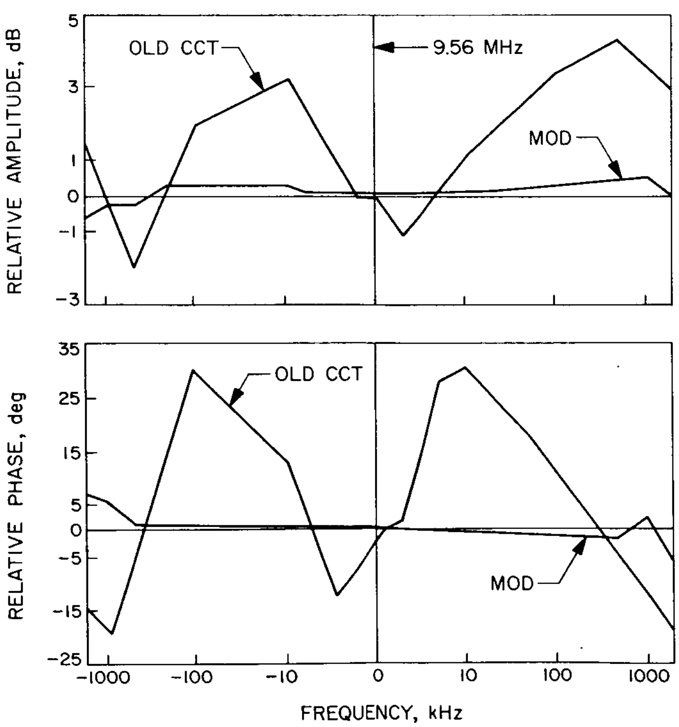

Fig. 8. Effect of crystal filter on ranging signal

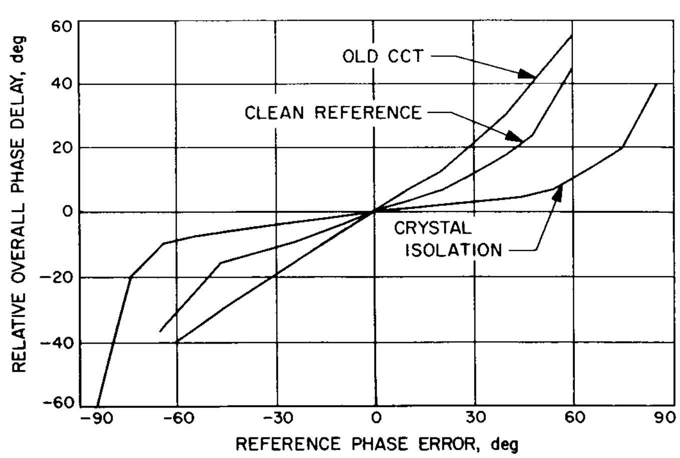

Fig. 9. Overall transponder ranging delay vs detector reference phase

LOW-DATA-RATE MFSK MODULATION/DETECTION SYSTEMS

NASA Work Unit 150-22-17-04-55
JPL 350-70400-2-3340
F. J. Charles
J. C. Springett

OBJECTIVE

The objective of this work unit is to develop and qualify a low-data-rate (0.5 bit/s or less) telemetry modulation/detection system for application to landed planetary capsules and deep space probes.

Basic studies relative to the analysis, performance verification, and mechanization of multifrequency FSK (noncoherent) system are being pursued. Items to be investigated include (1) analysis of the various approaches which can be used to implement a MFSK system, (2) establishment, through direct measurement, of statistical information relative to performance and the ability of the detector to synchronize to the actual signal set, and (3) alternate software implementations. The performance verification is being implemented by the use of an SDS 930 computer which operates on samples of the signal-plus-noise ensemble.

PROGRESS

During this report period the statistical properties of the spectral estimates used in the decision process by a spectrum analyzer receiver were derived and compared with the results obtained from an experimental study. These results were then used to determine the probability of error of the receiver when the computation of the correlation coefficients was prematurely terminated.

Figure 1 shows for a given signal-to-noise, the analytical and experimental results obtained for the variance of the spectral estimates as a function of the percentage of correlation coefficients computed. The variance σ_s^2 is at the frequency where the signal appears, and σ_n^2 is the variance at all other frequencies. Figures 2 and 3 clearly illustrate the degradation in system performance that results from truncating the correlation function. These results have been summarized in a paper presented at the NTC Conference in San Francisco, May 18, 1967.

ANTICIPATED FUTURE PROGRESS

Now that the studies of the performance of the ideal spectrum analyzer receiver are complete, future work will be directed toward (1) analysis of the synchronization properties of the spectrum analyzer receiver and (2) consideration of signal sets other than envelope orthogonal sinusoids.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.

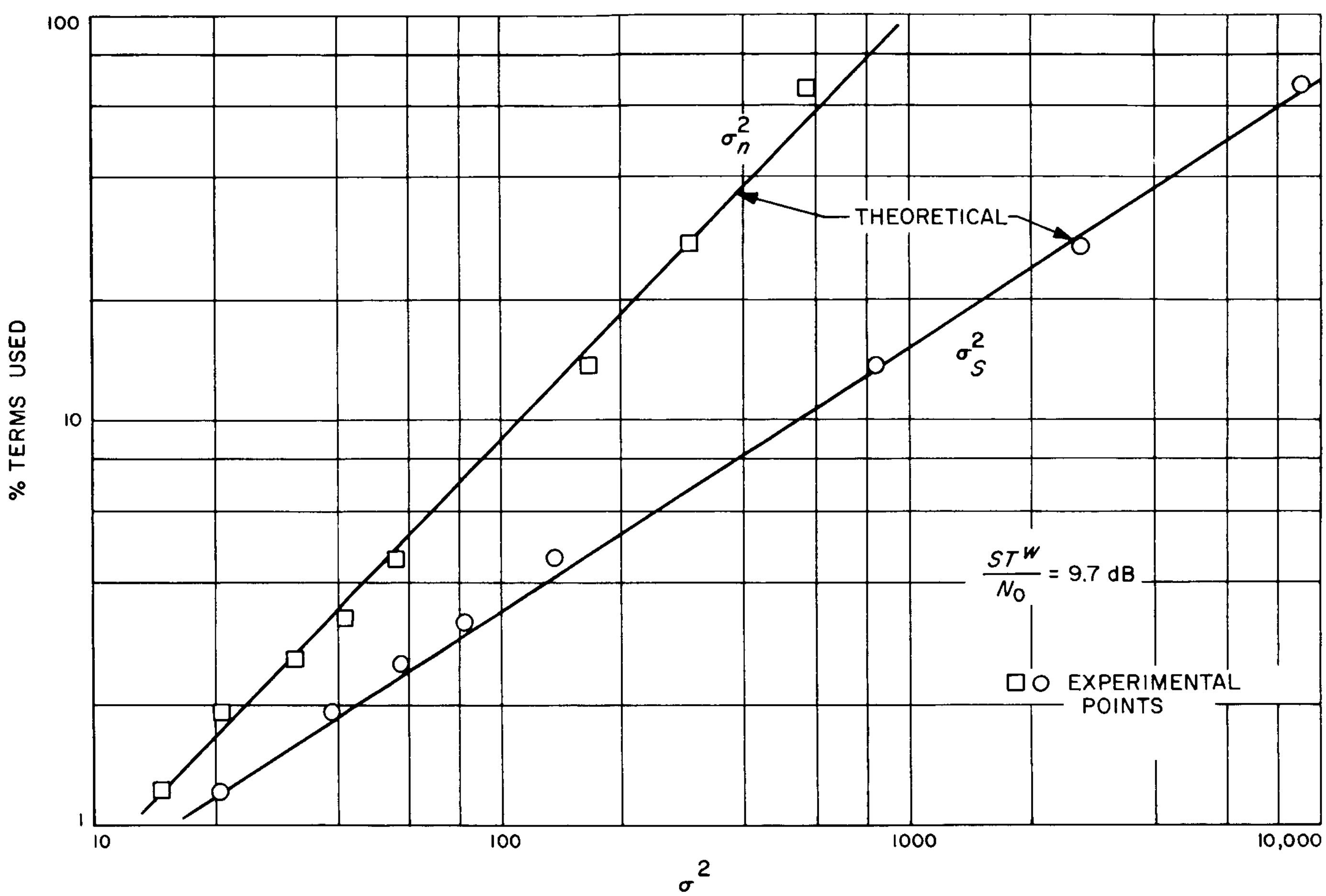

Fig. 1. Variance of spectral estimates

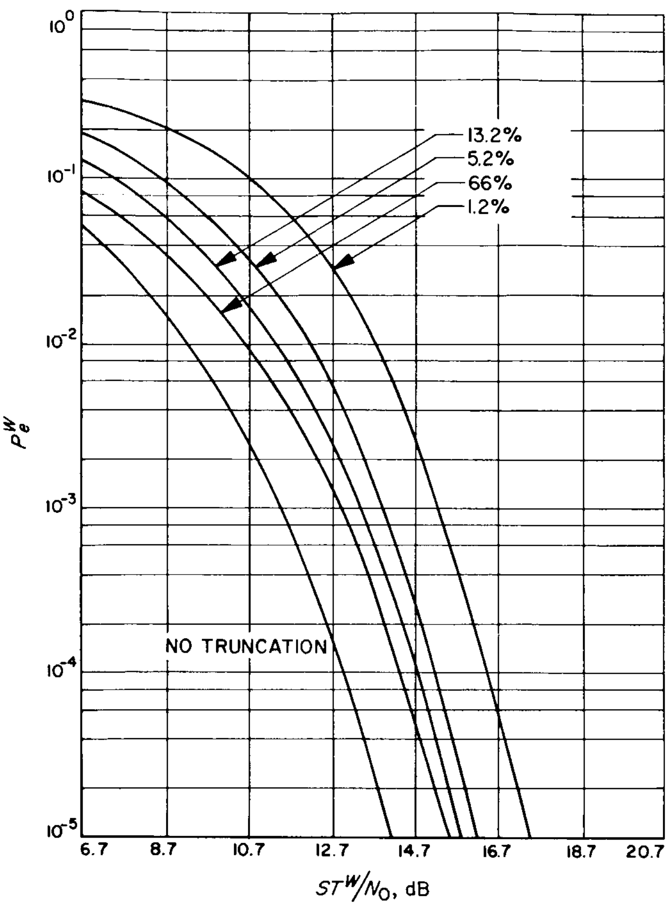

Fig. 2. Probability of error for the spectrum analyzer receiver, M = 2

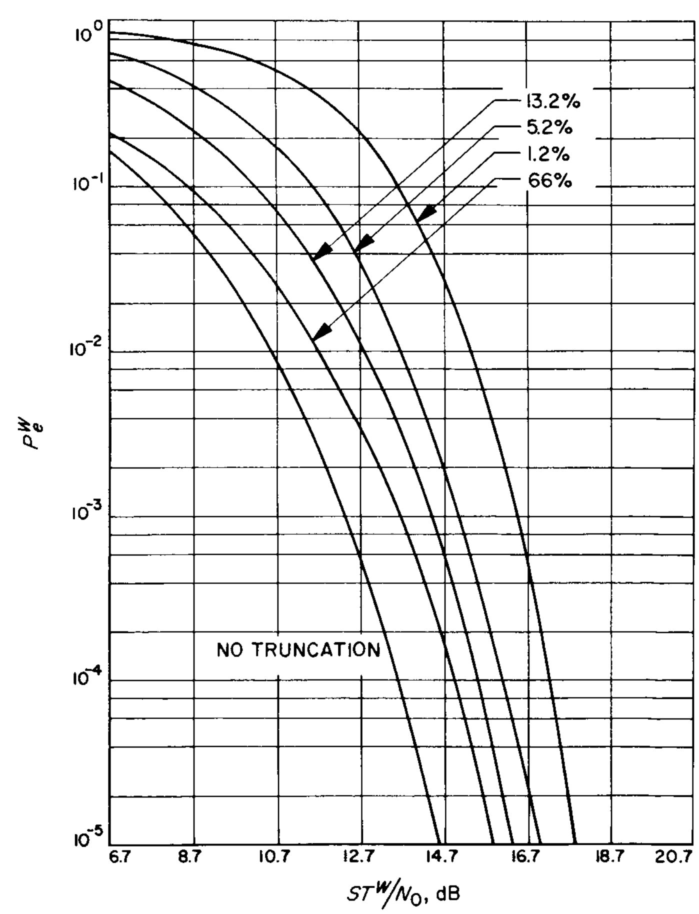

Fig. 3. Probability of error for the spectrum analyzer receiver, M = 32

LOW-DATA-RATE TELEMETRY RF SYSTEMS DEVELOPMENT

NASA Work Unit 150-22-17-06-55
JPL 350-70600-2-3360

A. W. Kermode
R. B. Postal

OBJECTIVE

The objective of this work unit is to extend the telemetry communications capability of the Deep Space Network (DSN) from its present lower limit of approximately 5 bit/s to rates of 0.1 bit/s or less. The intent is to develop a low-data-rate communications capability in support of deep solar system probes and small landed planetary capsules and for possible use as a self-contained battery powered failure mode system on any deep space mission. This is a companion task to NASA Work Unit 150-22-17-04-55 and will specifically support the development of the MFSK S-band transmitter. This transmitter will be designed to withstand a high impact landing, operate in a planetary atmosphere, and perform reliably after being subjected (nonoperating) to a heat sterilization process.

IN-HOUSE DEVELOPMENT PORTION OF THE SOLID STATE S-BAND TRANSMITTER

Figure 1 shows a block diagram of the 3-to-5-W high-impact sterilizable S-band transmitter under development. Modules 0, 1, and 2 generate a 575 MHz carrier at a level of 13 W and are being developed in-house. (With slight modifications modules 1 and 2 are suitable for use in the Capsule Relay Transmitter; see NASA 186-68-04-08-55.) These modules, with the exception of the crystal and a varactor diode, have survived 10,000-g shock levels. The varactor failure occurred at 5200 g. Additional types of varactors will be evaluated during the next reporting period. As previously reported, a heatsink problem existed in module 2 during thermal-vacuum testing (a large temperature difference was measured between chassis and the stud of a power transistor). An examination of the transistor revealed its stud mounting nut to be loose. Upon tightening the nut to the manufacturer's specifications, the temperature gradient was reduced to a normal level. Sterilization tests were performed on modules 1 and 2. These units were subjected to three 14-h temperature cycles of 145°C. No degradation in module performance was measured at the conclusion of these tests; however, there was significant discoloration of the component staking compound. RF breakdown tests were also performed on modules 1 and 2 over a wide range of pressures. No multipactor breakdown was noted at pressures between 10^{-3} and 10^{-6}mm Hg; however, ionic breakdown was observed at four locations in module 2 at a pressure of 1 mm Hg. This problem is presently being evaluated.

Considerable time and effort has been spent in the development of the MFSK modulator (module 0). The modulator circuitry consists of a low gain 31.875-MHz VCXO followed by two amplifiers. Of prime importance is oscillator frequency stability necessary to support a low-data-rate format. The proposed data profile consists of minimum word separations of only 10 Hz at S-band with a word time of 5 s. Present estimates of required frequency stability are of the order of

1×10^{-10}/s. Shown in Table 1 is a summary of modulator performance and stability tests to date. As shown, the greatest contributors to frequency instability are power supply and operating temperature changes. The frequency change due to power supply variations can be reduced to a satisfactory level of improving the power supply regulating circuits. Temperature compensation of the oscillator is extremely difficult because the Q of the frequency control circuit external to the crystal is very low. It is proposed to limit the frequency change due to temperature by using a crystal whose frequency-vs-temperature characteristics are $\pm 50 \times 10^{-9}$/°C or less and by limiting the rate of temperature change of the oscillator module to $\lessapprox 0.002$°C/s. Proportional oven and insulation techniques are being investigated.

ISOLATOR (JPL CONTRACT 951565)

An isolator is required to prevent instabilities in S-band solid state transmitters due to output impedance mismatch. The objective of the contract with the Rantec Corporation was to study the effects of heat sterilization (+135°C) and high impact (10,000 g) on magnetic materials typical of use in an S-band isolator. A high impact circulator structure was developed for use in evaluation of the magnetic materials.

The best combination of magnetic materials, resulting from the materials study, was assembled into a prototype high-impact circulator structure. The materials used were Trans-Tech G-600 garnet discs, Alnico 8 permanent magnets, and 0.050-mil Mumetal shielding straps. The circulator structure is shown in Fig. 2.

The prototype circulator was evaluated at JPL. The evaluation involved sterilization tests of three 26-h cycles of ETO gas treatment and three 64-h cycles of 135°C heat treatment, and high-impact (10,000 g) shock tests with magnetic mapping and electrical performance checks before and after the sterilization and shock tests.

The maximum radial magnetic field, as measured on the initial mapping, was less than 2.4 gamma at 1.5 ft. The maximum variation in the radial magnetic field was ±0.6 gamma, during exposures of forty (40) gauss deperm., followed by twenty-five (25) gauss perm., followed by eighty (80) gauss deperm.

Two RF connectors were damaged during the second high impact shock (10,000 g) test, due to a failure of the mounting screws. Consequently, the performance evaluation was not completed. The insertion loss and isolation performance characteristics of the prototype circulator have been summarized in Table 2 and in Table 3, respectively.

It can be concluded from the results of the study contract that suitable magnetic materials and mechanization techniques exist, such that an S-band isolator capable of surviving high-impact shock environments and sterilization is practical.

Obligations to date are $15,200. A contract is presently being negotiated for development of two high-impact, sterilizable prototype S-band isolators.

HIGH-IMPACT QUARTZ CRYSTAL DEVELOPMENT (JPL CONTRACT 951080)

The purpose of this contract is to develop a high-impact sterilizable crystal for use in the 3- to 5-W S-band transmitter. The vendor, Valpey-Fisher Corporation, has been under stop-work-order since January pending JPL evaluation of PTM units submitted by the vendor, and negotiations concerning a change in development plan for this contract. Of the three crystals submitted in November 1966, only one survived all the environmental requirements of the specification (JPL Spec. 30250-B). The unit also survived 8200 g shock levels but failed at 10,000 g. The remaining crystal units developed excessive phase jitter when subjected to vibration testing. Upon disassembly of one of the units, surface abrasions were found on the quartz resonator. A further examination of the ceramic holders showed high spots in the holder cavity that match the location of the resonator abrasions. This failure is apparently a manufacturing deficiency and can be corrected by careful ceramic grinding and depth measurement techniques.

In general, the change in development plan for this contract involves:

(1) Change in frequency to 31.875 MHz (from 19.125 MHz).

(2) Inclusion of the 10,000-g shock requirement to the specification.

(3) Inclusion of sterilization requirement to the specification.

Negotiations for this phase of the contract have been completed and contract reviewing is now in process. Contract distribution is expected July 17, 1967. Delivery of the ten crystals is scheduled for November 1967. Funds obligated to date are $64,000.

Two additional types of crystals were evaluated at JPL for impact resistance. One group of five TO-5 crystals (Valpey-Fisher) failed the first shock test of 5200 g. Post-test examination of these units showed the resonator to be supported with 0.001-in. ribbon leads rather than directly by the header feedthroughs. All resonators were found to be broken. Nine Midland CR-24 units were also impact-tested with the following results: two units failed at 2500 g, one failed at 5500 g, two failed at 6400 g, and two failed at 7500 g. The remaining two units survived twelve planes of testing through 7500 g. Frequency shifts of the nine units ranged between 0.3 and 5 part/10^6 per shock.

X-4 STRIPLINE FREQUENCY MULTIPLIER

As previously reported, Motorola responded to the JPL second solicitation with a bid to develop a X-4 stripline frequency multiplier capable of meeting all the requirements set forth in JPL statement of work SW 162-336. The bid was evaluated and a contract for $7,500 was awarded in January under PO BY 331739. The multiplier was delivered to JPL on May 9, 1967. Preliminary evaluation shows the unit to meet all RF specifications at room temperature under static conditions. Environmental testing will begin in July.

The high-impact work connected with this work unit is heavily supported by NASA 186-68-04-14-55, "High Impact Communications Subsystems Technology."

PUBLICATIONS DURING REPORTING PERIOD

Contractor Reports

1. Valpey-Fisher Corporation, Report Series 5718, N. Gillin, Monthly Progress Reports for the period January 1, 1967 through June 30, 1967. JPL Contract 951080.

2. Rantec, Progress Reports for the months of February and May, 1967. JPL Contract 951565.

ANTICIPATED PUBLICATIONS

1. Valpey-Fisher Corporation, Progress Reports.

2. Rantec, Final Report.

3. SPS Articles.

Table 1. Summary of MFSK modulator performance

Ambient drift (after 1-min turn-on)	0.1×10^{-9}/s
Temperature (worst case slope -10 to +65°C)	$\pm 100 \times 10^{-9}$/°C
Power supply variation (±1%)	$\pm 3 \times 10^{-9}$
Modulation sensitivity	11×10^{-9}/V
Modulation linearity (data range = 120×10^{-9})	3.3%
Crystal unit for above data is a 31.875 MHz 5th overtone (Midland ML 6-J).	

Table 2. Summary of prototype circulator insertion loss data

Frequency, GHz	Loss, dB		
	Initial bench test	Post ETO and heat sterilization (3 cycles each)	Post 10,000-g shock (single axis)
Ports I-II			
2.1	0.33	0.34	0.35
2.3	0.32	0.33	0.33
2.5	0.27	0.33	0.35
Ports II-III			
2.1	0.37	0.37	0.37
2.3	0.31	0.31	0.31
2.5	0.29	0.32	0.32
Ports III-I			
2.1	0.32	0.43	0.47
2.3	0.33	0.33	0.37
2.5	0.30	0.33	0.35

Table 3. Summary of prototype circulator isolation date

Frequency, GHz	Isolation, dB		
	Initial bench test	Post ETO and heat sterilization (3 cycles each)	Post 10,000-g shock (single axis)
Ports II-I			
2.1	35.0	36.5	42.5
2.3	33.5	37.0	34.3
2.5	32.5	29.4	30.8
Ports III-II			
2.1	31.0	37.0	34.0
2.3	32.5	24.2	23.8
2.5	32.7	26.6	26.3
Ports I-III			
2.1	27.3	28.9	30.7
2.3	34.7	34.2	34.4
2.5	36.6	37.8	34.2

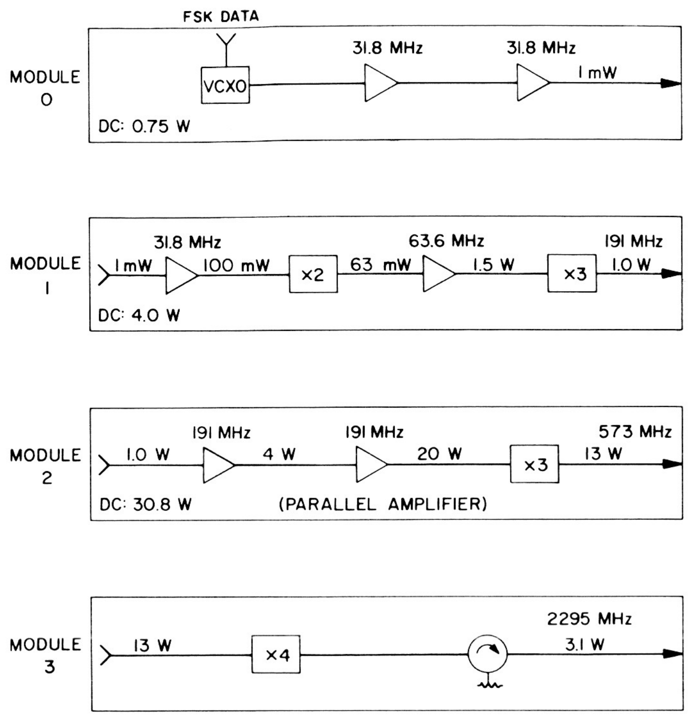

Fig. 1. Low-data-rate S-band high-impact solid state transmitter

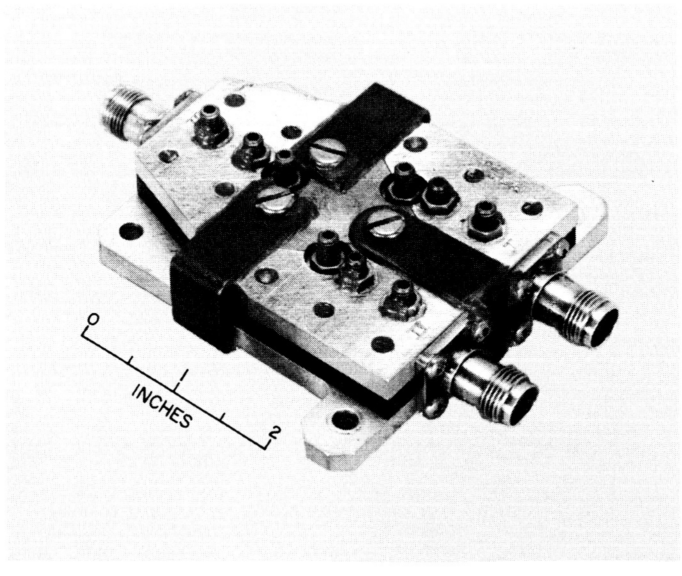

Fig. 2. Prototype sterilizable high-impact circulator

STANDARD TELEMETRY ACQUISITION AND DEMODULATION TECHNIQUES

NASA Work Unit 150-22-17-07-55
JPL 350-70700-X-3340
F. J. Charles
F. L. Larson

OBJECTIVE

The development of long-term or "standard" telemetry systems for application to all programs interfacing with the Deep Space Instrumentation Facility (DSIF) requires that various analyses and investigations be conducted relative to potential and fundamental problem areas. In particular, the interaction of proposed modulation/synchronization techniques with APC receivers, operating within the constraints imposed by the DSIF, requires considerable attention.

This task will primarily investigate the effects of threshold phenomena in coherent systems in order to more fully understand (1) the SNR degradation of received telemetry modulation and synchronization signals by noisy or imperfect demodulation references and (2) the interaction and effect of modulation signals on automatic RF acquisition receivers and the recovery of tracking information. Extensive experimental and analytical studies will be conducted to support and/or refine existing theoretical analysis and models in order to more uniquely determine the nonlinear behavior of coherent modulation/demodulation systems. The results will support the companion tasks "Standard Telemetry System Engineering" (NASA Work Unit 150-22-17-09) and "Standard Telemetry System Modulation and Coding" (NASA Work Unit 186-68-40-19).

PHASE-LOCKED LOOP STUDY

During this report period, the study of the cycle-slipping behavior of the second-order phase-locked loop was completed. Of particular interest was the probability distribution of the first time to loss of lock. The mean time to first loss of lock as a function of signal-to-noise ratio is shown in Fig. 1, α is the signal-to-noise ratio in the bandwidth of the loop. The equation $T = \alpha/(1-2 \log \alpha)$ is a fit to the experimental values. Further progress on this particular effort was not possible for most of the reporting period because of reassignment of personnel to the Mariner 69 High Rate Telemetry Project.

ANTICIPATED FUTURE PROGRESS

A large percentage of the time spent on this task during the first half of FY 1968 will be directed toward performance evaluation of the proposed Mariner 69 High Rate Telemetry System. Special attention will be given to the ability of the blocked-coded detector to synchronize, and the effects of noisy references in the proposed system.

PUBLICATIONS DURING REPORT PERIOD

SPS Contribution

1. Charles, F. J., and Larson, F. L., "The Distribution of the Time to First Loss of Lock for a Second-Order Phase-Locked Loop."

ANTICIPATED PUBLICATIONS

1. Charles, F. J., and Larson, F. L., "The First Passage Time Properties of the Second-Order Phase-Locked Loop."

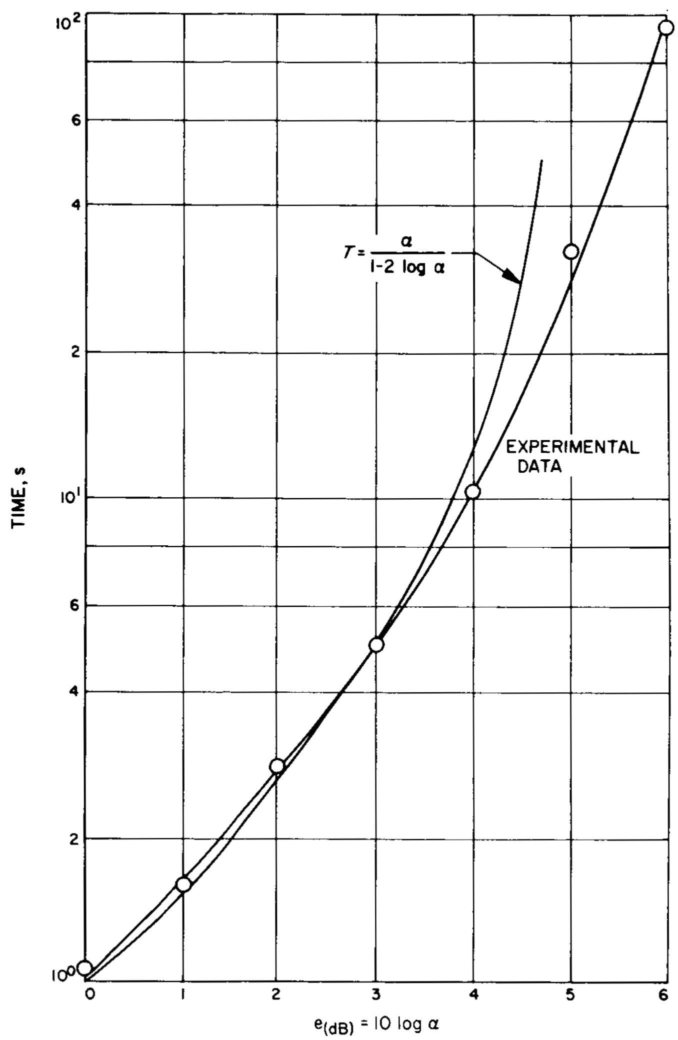

Fig. 1. Mean time to first loss of lock

DATA COMPRESSION TECHNIQUES

NASA Work Unit 150-22-17-08-55
JPL 350-70800-X-3310

Eugene R. Rodemich

OBJECTIVE

This work unit uses advanced mathematical and statistical techniques to devise and analyze methods of data compression for planetary spacecraft telemetry systems, as well as for the DSN Ground Communication System. These techniques are pushed to the point at which the work can be picked up by the companion Advanced Engineering work unit, "Data Compression Engineering," NASA Work Unit 150-22-15-14-33.

PROGRESS

During the second half of FY 1967, work continued on developing the theory of epsilon entropy as the foundation for a general theory of data compression. A major paper on epsilon entropy was accepted for publication (D-1).[1] Another paper giving more specific results will be submitted to the same journal (C-2). Further results along the same lines which may yield data compression schemes that are more easily implementable are being put into yet another paper (C-3). Some of this work was presented at a professional society meeting (A-1). Symposia on this subject were also given at various universities: University of California at San Diego, Applied Electrophysics Colloquium, February 1967, and Analysis and Probability Seminar, June 1967; UCLA Mathematics and Information Systems Seminar, April 1967. Work is proceeding vigorously on various aspects of the theory.

The applicability of quantiles to data compression was extended (B-1, B-3, D-1). A comprehensive report (D-1) on the use of quantiles for hypothesis testing in space experiments extends previous theory to six and eight quantiles, and was done to support the design of an Advanced Histogrammer-Quantiler done under the companion Data Compression Engineering work unit.

A visit was made in May (by E. Posner) to the University of Chicago, Laboratory for Space Science and Astrophysics, to confer with cognizant personnel involved in the "Chicago Cosmic Ray" experiment on board the Pioneer spacecraft. The purpose was to find out how quantiles can be used for data compression on ground lines so that the experimenters can get back real-time data from their experiment.

PLANS

During FY 1968, work will continue on various aspects of the theory of epsilon entropy, with compression ratios for various classes of experiments being found. The eigenfunction method of data compression will be studied for possible use in experiments similar to the Mariner IV magnetometer. A study of the applicability

[1]Numbers in parentheses refer to publications at the end of this work unit.

of slope tracking to TV data compression will be made. Data compression on the Ground Communication System will be sought, especially for the Chicago Cosmic Ray experiment, which, because of its many pulse-height analyses, is particularly amenable to data compression by quantiles. To support this work, methods of estimating bivariate distributions from quantiles need to be developed; such a theory will allow quantiles to be used on pulse-height experiments involving two particle detectors in series.

PUBLICATIONS DURING REPORT PERIOD

A. Symposia

1. Posner, E. C., Rodemich, E. R., and Rumsey, J., Jr., "Epsilon Entropy and Data Compression," presented by E. Rodemich at annual meeting of Society of Industrial and Applied Mathematics, Washington, D.C., June 12-15, 1967.

B. JPL SPS Articles

1. Eisenberger, I., "Use of Six and Eight Quantiles to Test Hypotheses in Data-Compressed Experiments," SPS 37-44, Vol. IV.

2. Eisenberger, I., "A Goodness-of-Fit Test Using Six and Eight Quantiles," SPS 37-35, Vol. IV.

ANTICIPATED PUBLICATIONS

C. Open Literature

1. Posner, E. C., Rodemich, E. R., and Rumsey, H., Jr., "Epsilon Entropy of Stochastic Processes," to appear in Ann. Math. Stat., September 1967.

2. Posner, E. C., Rodemich, E. R., and Rumsey, H., Jr., "Epsilon Entropy of Gaussian Processes," to be submitted to Ann. Math. Stat.

D. JPL Technical Reports

1. Eisenberger, I., Tests of Hypotheses Using Six and Eight Quantiles, submitted for JPL Technical Report.

STANDARD TELEMETRY SYSTEM ENGINEERING

NASA Work Unit 150-22-17-09-55
JPL 350-70900-0-3340
A. Couvillon

OBJECTIVE

The continuing objective of this work unit is to coordinate and gather together other Research Advanced Development efforts in the area of telemetry data handling, modulation and coding, and storage, with the intent of organizing such results into a "standard" or relatively mission-independent set of telemetry components and techniques.

PROGRESS

This work unit is to be terminated in June 1967, because its objectives have been integrated into those of other work units. For example, the search for a mission-independent telemetry modulation system has apparently been satisfied by development of the Multi-Mission Telemetry System (MMTS), the first user of which will be Mariner Mars 1969. Mariner 69 will also use a coded high-rate telemetry channel, the development of which will require the "coordination and gathering together" of coding-related work units. Such system engineering will be accomplished on other work units, so that the need for NASA Work Unit 150-22-17-09 no longer exists.

PUBLICATIONS DURING REPORT PERIOD

None.

ANTICIPATED PUBLICATIONS

None.