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REPORT NO. P68–06

STUDY AND DEVELOPMENT OF A MATHEMATICAL ANALYSIS FOR THE PERFORMANCE ASSESSMENT OF SPACE COMMUNICATION SYSTEM PARAMETERS

By L. S. Stokes, K. L. Brinkman
and
W. K. Pratt

MARCH 1968

Prepared under Contract No. NAS 12–566 by
AEROSPACE GROUP
HUGHES AIRCRAFT COMPANY
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ELECTRONICS RESEARCH CENTER
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TABLES

1.0 SUMMARY

The Hughes Aircraft Company entered into a six month contract, NAS 12-566, with the Electronics Research Center of NASA on 17 July 1967. This report is the Final Technical Report for that contract. In this summary section, four parts are given which form summaries of: 1) the contract goals and how they were met, 2) the sensitivity analysis, 3) the COPTRAN program and 4) the computer interface equipment summary.

1.1 Program Goals

The complete statement of work for contract NAS 12-566 is given in Section 6.0 and is summarized in this section as Table I-I. It is the purpose of this section to summarize these goals and to note where the documentation of their completion may be found, this now follows.

Under contract NAS 5-9637, between the Hughes Aircraft Company and GSFC-NASA, mathematical models for several types of communication were developed for transmission using laser and radio. These were combined into a single computer program, COPS, under contract NAS 12-566. The COPS program is documented in the Interim Technical Report for this contract, dated 15 October 1967. It contained the stops, detection methods and fixed values required and was delivered in the form of a FORTRAN deck also. The values for the many parameters in the COPS program were derived from actual experimental data as far as possible.

The flexible input/output investigation has resulted in COPTRAN, which enables the COPS program to be used easily. COPTRAN is documented in Section 4.0 of this report and summarized in Section 1.3 of this report. It enables a user to evaluate and select future work (Item 1d of Table I-I) and goes somewhat beyond the recommendations required by Item 2 (Table I-I).

The sensitivity analysis (Item 1f of Table I-I) was completed during the first half of the contract period and is documented in the Interim Technical Report. A summary of that analysis is contained in this report in Section 1.2.

TABLE I-I
SUMMARY OF PROGRAM GOALS FOR NAS 12-566

1. Extend Math Model begun under Contract NAS 5-9637

   a. It shall contain a method of evaluating and selecting future work.

   b. Additional stops, detection method, fixed values shall be included. A FORTRAN deck shall be delivered.

   c. Use of actual experimental data shall be included in the math model.

   d. The math model shall have a flexible input/output.

   e. Optimization criteria shall be reviewed.

   f. A sensitivity analysis shall be performed.

2. Investigate Executive Models

   Look at possible output forms, list steps for obtaining an executive program. A recommended approach shall be given. Factors to be included are:

   a. Investigate remote computer usage

   b. Investigate batch usage

3. Evaluate a follow-on math analysis considering the following:

   a. The optimization criteria

   b. The model versatility required

   c. Identification of parameters and rate their importance

   d. Determination of the applicability and specifications for future remote and batch analysis.

In addition to the development of COPTRAN (see Section 1.3), a second effort was expended to investigate executive use of the communications analysis. That effort was determining the equipment which would be appropriate as interface equipment between the user and the computer. The documentation of that effort is given in Section 5.0 of this report and is summarized in Section 1.4 of this report.

The evaluation of a follow-on mathematical analysis is given in Section 6.0 of this report (Item 3 of Table I-I). It is summarized in Table I-II.

TABLE I-II
SUMMARY OF PROPOSED FOLLOW ON ANALYSIS

1. Model Refinement, versatility

   a. Inclusion of PPM (1.06μ, 0.84μ, 0.51μ)

   b. Documentation of basic mathematics used in the methodology

   c. Visit recognized authorities to check values used in methodology

   d. Implement a discrete point input program

   e. Represent parameter burdens by more than 3 constants

   f. Investigate certain promising implementation techniques such as

      Solid state microwave sources

      Antenna arrays

      Power supplies

2. Executive Model

   a. Develop a specific executive model No. 1

   b. Develop a specific executive model No. 2

   c. Develop an executive model check

3. Console for Executive/Computer Interface

   Design a console for executive/computer interface for executive model No. 2

4. Review optimization criteria

5. Deviation Analysis – determine the worth of extending the state of the art in certain technology areas.

1.2 Sensitivity Analysis

The sensitivity analysis of the COPS program (Communication system Optimization Program with Stops) was designed to determine the sensitivity of each of the Major System Parameter values; transmitted power, P_{TO}; transmitting antenna diameter, d_{TO}; and receiving antenna diameter, d_{RO}; to variations in each of the 25 constants used in the burden relationships. Analytical relationships were derived and the entire sensitivity analysis implemented into the computer. Four major cases were completed to determine the sensitivity of the optimized parameter values, P_{TO}, d_{TO} and d_{RO}, to each of the 25 constants. The four major cases run were 1) a 2.3 GHz system, cost optimized, 2) a 10.6μ system, cost optimized, 3) a 2.3 GHz system, weight optimized, and 4) a 10.6μ system, weight optimized. Summary tables, Tables I-III through I-VI, show the variables which caused the greatest influence. These tables show three general areas of sensitivity. The first is the rather large effect various exponent values (m_T, n_T, etc.) have when they are varied as compared to the linear constants (K_{W_T}, K_{SA}, etc.). The second is that all constants used to describe the power output have a strong effect. This is due to the influence the power output has on the power supply, the power prime source and the heat radiators. The third is the case of the optical calculation or HOPS in which the variation in the acquisition and tracking constants has a strong effect.

Two other observations should be made. The first is the sensitivity variation with bit rate. Since most burden values occur in only one term of a burden equation, the bit rate at which that term is dominant in the equation is the bit rate where a variation in the parameter value has the greatest effect. The second is a change in parameter value such as m_T, which is in the equation describing d_T, affects d_{TO} much more than it affects d_{RO} or P_{TO}. That is, there is relatively little crosstalk.

In addition to Tables I-III to I-VI, which summarize the most sensitive parameters, Table I-VII indicates the sensitivity range for all the parameters in the COPS program.

TABLE I-III
SENSITIVITY ANALYSIS SUMMARY RESULTS FOR RADIO COMMUNICATION SYSTEMS OPTIMIZATION PROGRAM (ROPS) – COST OPTIMIZED

5 Percent Change in	Percent Change in Optimized Parameters			Variable Description
	d_{TO}	P_{TO}	d_{RO}	
m_R	0.74 to 0.68*	1.28 to 1.35	36.0 to 46.7	Exponent relating receiver antenna fabrication cost to diameter
n_R	0.74 to 0.68	1.28 to 1.35	36.0 to 46.7	Exponent relating receiver antenna fabrication weight to diameter
g_T	0.99 to 0.91	-19.3 to -48.3	0.64 to 0.68	Exponent relating transmitter fabrication cost to power
h_T	0.99 to 0.91	-19.3 to -48.3	0.64 to 0.68	Exponent relating transmitter fabrication weight to power
m_T	-16.0 to -28.9	2.73 to 1.42	1.01 to 0.52	Exponent relating transmitter antenna fabrication cost to diameter
n_T	-4.77 to -8.61	0.82 to 0.43	0.3 to 0.157	Exponent relating transmitter antenna weight to diameter
k_e	0.00	-4.7	0.00	Transmitter power efficiency

*The maximum and minimum values over a bit rate range of 1 b/s to 10^7 b/s.

1.3 COPTRAN Summary

The analysis of a communication link for space involves many practical considerations framed within the bounds of the appropriate transmission equation. The practical considerations and the appropriate equations have been combined in a single set of mathematical expressions which provide an optimum* solution to the problem. The mathematical expressions or the methodology is quite involved and its solution is tedious. A first step towards alleviating these drawbacks was to implement the methodology on a computer

*Lightest weight or lowest cost.

TABLE I-IV
SENSITIVITY ANALYSIS SUMMARY RESULTS FOR HETERODYNE DETECTION OPTICAL RECEIVER OPTIMIZATION PROGRAM (HOPS) – COST OPTIMIZED

5 Percent Change in	Percent Change in Optimized Parameters			Variable Description
	d_{TO}	P_{RO}	d_{RO}	
q_T	-45.1 to -5.2*	3.77 to -5.04	1.89 to -4.8	Exponent relating transmitter acquisition and track system fabrication cost to transmitter beamwidth
m_R	1.92 to 0.92	0.58 to 1.57	-25.3 to -32.8	Exponent relating receiver antenna fabrication cost to diameter
n_R	1.92 to 0.92	0.58 to 1.57	-25.3 to -32.8	Exponent relating receiver antenna fabrication weight to diameter
g_T	1.92 to 0.94	-13.5 to -28.5	0.29 to 0.79	Exponent relating transmitter fabrication cost to power
h_T	1.92 to 0.94	-13.5 to -28.5	0.29 to 0.79	Exponent relating transmitter fabrication weight to power
n_T	0.0056 to -20.1	0.0049 to 4.2	0.0024 to 2.4	Exponent relating transmitter antenna weight to diameter
K_{AT}	-16.2 to -1.39	-0.026 to -1.5	0.0133 to 1.66	Constant relating transmitter tracking equipment fabrication cost to transmitter beamwidth
m_T	0.0012 to -4.3	0.01 to 0.67	0.00052 to 0.335	Exponent relating transmitter antenna fabrication cost to diameter
K_{SA}	0.0054 to 1.75	-3.66 to -3.49	0.0015 to 0.2	Cost per unit weight for transmitter system equipment

*The maximum and minimum values over a bit rate range of 1 b/s to 10^7 b/s.

TABLE I-V
SENSITIVITY ANALYSIS SUMMARY RESULTS FOR RADIO COMMUNICATION SYSTEM OPTIMIZATION PROGRAM (ROPS) – WEIGHT OPTIMIZED

5 Percent Change in	Percent Change in Optimized Parameter		Variable Description
	d_{TO}	P_{TO}	
n_T	-19.5 to -39.6*	2.5	Exponent relating transmitter antenna weight to diameter
h_T	1.25	-5.6 to -45.9	Exponent relating transmitter fabrication weight to power
K_{SA}	-2.5	-5.0	Cost per unit weight for transmitter system equipment
k_e	0	-4.7	Transmitter power efficiency

*The maximum and minimum values over a bit rate range of 1 b/s to 10^7 b/s.

(COPS program). This produced solutions easily but required the user have considerable knowledge of the computer or work through someone who did. An important step has been taken to reduce the amount of computer knowledge needed by the user. This has been done by developing COPTRAN, a special input interface method for the COPS computer program. COPTRAN allows the user to instruct the computer in terms which are familiar to him. These instructions are then key punched onto computer cards, combined with the previously prepared card decks, and run on a computer. The computer output is in the form of printed answers and in the form of graphical plots. Figure 1-1 summarizes the steps in the solution of a communications problem.

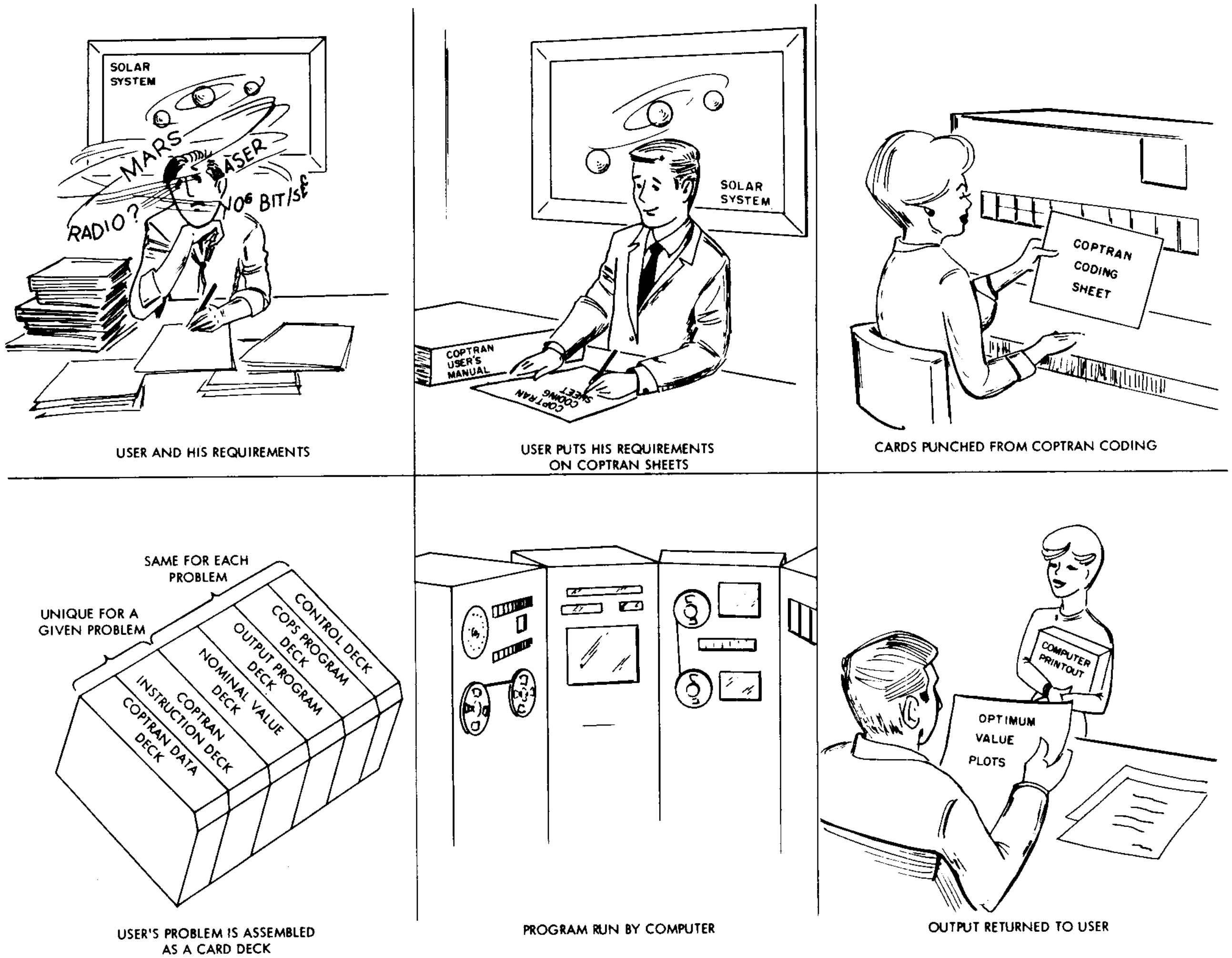


Figure 1-1. COPTRAN Programming

TABLE I-VI
SENSITIVITY ANALYSIS SUMMARY RESULTS FOR HETERODYNE DETECTION OPTICAL RECEIVER OPTIMIZATION PROGRAM (HOPS) – WEIGHT OPTIMIZED

5 Percent Change in	Percent Change in Optimized Parameter		Variable Description
	d_{TO}	P_{TO}	
n_T	-6.93 to -27.0*	2.5	Exponent relating transmitter antenna weight to diameter
h_T	1.25	33.7 to -28.4	Exponent relating transmitter fabrication weight to power
K_{SA}	-2.5	-5.0	Cost per unit weight for transmitter system equipment
k_e	0	-3.45	Transmitter power efficiency

*The maximum and minimum values over a bit rate range of 1 b/s to 10^7 b/s.

Section 4.0 of this report is a User's Manual for COPTRAN, a Method of Optimum Communication System Design. It presents the COPTRAN language, which is used to instruct the computer using terms familiar to the user. The user must only answer a series of questions pertinent to his problem.

For instance one question is: "Where is the transmitter?" The answer will be either "in space" or "on the earth." Following this question is a choice of two six letter mnenomics and their meanings. One of these, SPXMTR, may be chosen to tell the COPS methodology through the COPTRAN buffer language that the transmitter (XMTR) is located in space (SP).

In addition to describing how to instruct the COPTRAN program, the User's Manual describes how to insert data points which may be of particular concern to the user.

TABLE I-VII
SENSITIVITY ANALYSIS SUMMARY

5 Percent Change in	Percent Change in Optimized Parameters: ROPS Cost Optimized			HOPS Cost Optimized			ROPS Weight Optimized		HOPS Weight Optimized		Variable Description
	d_{TO}	P_{TO}	d_{RO}	d_{TO}	P_{TO}	d_{RO}	d_{TO}	P_{TO}	d_{TO}	P_{TO}	
m_T	-16 to -29	2.7 to 1.4	1.0 to 0.5	0 to -4.3	0.01 to 0.67	0 to 0.33					Exponent relating transmitter antenna fabrication cost to diameter
n_T	-4.7 to -8.6	0.8 to 0.4	0.3 to 0.2	0 to -20.1	0 to 4.2	0 to 2.4	-19.4 to -39.6	2.5	-6.9 to -27.0	2.5	Exponent relating transmitter antenna weight to diameter
q_T	0.9 to 0.01	0.4 to 0.01	0.15 to 0	-45.1 to -5.28	3.77 to -5.0	1.89 to -4.8					Exponent relating transmitter acquisition and track system fabrication cost to transmitter beamwidth
m_R	0.7 to 0.67	1.3 to 1.35	-36 to -47	1.9 to 0.9	0.58 to 1.57	-25.3 to -32.8					Exponent relating receiver antenna fabrication cost to diameter
n_R	0.7 to 0.67	1.3 to 1.35	-36 to -47	1.9 to 0.9	0.58 to 1.57	-25.3 to -32.8					Exponent relating receiver antenna weight to diameter
g_T	0.99 to 0.91	-19.3 to -48.3	0.64 to 0.67	1.9 to 0.92	-13.5 to -28.5	0.29 to 0.78					Exponent relating transmitter fabrication cost to power
h_T	0.99 to 0.91	-19.3 to -48.3	0.64 to 0.67	1.9 to 0.92	-13.5 to -28.5	0.29 to 0.78	1.25	-5.6 to -45.9	1.25	33.7 to -28.4	Exponent relating transmitter weight to power
K_{P_T}	0	0.133	0	0	0	0					Constant relating transmitter fabrication cost to transmitter power
K_{W_T}	0	0.181	0	0	-1.15	0	0	-0.181	0	0.181	Constant relating transmitter weight to transmitter power
K_{S_A}	-0.4 to -0.43	-3.2	0	0 to -1.75	-3.5	0 to 0.2	-2.5	-5.0	-2.5	-5.0	Cost per unit weight for transmitter system equipment
K_{WS_T}	-0.25	-3.0	0	0 to -0.23	-2.33	0 to -0.02	-1.464	-4.67	-0.326	-3.25	Constant relating transmitter power supply weight to power requirement
k_e	0	-4.7	0	0	-3.85	0	0	-4.7	0	-3.45	Transmitter power efficiency
K_X	0	-0.038	0	0	-0.13	0	0	-0.06	0	-0.177	Constant relating transmitter heat exchanger weight to transmitter power dissipation
K_{S_T}	-0.141	-1.66	0	0 to -0.127	-1.3	0 to 0.01					Constant relating transmitter power supply fabrication cost to power requirement
K_H	0	0	0	0	0	0					Constant relating transmitter heat exchanger fabrication cost to transmitter power dissipation
K_{θ_T}	-1.92	0.17 to 0	0.06 to 0	0 to -0.4	0 to 0.09	0 to 0.04					Constant relating transmitter antenna fabrication cost to transmitter aperture diameter
$K_{W_{AT}}$	-0.47	0.04 to 0	0.01 to 0	0 to -1.4	0 to 0.3	0 to 0.15	-1.9	0	-1.85	0	Constant relating transmitter tracking equipment weight to transmitter antenna weight
K_{d_T}	-0.57	0.05 to 0	0.02 to 0	0 to -1.88	0 to 0.4	0 to 0.2	-2.5	0	-2.5	0	Constant relating transmitter antenna weight to transmitter aperture diameter
$K_{P_{QT}}$	-0.39	0.03 to 0	0.01 to 0	0 to -0.35	0 to 0.07	0 to 0.039	-1.46	0	-0.326	0	Constant relating transmitter acquisition and track equipment power requirement to equipment weight
K_{AT}	-0.3 to 0	-1.48 to 0.01	-0.5 to 0	-16.6 to -1.39	-0.02 to -3.3	0.01 to 1.66					Constant relating transmitter tracking equipment fabrication cost to transmitter beamwidth
K_{θ_R}	0	0	-1.85	0	0	-2.25					Constant relating receiver antenna fabrication cost to receiver aperture diameter
K_{d_R}				0	0	-0.248					Constant relating receiver antenna weight to receiver aperture diameter
$K_{W_{AR}}$				0	0	-0.248					Constant relating receiver tracking equipment weight to receiver antenna weight
$K_{P_{QR}}$				0	0	-0.248					Constant relating receiver acquisition and track equipment power requirement to equipment weight
K_{SR}				0	0	-0.248					Constant relating receiver power supply fabrication cost to power requirement

Four examples of COPTRAN use are given. Those examples exercise all the types of flexibilities that are incorporated into COPTRAN to aid the user in the solution of his problem.

The COPTRAN program is arranged such that "nominal" values are used unless otherwise specified by the user. The COPTRAN User's Manual documents these nominal data sets, notes the provision in the COPTRAN language for additional nominal sets to be defined by the user and documents the logic used in the selection of nominal data.

1.4 Interface Equipment Summary

The COPS digital computer program can be controlled using COPTRAN, a buffer language between the user and the computer. This program presently operates in a batch processing mode. Program controls and data are input by means of a prepared card deck and the program operates on the input to produce tabular and graphical outputs.

To fully utilize the computer as a design tool, an interactive console terminal should be provided. Then with the appropriate conversational software, the designer will be able to control the computer directly using the COPTRAN program through a console. Results could be made available immediately and changes in input parameters could be made quickly to determine their effects. The user would converse with the computer in terms familiar to him or merely supply information to the computer as required in a question-and-answer session.

There is a wide spectrum of capability which can be made available to the user as interface equipment. Features which can be provided at a remote terminal include:

Input: Keyboard
Light pen graphics
Stylus graphics

Output: Printer (High-or-Low-Speed)
Plotter
CRT Alpha-Numerics
CRT Display graphics

These features may be combined in various ways to achieve many different degrees of sophistication. The configuration might run from something as simple as a teletype and plotter to a general purpose graphic display terminal with independent software, central processing unit, light pen, high speed printer, and graphic hard copy capability. (See Figure 1-2.)

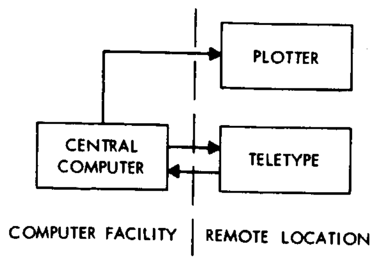
A survey of currently available equipment which could form a remote terminal has been made. The assumptions were: 1) the computer used would be a Honeywell DDP 516, with possible conversion at a later date to a larger computer in the SDS Sigma 5 class and 2) input/output capability should conform as closely as possible to the requirements of COPS and COPTRAN.

A summary of the input/output equipment investigated is given in Table I-VIII. As noted in the table further descriptive material of the various equipments is given in several appendices at the end of this report.

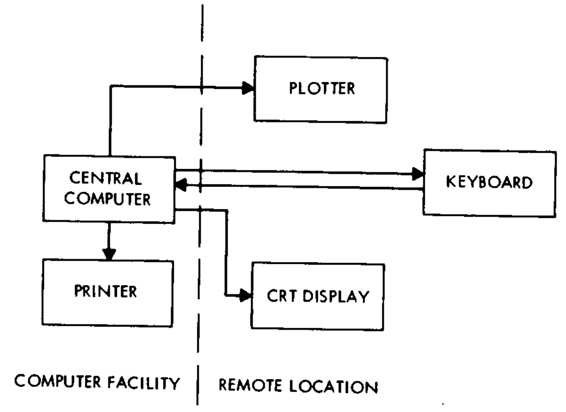
Perhaps the most prudent initial approach is to use a terminal similar to that given in Figure 1-2a, a typewriter or teletype with a plotter. There are two reasons for this choice: 1) it provides lowest cost and ease of interfacing, and 2) with a small initial investment, an operational conversational mode can be made operational.

The most logical unit to serve as the interactive device is Honeywell's ASR33. It undoubtedly would present the least interfacing problem and could be either the existing console teletype or logically be made to appear as the same. Hard copy graphic output would be produced on a CalComp plotter. The present DDP-516 system configuration does not include such a plotter however, a standard interface to the DDP-516 does exist and there is a possibility that a plotter will be added to the ERC computer installation.

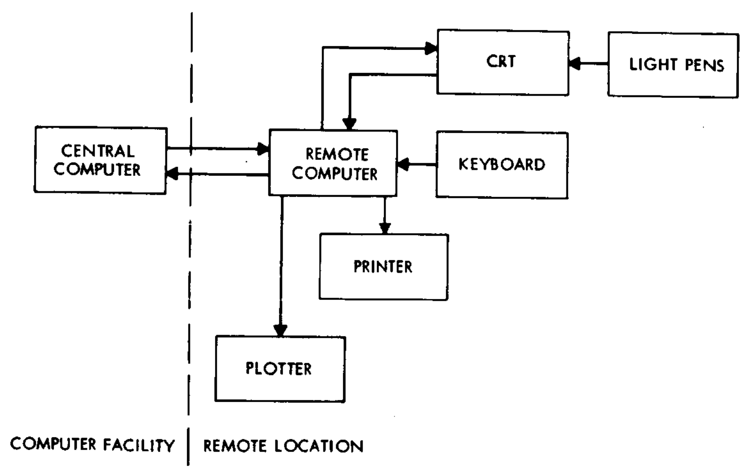
Because the DDP-516 system is at the outset a graphics oriented system, another option well worth considering is the use of an IDI display device (at a cost of about $15, 000).



a. Teletype/Plotter Remote Station



b. Keyboard/CRT Alphanumeric Output/Plotter/ Printer Remote Station



c. Complete Remote Graphic Processing Remote Terminal

Figure 1-2. Remote Configurations for Computer Control

TABLE I-VIII
EQUIPMENT SUMMARY

Name	1. Description	2. Approximate Cost	3. Alpha-numeric Input	4. Alpha-numeric Output	5. Graphic Input	6. Graphic Output	7. Produces Hard Copy	8. Software Supplied	9. Programmable Remote Processor
AGT/10 AGT/30 AGT/50	This is a family of highly sophisticated graphics terminals – very flexible and expensive. Extensive software is provided for remote processor. AGT/10 probably sufficient for conversational COPS – later version.	60 K 125 K 175 K	KBD	a. PRT b. CRT	LPEN	CRT	Yes	Yes Extended	Yes
Grafacon	Highly sophisticated. A major item is the graphic stylus which is probably unnecessary for COPS. Does include CRT, keyboard.	N/A	KBD	CRT	Stylus	CRT	–	–	–
CALCOMP	Incremental plotter. S16 interface available but manufacturer does not yet have S16 plotting routines. These may be available from other DDP 516/ CALCOMP installations.	$4500	None	None	None	Plotter	Yes	No	No
CC-30	Modular remote system designed for data phone use. Uses standard TV set for alphanumeric and graphic output.	$12 K minimum	KBD	TV, PTR	LPEN	TV	Yes	No	Yes, limited
DEC-338	Provides remote graphic capability. PDP-8 computer serves as remote processor – much software available with it.	$56 K	KBD	CRT, PTR	LPEN	CRT	Yes	Yes	Yes
Friden 7100	Typewriter terminal. 130 characters/ line. Up to 12 characters/second.	$3200	KBD	TYP	None	None	Yes	No	No
Gerber 22	Smallest of Gerber line is 4 by 5-foot drafting table. Provides fairly high accuracy.	N/A	None	None	None	Plotter	Yes	–	No
ASR 33	Teletype unit supplied with Honeywell computers. Easiest to interface. 72 characters/line, 12 characters/ second maximum.	$1200	KBD	TYP	None	None	Yes	Yes	No
S54-00	Honeywell's alphanumeric CRT remote terminal.	N/A	KBD	CRT	None	None	No	No	No
IBM-2740	IBM selectric remote terminal. Uses 6 bit code. 130 characters/line.	N/A	KBD	TYP	None	None	Yes	Some	No
IBM-2250	IBM's sophisticated remote graphic terminal. Probably interface problems. 6-bit code.	N/A	KBD	CRT	LPEN	CRT	Optional	Some	Limited
IDIIOM	Sophisticated graphics terminal. Versatile.	N/A	KBD	CRT/ TYP	LPEN	CRT	Yes	Yes	Yes
TEC-LITE	Small CRT alphanumeric terminal. Keyboard and function displays. Character display capability somewhat limited – to be increased this year (1968).	N/A	KBD	CRT	None	None	No	–	No

2.0 INTRODUCTION

The Hughes Aircraft Company entered into a six month contract NAS 12-566, with the Electronics Research Center of NASA on 17 July 1967. This report is the final technical report of the contract. The purpose of the contract was to establish a detailed mathematical model for the performance assessment of space communications system parameters. This goal was to be achieved by basing the work on the efforts of two other contracts, NAS 12-81 and NAS 5-9637.

The contractual goals may be seen in graphical form in Figure 2-1, the master program plan. This plan indicates the first half of the program was devoted to an examination of the mathematical model generated under contract NAS 5-9637 in two ways. The first is a reassessment of all the burden constants used in that model. The second method of examination is that of a sensitivity analysis, that is, of determining those constants which effect the overall results by the greatest amount. These tasks have been completed and were reported in the Interim Technical Report. (A summary of the sensitivity analysis is repeated in this report in Section 1.2.) An additional task accomplished during the first quarter of the contract was that of assembling four computer programs, developed under contract NAS 5-9637, into a single program. The second quarter goals have included: 1) a more detailed examination of a selected number of parametric relationship which the sensitivity analysis and burden review have shown to be the most important; 2) an examination of methods of implementing inputs and outputs to the computer to permit it to be used as an executive model; and 3) an evaluation and determination of the follow-on mathematical analysis for the next generation of communication system models.

Following the introduction, this report has been organized into the following sections:

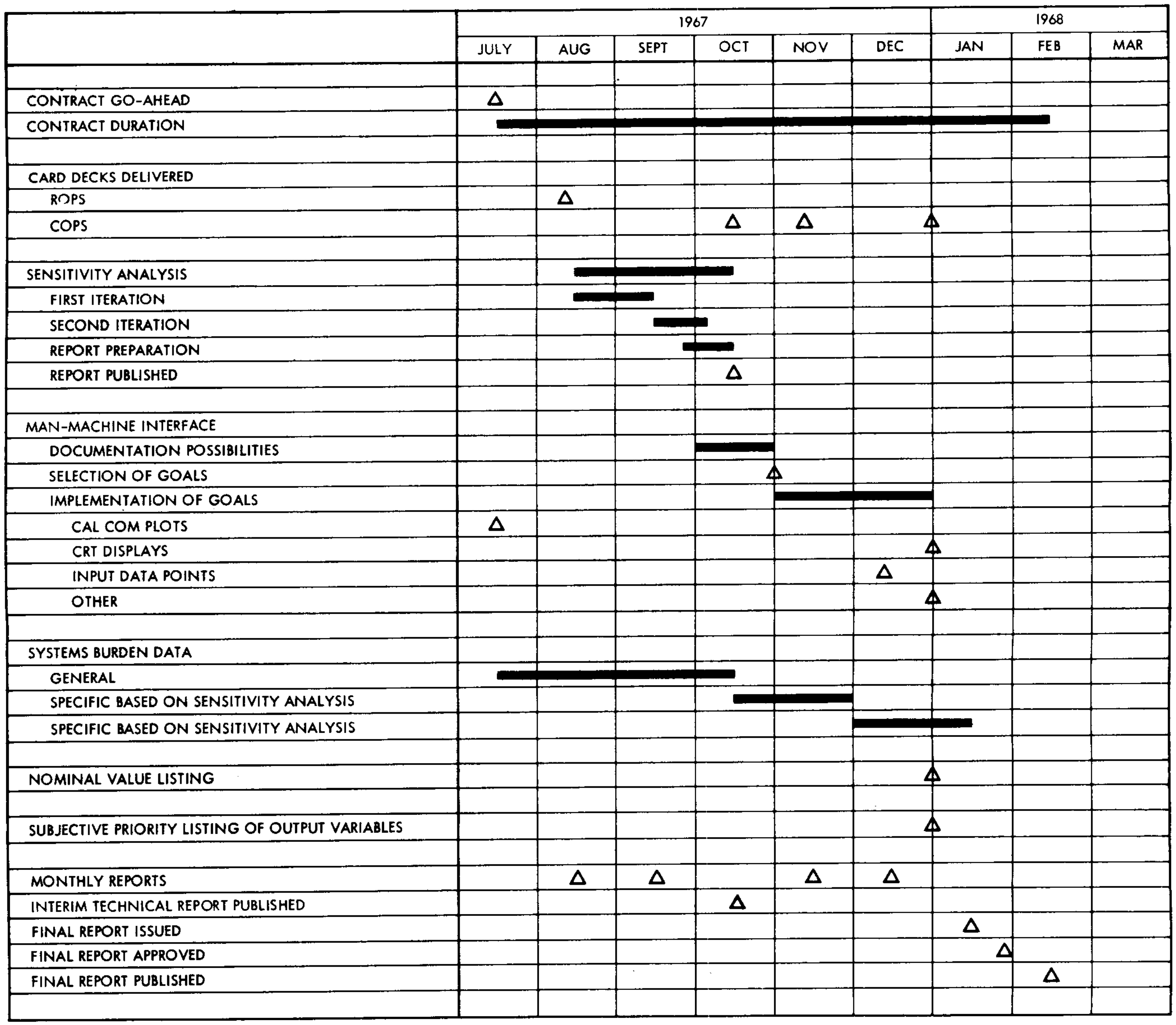


Figure 2-1. Master Program Plan for Contract NAS 12-566

Symbols

This section contains nomenclature for the COPS program and for the COPTRAN program.

User's Manual for COPTRAN, A Method of Optimum Communication System Design

This section describes COPTRAN programming. COPTRAN enables a user who is not familiar with computer operation to instruct the computer to solve a communication problem. The section contains the COPTRAN language, its usage, and gives examples of its use. In addition, a library of nominal data sets are given as is the logic used by COPTRAN to select automatically data from its data banks.

Interface Equipment Summary

COPTRAN programming is presently run by a computer using batch processing. It is desired to use a faster processing method, preferably in a conversational mode between the computer and the user. For this reason interface equipment was investigated and its suitability documented.

Contract End Item

A required end item for contract NAS 12-566 was to list potential areas for further development, study, and investigation. This has been documented in this section.

3.0 SYMBOLS

The symbols or nomenclature for this contract are listed in two parts, that part dealing with the COPS program and that part dealing with the COPTRAN program.

3.1 COPS Nomenclature

Computer Symbol	Text Symbol	Description
		System Parameters
ROP	ROP	mnemonic for Radio receiver Optimization Program without component stops
HOP	HOP	mnemonic for Heterodyne detection optical receiver Optimization Program without component stops
TOP	TOP	mnemonic for Thermal noise limited direct detection optical receiver Optimization Program without component stops
SOP	SOP	mnemonic for Shot noise limited direct detection optical receiver Optimization Program without component stops
ROPS	ROPS	mnemonic for Radio receiver Optimization Program with component stops
HOPS	HOPS	mnemonic for Heterodyne detection optical receiver Optimization Program with component stops
TOPS	TOPS	mnemonic for Thermal noise limited direct detection optical receiver Optimization Program with component stops
SOPS	SOPS	mnemonic for Shot noise limited direct detection optical receiver Optimization Program with component stops

Computer Symbol	Text Symbol	Description
PT	P_T	transmitter power
DT	d_T	transmitter antenna diameter
GT	G_T	transmitter antenna gain
DR	d_R	receiver antenna diameter
GR	G_R	receiver antenna gain
THER	θ_R	receiver field of view
RB	R_B	information rate
PTO	P_{TO}	optimum value of P_T
DTO	d_{TO}	optimum value of d_T
GTO	G_{TO}	optimum value of G_T
DRO	d_{RO}	optimum value of d_R
GRO	G_{RO}	optimum value of G_R
THERO	θ_{RO}	optimum value of θ_R
PTI	P_{TI}	initial program value of P_T
DTI	d_{TI}	initial program value of d_T
GTI	G_{TI}	initial program value of G_T
DRI	d_{RI}	initial program value of d_R
GRI	G_{RI}	initial program value of G_R
THRI	θ_{RI}	initial program value of θ_R
PTB	P_{TB}	limit value of P_T
DTB	d_{TB}	limit value of d_T
GTB	G_{TB}	limit value of G_T
DRB	d_{RB}	limit value of d_R
GRB	G_{RB}	limit value of G_R

Computer Symbol	Text Symbol	Description
THERB	θ_{RB}	limit value of θ_R
PTM	P_{TM}	fixed value of P_T (= O for no constraint)
DTM	d_{TM}	fixed value of d_T (= O for no constraint)
GTM	G_{TM}	fixed value of G_T (= O for no constraint)
DRM	d_{RM}	fixed value of d_R (= O for no constraint)
GRM	G_{RM}	fixed value of G_R (= O for no constraint)
THERM	θ_{RM}	fixed value of θ_R (= O for no constraint)

Computer Symbol	Text Symbol	Description
		System Costs
CDT	C_{d_T}	transmitter antenna cost
CDR	C_{d_R}	receiver antenna cost
CAT	C_{AT}	transmitter acquisition and track equipment fabrication cost independent of transmitter beamwidth
CTHT	C_{θ_T}	transmitter antenna fabrication cost
CTHR	C_{θ_R}	receiver antenna fabrication cost
CQT	C_{QT}	transmitter acquisition and track equipment cost
CNT	C_{NT}	transmitter acquisition and track equipment fabrication cost
CAR	C_{AR}	receiver acquisition and track equipment fabrication cost independent of receiver field of view
CQR	C_{QR}	receiver acquisition and track equipment cost
CNR	C_{NR}	receiver acquisition and track equipment fabrication cost
CFL	C_{FL}	transmitter fabrication cost
CPT	C_{P_T}	transmitter cost
CM	C_M	modulation equipment cost
CD	C_D	demodulation equipment cost
CFM	C_{FM}	modulation equipment fabrication cost
CFD	C_{FD}	demodulation equipment fabrication cost
CKT	C_{KT}	transmitter antenna fabrication cost independent of transmitter aperture diameter
CKR	C_{KR}	receiver antenna fabrication cost independent of receiver aperture diameter

Computer Symbol	Text Symbol	Description
CKH	C_{KH}	transmitter heat exchanger fabrication cost independent of transmitter power dissipation
CST	C_{ST}	transmitter power supply cost
CSR	C_{SR}	receiver power supply cost
CH	C_{H}	heat exchanger fabrication cost
CFT	C_{FT}	transmitter power supply fabrication cost
CFR	C_{FR}	receiver power supply fabrication cost
CKP	C_{KP}	transmitter fabrication cost independent of transmitter power
CKM	C_{KM}	modulation equipment fabrication cost independent of information rate
CKD	C_{KD}	demodulation equipment fabrication cost independent of information rate
CKE	C_{KE}	transmitter power supply fabrication cost independent of transmitter power requirement
CKF	C_{KF}	receiver power supply fabrication cost independent of receiver power requirement
CS	C_{S}	total system cost
CV	C_{V}	variable part of total system cost (optimization cost)
CFA	C_{FA}	fixed part of total transmitter cost
CFB	C_{FB}	fixed part of total receiver cost
CG	C_{G}	cost of transmitter, transmitter power supply, and transmitter heat exchanger which is dependent upon transmitter power

Computer Symbol	Text Symbol	Description
CT	C_T	cost of transmitter antenna, transmitter acquisition and track equipment, and associated power supply which is dependent upon transmitter aperture diameter
CQ	C_Q	cost of receiver acquisition and track equipment which is dependent upon receiver field of view
CR	C_R	cost of receiver antenna, receiver acquisition and track equipment, and associated power supply which is dependent upon receiver aperture diameter
CFA	C_{FA}	total transmitter fabrication costs for optimum system parameters
CFB	C_{FB}	total receiver fabrication costs for optimum system parameters
CA	C_A	total transmitter cost for optimum system parameters
CB	C_{BO}	total receiver cost for optimum system parameters
CTO	C_{TO}	value of C_T for optimum system parameters
CRO	C_{RO}	value of C_R for optimum system parameters
CGO	C_{GO}	value of C_G for optimum system parameters
CQO	C_{QO}	value of C_Q for optimum system parameters
CVO	C_{VO}	value of C_V for optimum system parameters

Computer Symbol	Text Symbol	Description
		System Weights
WDT	W_{d_T}	transmitter antenna weight
WDR	W_{d_R}	receiver antenna weight
WQT	W_{QT}	transmitter acquisition and track equipment weight
WBT	W_{BT}	transmitter acquisition and track equipment weight independent of transmitter beamwidth
WQR	W_{QR}	receiver acquisition and track equipment weight
WBR	W_{BR}	receiver acquisition and track equipment weight independent of receiver field of view.
WT	W_T	transmitter weight
WM	W_M	modulation equipment weight
WD	W_D	demodulation equipment weight
WSR	W_{SR}	receiver power supply weight
WST	W_{ST}	transmitter power supply weight
WH	W_H	transmitter heat exchanger weight
WKT	W_{KT}	transmitter antenna weight independent of transmitter aperture diameter
WKR	W_{KR}	receiver antenna weight independent of receiver aperture diameter
WKP	W_{KP}	transmitter weight independent of transmitter power
WKH	W_{KH}	transmitter heat exchanger weight independent of transmitter power dissipation

Computer Symbol	Text Symbol	Description
WKM	W_{KM}	modulation equipment weight independent of information rate
WKD	W_{KD}	demodulation equipment weight independent of information rate
WKE	W_{KE}	transmitter power supply weight independent of transmitter power requirement
WKF	W_{KF}	receiver power supply weight independent of receiver power requirement
WA	W_A	total transmitter weight for optimum system parameters
WB	W_B	total receiver weight for optimum system parameters

Computer Symbol	Text Symbol	Description
		System Power Requirements
PQT	P_{QT}	transmitter acquisition and track equipment power requirement
PQR	P_{QR}	receiver acquisition and track equipment power requirement
PPT	P_{PT}	transmitter power requirement
PM	P_{M}	modulation equipment power requirement
PD	P_{D}	demodulation equipment power requirement
PST	P_{ST}	transmitter power supply power requirement
PSR	P_{SR}	receiver power supply power requirement
PA	P_{A}	total transmitter power requirement for optimum system parameters
PB	P_{B}	total receiver power requirement for optimum system parameters

Computer Symbol	Text Symbol	Description
		System Constants of Proportionality
KA	K_A	transmitter system optimization variable (K_A = 1 indicates transmitter system fabrication cost optimization; K_A = 0 indicates no transmitter system fabrication cost optimization)
KB	K_B	receiver system optimization variable (K_B = 1 indicates receiver system fabrication cost optimization; K_B = 0 indicates no receiver system fabrication cost optimization)
KC	K_C	transmitter system optimization variable (K_C = 1 indicates transmitter system weight optimization; K_C = 0 indicates no transmitter system weight optimization)
ZD	K_D	receiver system optimization variable (K_D = 1 indicates receiver system weight optimization; K_D = 0 indicates no receiver system weight optimization)
KSA	K_{SA}	cost per unit weight for transmitter system equipment
KSB	K_{SB}	cost per unit weight for receiver system equipment
KDT	K_{d_T}	constant relating transmitter antenna weight to transmitter aperture diameter
KTHT	K_{θ_T}	constant relating transmitter antenna fabrication cost to transmitter aperture diameter
KDR	K_{d_R}	constant relating receiver antenna weight to receiver aperture diameter
KTHR	K_{θ_R}	constant relating receiver antenna fabrication cost to receiver aperture diameter
KAT	K_{AT}	constant relating transmitter tracking equipment fabrication cost to transmitter beamwidth
KWAT	$K_{W_{AT}}$	constant relating transmitter tracking equipment weight to transmitter antenna weight
KPQT	$K_{P_{QT}}$	constant relating transmitter acquisition and track equipment power requirement to equipment weight
KAR	K_{AR}	constant relating receiver tracking equipment fabrication cost to receiver field of view

Computer Symbol	Text Symbol	Description
KWAR	$K_{W_{AR}}$	constant relating receiver tracking equipment weight to receiver antenna weight
KPQR	$K_{P_{QR}}$	constant relating receiver acquisition and track equipment power requirement to equipment weight
KWT	K_{W_T}	constant relating transmitter weight to transmitter power
KPT	K_{P_T}	constant relating transmitter fabrication cost to transmitter power
KPM	K_{P_M}	constant relating modulation equipment power requirement to equipment weight
KPD	K_{P_D}	constant relating demodulation equipment power requirement to equipment weight
KST	K_{ST}	constant relating transmitter power supply fabrication cost to power requirement
KWST	$K_{W_{ST}}$	constant relating transmitter power supply weight to power requirement
KSR	K_{SR}	constant relating receiver power supply fabrication cost to power requirement
KWR	K_{WR}	constant relating receiver power supply weight to power requirement
KH	K_H	constant relating transmitter heat exchanger fabrication cost to transmitter power dissipation
KX	K_X	constant relating transmitter heat exchanger weight to transmitter power dissipation
KM	K_M	constant relating modulation equipment weight to information rate
KFM	K_{FM}	constant relating modulation equipment fabrication cost to information rate
KD	K_D	constant relating demodulation equipment weight to information rate
KFD	K_{F_D}	constant relating demodulation equipment fabrication cost to information rate

Computer Symbol	Text Symbol	Description
KQT	K_{q_T}	$K_A\ K_{AT}/(\lambda)^{q_T}$
KMT	K_{m_T}	$K_A\ K_{\theta_T}$
KNT	K_{n_T}	$K_A \left\{K_{d_T}\ K_{PQT}\ K_{W_{AT}}\ K_{ST}\right\} + K_C\ K_{SA} \left\{K_{d_T}\left[1 + K_{W_{AT}} + K_{PQT}\ K_{W_{AT}}\ K_{W_{ST}}\right]\right\}$
KQR	K_{q_R}	$K_B\ K_{AR}$
KMR	K_{m_R}	$K_B\ K_{\theta_R}$
KNR	K_{n_R}	$K_B \left\{K_{d_R}\ K_{PQP}\ K_{W_{AR}}\ K_{SR}\right\} + K_D\ K_{SB} \left\{K_{d_R}\left[1 + K_{W_{AR}} + K_{PQR}\ K_{W_{AR}}\ K_{W_{SR}}\right]\right\}$
KGT	K_{g_T}	$K_C\ K_A\ K_{P_T}$
KHT	K_{h_T}	$K_{SA}\ K_{W_T}$
KJT	K_{j_T}	$K_A \left\{K_{ST}/k_e + K_H\left[1 - k_e/k_e\right]\right\} + K_C\ K_{SA} \left\{K_{W_{ST}}/k_e + K_x\ \left[1 - k_e/k_e\right]\right\}$
QT	q_T	exponent relating transmitter acquisition and track system fabrication cost to transmitter beamwidth
MT	m_T	exponent relating transmitter antenna fabrication cost to diameter
NT	n_T	exponent relating transmitter antenna weight to diameter
QR	q_R	exponent relating receiver acquisition and track system fabrication cost to receiver field of view
MR	m_R	exponent relating receiver antenna fabrication cost to diameter
NR	n_R	exponent relating receiver antenna weight to diameter
ZT	g_T	exponent relating transmitter fabrication cost to power
HT	h_T	exponent relating transmitter weight to power
JT	j_T	exponent of symmetrical convenience needed in the sensitivity analysis
KNS	K_{NS}	SNR constant for shot noise limited direct and heterodyne detection optical receiver

Computer Symbol	Text Symbol	Description
K	K	SNR constant for shot noise limited direct detection optical receiver
KRB	KRB	SNR constant for shot noise limited direct detection optical receiver
KM	K_M	SNR constant for thermal noise limited direct detection optical receiver
KN	K_N	SNR constant for heterodyne detection optical receiving
KR	K_R	SNR constant for radio receiver
KE	k_e	transmitter power efficiency
R	R	transmission range
LMBDI	λ_i	receiver input filter bandwidth in wavelength units
	B_O	receiver output filter bandwidth in frequency units
	Λ	optimization dummy variable
	Q	optimization dummy variable
	G	detector current gain
	I_D	detector dark current
TAUT	τ_t	transmitter transmissivity
TAUR	τ_r	receiver transmissivity
TAUA	τ_a	atmospheric transmissivity
ETA	η	detector quantum efficiency
QB	Q_B	background radiation photon spectral radiance
LAMBDA	λ	transmission wavelength
RL	R_L	receiver load resistance
SMK	k	Boltzmann's constant
H	h	Planck's constant
Q	q	electronic charge
C	c	velocity of light
TE	T_e	receiver temperature
USTQ	$(\mu_{S,T})_{Req.}$	number of signal photoelectrons required per decision interval
UNTQ	$(\mu_{N,T})_{Req.}$	number of noise photoelectrons required per decision interval

Computer Symbol	Text Symbol	Description
USS	$\mu_{S,S}$	number of signal photoelectrons per second
UNS	$\mu_{N,S}$	number of noise photoelectrons per second
SN	$\left(\frac{S}{N}\right)$	receiver output power signal-to-noise ratio
RB	R_B	information rate in bits per second
RBQ	$(R_B)_{Req.}$	required information rate in bits per second
CN	$\left(\frac{C}{N}\right)$	constant relating shot noise powers due to signal and background radiation
RHOT	ρ_T	transmitter antenna aperature efficiency
RHOR	ρ_R	receiver antenna aperture efficiency

3.2 COPTRAN Instruction Mnemonics

SPXMTR	Spacecraft transmitter
EAXMTR	Earth transmitter
SPRCVR	Spacecraft receiver
EARCVR	Earth receiver
RANMAR	Mars range (10^8 km)
RANJUP	Jupiter range (7.5×10^8 km)
RANSAT	Synchronous satellite range (3.6×10^4 km)
RANOTH	Other range value must be submitted with COPTRAN Data Deck. In addition all nominal burdens affected by range must be furnished by user and included in COPTRAN Data Deck.
LAM051	$\lambda = 0.51$ micron
LAM084	$\lambda = 0.84$ micron
LAM106	$\lambda = 10.6$ microns
LAM13C	$\lambda = 13$ cm
LAMOTH	Other value must be submitted with COPTRAN Data Deck data. All nominal burdens affected by this wavelength must be furnished by user and included in COPTRAN Data Deck.
BKMARS	Mars background
BKJUPT	Jupiter background
BKMOON	Moon background
BKERTH	Earth background
BKDSKY	Day sky background
BKNSKY	Night sky background
BKGALT	Galactic background
BKOTHR	Other background value must be submitted with COPTRAN Data Deck
PCM/AM	PCM amplitude modulation
PCM/IM	PCM intensity modulation
PCM/PL	PCM polarization modulation
PCM/FM	PCM frequency modulation
PCM/PM	PCM phase modulation
PPM/IM	PPM intensity modulation

OPTDIR	Optical direct detection
OPTHET	Optical heterodyne detection
OPTHOM	Optical homodyne detection
RADHET	Radio heterodyne detection
RANHOM	Radio homodyne detection
XMWTOP	Transmitter weight optimization
RCWTOP	Receiver weight optimization
XMFCOP	Transmitter fabrication cost optimization
RCFCOP	Receiver fabrication cost optimization
DTDROP	Transmitter antenna diameter and receiver antenna diameter optimization
GTDROP	Transmitter antenna gain and receiver antenna diameter optimization
DTGROP	Transmitter antenna diameter and receiver antenna gain optimization
GTGROP	Transmitter antenna gain and receiver antenna gain optimization
NXANT___	Lists A to T, nominal transmitter antenna burdens
NRANT___	Lists A to T, nominal receiver antenna burdens
NXACT___	Lists A to T, nominal transmitter acquisition and track burdens
NRACT___	Lists A to T, nominal receiver acquisition and track burdens
NMODE___	Lists A to T, nominal modulator burdens
NDMOD___	Lists A to T, nominal demodulator burdens
NXPWS___	Lists A to T, nominal transmitter power supply burdens
NRPWS___	Lists A to T, nominal receiver power supply burdens
NXMTR___	Lists A to T, nominal transmitter burdens
NBOOS___	Lists A to T, nominal booster burdens
RBFRQ___	Number of information rate computations per decade, 1, 2, 4, 5, 8, 0 according to following table

RBFRQ1	RBFRQ2	RBFRQ4	RBFRQ5	RBFRQ8	RBFRQ0
10^n	10^n	10^n	10^n	10^n	10^n
10^{n-1}	0.5×10^n	0.75×10^n	0.8×10^n	0.875×10^n	0.9×10^n
	10^{n-1}	0.50×10^n	0.6×10^n	0.750×10^n	0.8×10^n
		0.25×10^n	0.4×10^n	0.625×10^n	0.7×10^n
		10^{n-1}	0.2×10^n	0.500×10^n	0.6×10^n
			10^{n-1}	0.375×10^n	0.5×10^n
				0.250×10^n	0.4×10^n
				0.125×10^n	0.3×10^n
				10^{n-1}	0.2×10^n
					10^{n-1}

RBINT___	Initial information rate, exponent 0 to 8 (e.g., $R_B = 10^0, 10^1, \ldots, 10^8$)
RBFIN___	Final information rate, exponent 1 to 9 (e.g., $R_B = 10^1, 10^2, \ldots, 10^9$). Note that final information rate must be greater than initial information rate
PRTBUR	Print system burdens data
PRTSPD	Print system physical data
PRTSNC	Print signal-to-noise ratio constants
PRTBRC	Print system burden constants
PRTSPC	Print system parameter constraints
PRTOPT	Print optimum system parameters
PRTWGT	Print weight burdens for optimum system parameters
PRTPWP	Print power burdens for optimum system parameters
PRTFAB	Print fabrication cost burdens for optimum system parameters
PRTSYC	Print system cost burdens for optimum system parameters
PRTALL	Prints all of above data
PRTDAT	Print system burdens data, systems physical data, signal-to-noise ratio constants, system burden constants and system parameter constants.

PLTOPT	Plot optimum system parameters
PLTOTO	Plot optimum value of transmitter antenna diameter
PLTGTO	Plot optimum value of transmitter antenna gain
PLTDRO	Plot optimum value of receiver antenna diameter
PLTGRO	Plot optimum value of receiver antenna gain
PLTPTO	Plot optimum value of transmitter power
PLTTRO	Plot optimum value of receiver field of view
PLTWDT	Plot transmitter antenna weight
PLTWQT	Plot transmitter acquisition and track equipment weight
PLTWQR	Plot receiver acquisition and track equipment weight
PLTWX	Plot transmitter weight
PLTWH	Plot transmitter heat exchanger weight
PLTWM	Plot modulation equipment weight
PLTWD	Plot demodulation equipment weight
PLTWST	Plot transmitter power supply weight
PLTWSR	Plot receiver power supply weight
PLTWA	Plot transmitter system weight
PLTWB	Plot receiver system weight
PLTPQT	Plot transmitter acquisition and track equipment power requirement
PLTPX	Plot transmitter power requirement
PLTPM	Plot modulation equipment power requirement
PLTPD	Plot demodulation equipment power requirement
PLTPA	Plot transmitter system power requirement
PLTPB	Plot receiver system power requirement
PLTCDT	Plot transmitter antenna fabrication cost
PLTCDR	Plot receiver antenna fabrication cost
PLTCQT	Plot transmitter acquisition and track equipment fabrication cost
PLTCQR	Plot receiver acquisition and track equipment fabrication cost
PLTCX	Plot transmitter fabrication cost
PLTCH	Plot transmitter heat exchanger fabrication cost
PLTCM	Plot modulation equipment fabrication cost

PLTCD	Plot demodulation equipment fabrication cost
PLTCST	Plot transmitter power supply fabrication cost
PLTCSR	Plot receiver power supply fabrication cost
PLTCA	Plot transmitter system fabrication cost
PLTCB	Plot receiver system fabrication cost
PLTCTO	Plot transmitter antenna cost burden
PLTCRO	Plot receiver antenna cost burden
PLTCQO	Plot receiver field of view cost burden
PLTCGO	Plot transmitter power cost burden
PLTCV	Plot optimization cost
PLTCS	Plot total system cost
ENDINS	Instruction end
ENDDAT	Data end
ENDCAS	Case end

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USER'S MANUAL FOR COPTRAN, A METHOD OF OPTIMUM COMMUNICATION SYSTEM DESIGN

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4.0 USER'S MANUAL FOR COPTRAN, A METHOD OF OPTIMUM COMMUNICATION SYSTEM DESIGN

4.1 Introduction

Calculations to determine communication capability of a transmission link are basically dependent on a single equation, the one way transmission equation. While there are variants in this equation to account for different types of noise, modulation and demodulation techniques, this one equation documents the interrelationships among the communication parameters of range, transmitter power, antenna gains, noise, etc. Since these parameters are multiplicative in the range equation it is possible to trade one parameter value against others while maintaining a given performance. Thus, it is difficult in many cases, to determine the "best" combination of parameters for a particular application although this is an important determination, especially to space missions.

It is therefore desirable to formulate an analytical method or methodology of not only selecting parameters which produce the desired performance within the regulation of the range equation but of selecting <u>optimum</u> parameter values which meet the desired performance.

Consider the following relatively simple optimization example for a deep space communication system. The effective radiated power from a spacecraft is to be maximized for a specified maximum weight. Now the effective radiated power may be increased by increasing either the size of the transmitting antenna or the transmitter power, or by some suitable combination of increases in these two parameters. The problem is to determine the proper split in weight between these two elements to maximize the effective radiated power subject to the given weight constraint. Clearly, the combination of an extremely large antenna using almost all the available weight with a minimal transmitter would not give the best possible performance, nor would the combination of an extremely heavy transmitter with a very low-gain antenna. The optimum configuration must therefore lie somewhere between these two extremes. In order to determine the optimum configuration, both transmitter power and antenna gain must be expressed in terms of weight. If these two relationships are known, a straight forward optimization procedure can be employed to determine the optimum values for both transmitter power and the antenna size associated with the resulting antenna gain.

Such a concept has been expanded to all applicable parameter values in the range equation for both a weight optimization and a cost optimization. The resulting methodology has been implemented in a computer program known as COPS (Communication system Optimization Program with Stops).

The COPS program optimizes the values of the Major Communication Systems Parameters which are: the transmitter antenna diameter or gain, the receiver antenna diameter or gain, the transmitter power, and the receiver field of view. The program is implemented for radio frequency homodyne detection systems, optical frequency heterodyne detection systems, and for optical frequency thermal or shot noise limited direct detection systems.

The COPS program maximizes the signal-to-noise ratio, the transmission range, and the information rate and minimizes the probability of detection error for each communication system. The optimization uses as a criteria, the transmitter system weight, transmitter system fabrication cost, receiver system weight, receiver system fabrication cost either singly or in any combination. Fixed values for any of the Major System Parameters may be entered into the programs. In addition, maximum parameter values or "stops" may be placed on each of the Major System Parameters.

The COPS program provides a tabulation of optimum values of Major System Parameters as a function of information rate as outputs. Other outputs include: optimum transmitter antenna diameter or gain versus information rate; optimum receiver antenna diameter or gain versus information rate; optimum transmitter power versus information rate; and optimum receiver field of view versus information rate.

The inputs required for the COPS program are a tabulation of Systems Physical Data such as: range, sky noise background, wavelength, transmissivity losses etc; System Burdens Data such as: constants relating transmitter power to weight; antenna size to cost; etc., and System Parameter Constraints such as the maximum or fixed values for the Major Systems Parameters.

The COPS program has been written in Fortran IV language. In order to facilitate the use of the COPS program by persons unfamiliar with computer operation or programming, a buffer computer language called COPTRAN (Communication system Optimization Program TRANslator) has been developed.

To operate the COPS optimization program using the COPTRAN language involves answering a few simple questions which are written in the language of the user. For instance one question is: "What is the transmission range?" Following this question is a choice of four six letter mnemonics and their meanings. One of these, RANMAR, may be chosen to tell the COPS methodology through the COPTRAN buffer language that the range (RAN) is a Mars (MAR) distance, 10^8 km.

Similar simple questions, again using a multiple choice listing of mnemonics, are answered for such topics as the modulation type, the type of optimization desired, the type of output desired, etc.

The user may also use standard sets of data for the interrelationship of transmitter cost to power, etc. (burden relationships). Or if the user desires, he may change one or all the nominal constants, thus superceding the stored values.

The mnemonic answers and data values that are selected by the user to describe the problem he wishes to solve are written down by the user on a simple COPTRAN form. This form is then used to punch computer cards, one card per mnemonic or data value. The cards become part of the COPTRAN program and are batch processed by a computer.

The computer results are returned to the user either in a line printout or in Cal Compplots. [Section 5.4 of this final report lists several equipments which could be used with the COPTRAN language and the DDP-516 computer to implement a "conversational" operating procedure. This mode is proposed for a subsequent implementation phase. (See Section 6.3)]

Figure 4-1 summarizes the steps in obtaining optimized communications parameters using the COPS computer program with the COPTRAN language.

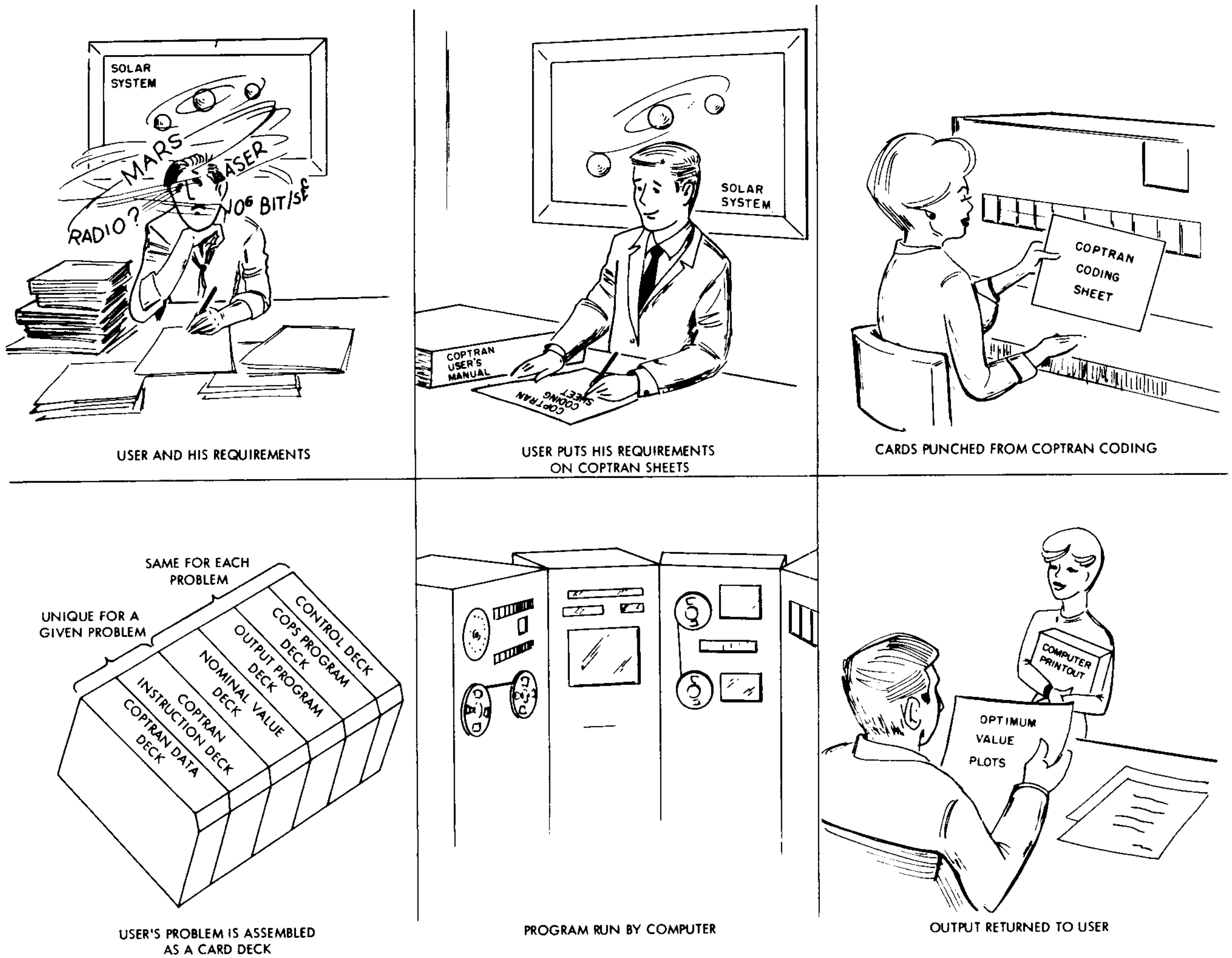

Figure 4-1. COPTRAN Programming

4.2 COPTRAN Programming Structure

4.2.1 Introduction. – COPTRAN programming language is a specialized, simple computer language used in the design of communication systems. COPTRAN allows a user to determine the optimum configuration of a communication system with relatively few instructions phrased in the context of his problem and without the necessity of supplying large quantities of data to the computer. This is accomplished by storing nominal values of the program data in the computer data banks. The pertinent data for a particular problem is then automatically fetched by the COPTRAN program unless countermanded by particular user selections.

The COPTRAN program structure is composed of six main parts. These parts are: 1) The Control Program Deck, 2) the COPS Program Deck, 3) the Output Program Deck, 4) the Nominal Value Decks, 5) The COPTRAN Instruction Deck, and 6) the COPTRAN Data Deck. Of these, only the last two are of concern to the COPTRAN user, and in many cases, only the COPTRAN Instruction Deck will be needed. It is the purpose of this instruction manual to describe these two portions of the COPTRAN Program in detail.

4.2.2 COPTRAN instruction deck. – The COPTRAN Instruction Deck is composed of punched cards, each of which has a single mnemonic. The mnemonics describe the communications problem to be solved in the following five categories.

1. Physical Environment

    Transmitter location (spacecraft)

    Receiver location (earth)

    Transmission range (one of a set of selected ranges may be chosen to indicate physical environment or another range choice may be made and the environment specified)

    Background (choice of physical source of background radiation)

2. Communication System

    Transmission wavelength (one selected wavelength may be chosen)

Modulation and demodulation methods (choice of one of several sets are available)

3. Optimization

Optimization basis (transmitter system weight, transmitter system fabrication cost, receiver system weight, and receiver system fabrication cost may be minimized individually or in any combination)

Antenna parameter optimization (transmitter antenna gain or diameter and receiver antenna gain or diameter may be optimized)

4. Nominal System Burdens* (see Section 4.5 for data description)

Choices of system burdens may be made from a data bank list if automatic selections are not desired. (Section 4.6 describes automatic data selection.) System burdens values may also be entered as new data if desired.

5. Processing

Computation format (choice of initial and final values of information rate and number of information rate data points calculated)

Print format (choice of data and results to be printed in tabular form)

Plot format (choice of results to be plotted by Cal Comp plotter)

4.2.3 COPTRAN data deck. – The COPTRAN Data Deck is the means by which individual burdens, physical data, stops, and fixed values are inserted into the COPTRAN program. If the automatic burdens and physical data

*Burdens are the "constants" which represent the modeled relationship between system parameters such as transmitter power, P_T, and weight of the transmitter, W_{P_T}. In the following equation W_{KP}, K_{W_T}, and h_T are "burdens": $W_{P_T} = W_{KP} + K_{W_T}(P_T)^{h_T}$.

selections provided by the COPTRAN instructions are acceptable to the user, and no parameter stops or fixed values are specified, there will be no COPTRAN Data Deck for the COPTRAN program (except an end data card, ENDDAT). The COPTRAN program has been developed so that input data in the COPTRAN Data Deck automatically replaces items of data normally selected from data banks. The program data is of three types.

1. System Physical Data

   Physical data such as signal-to-noise rate, atmospheric transmissivity, receiver temperature, etc.

2. System Burdens Data

   Weight, fabrication cost, and power requirement burdens for communication system components.

3. System Parameter Constraints

   Fixed and stop values of the Major Communication System Parameters namely transmitting or receiving antenna gains or diameters, transmitter power, and receiver field of view. (A "fixed" parameter value is one that remains fixed throughout all portions of the optimization. A "stop" in the parameter value is the maximum value the parameter may take. For instance, a communication problem may require a fixed antenna size for a receiving antenna on earth of 64 meters and have a stop value for an antenna in space of 10 meters. The optimization program will determine the optimum split between the spacecraft antenna size as a function of data rate. As the data rate requirements increase, the transmitter power and antenna size will increase until the antenna size of 10 meters is reached. For larger data rates, the antenna size will remain at 10 meters and the transmitter power will increase, at a faster rate now, to meet the demands of higher data rates.)

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4.3 COPTRAN Use

A COPTRAN program is considered to be the set of COPTRAN instructions and COPTRAN data cards which describe the communication system(s) to be optimized. This program, when submitted with the proper control cards and the COPTRAN card decks comprises a COPTRAN job. The COPTRAN card decks are supplied to the user and may not be altered. A typical COPTRAN job deck structure is shown in Figure 4-2. The COPTRAN instruction and data cards which must be supplied by the user are described in the following paragraphs.

The job deck set-up shown in Figure 4-2 is for a particular computer system: The GE 635 GECOS III system. No matter what physical system is used, the COPTRAN card decks and the COPTRAN program will be the same. The control cards, however, (identified by a '$' in card column 1) will vary with the system. They are pictured here to indicate relative location in a job deck and the information required. The operations staff of a particular facility should be contacted for more specific information on control cards.

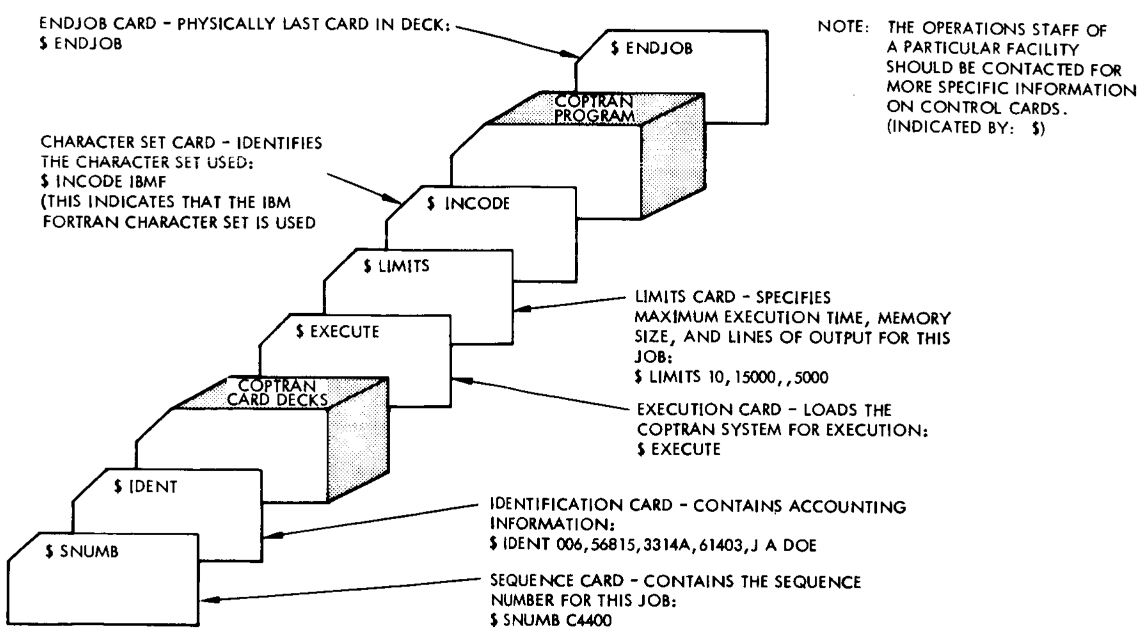

Figure 4-2. COPTRAN Job Deck Structure

4.3.1 COPTRAN program description. – A COPTRAN program is composed of single word COPTRAN instructions and a set of data values supplied to the program where they are different from the ones automatically supplied by the COPTRAN system. Each instruction is entered in columns 1-6 of one line of the COPTRAN coding sheet (see Figure 4-3). In order to properly specify a problem, the user should supply at least one instruction from each of the categories in Table IV-I. In some cases, more than one instruction in one category may be supplied. The remarks in each category in Table IV-I indicate the options which are available. It is suggested that the user prepare his program by examining each category in Table IV-I in sequence and selecting the instruction(s) from that category which best describe(s) his problem. It is important to note the restrictions which are placed on the use of certain instructions.

COPTRAN CODING SHEET A

NAME ________________ DATE __________ PROBLEM ____________________

COPTRAN INSTRUCTIONS AND DATA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1																								
2																								
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22																								
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24																								
25																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1																								
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24																								
25																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

Figure 4-3. COPTRAN Coding Sheet A

TABLE IV-I
COMPLETE LISTING OF COPTRAN INSTRUCTION MNEMONICS

1. Transmitter Location (Only one available)	
SPXMTR	Spacecraft transmitter
2. Receiver Location (Only one available)	
EARCVR	Earth receiver
3. Transmitter Range (Choose only one)	
RANMAR	Mars range (10^8 km)
RANJUP	Jupiter range (7.5×10^8 km)
RANSAT	Synchronous satellite range (3.6×10^4 km)
RANOTH	Range other than those above will be supplied with COPTRAN data. In addition, power supply burdens affected by range must be supplied by the user and included with COPTRAN data.
4. Transmission Wavelength (Choose only one)	
LAM051	$\lambda = 0.51$ micron
LAM084	$\lambda = 0.84$ micron
LAM106	$\lambda = 10.6$ microns
LAM13C	$\lambda = 13$ cm (2.3 GHz)
5. Background (Choose only one)	
BKDSKY	Day sky
BKNSKY	Night sky
BKGALT	Galactic

TABLE IV-I (continued)
COMPLETE LISTING OF COPTRAN INSTRUCTION MNEMONICS

6. Modulation and Demodulation Methods (Choose only one modulation and demodulation method pair)

PCM/AM	PCM amplitude modulation
OPTDIR	Optical direct detection (Use only when $\lambda = 10.6$ microns. No other burdens are available.)
PCM/PL	PCM polarization modulation
OPTDIR	Optical direct detection (Use only when $\lambda = 0.51$ microns. No other burdens are available.)
PCM/FM	PCM frequency modulation
OPTHET	Optical heterodyne detection (Use only when $\lambda =$ 10.6 microns. No other burdens are available.)
PCM/PM	PCM phase modulation
RADHOM	Radio homodyne detection (Use only when $\lambda = 13$ cm. No other burdens are available.)

7. Optimization Basis (Choose at least one)

[Note: If receiver parameters d_R and θ_R or transmitter parameters d_T and P_T are not to be optimized in weight or fabrication cost, their fixed values must be given in the COPTRAN data deck. Selection of more than one instruction in this category provides joint optimization or burdens (i. e., fabrication cost or weight) selected.]

XMWTOP	Transmitter weight optimization
RCWTOP	Receiver weight optimization
XMFTOP	Transmitter fabrication cost optimization
RCFCOP	Receiver fabrication cost optimization

8. Antenna Parameter Optimization (Choose only one)

DTDROP	Transmitter antenna diameter and receiver antenna diameter optimization
GTDROP	Transmitter antenna gain and receiver antenna diameter optimization. (Use only with radio systems

TABLE IV-I (continued)
COMPLETE LISTING OF COPTRAN INSTRUCTION MNEMONICS

DTGROP	Transmitter antenna diameter and receiver antenna gain optimization. (Use only with radio systems)
GTGROP	Transmitter antenna gain and receiver antenna gain optimization. (Use only one radio systems

9. Nominal System Burdens Data (Choose one from each set desired. See section 4.5 for detail value Listing.)

(Note: If no choice is made, program automatically selects burdens based on internal logic. See section 4.6.)

Transmitter Antenna Burdens

NXANTA	λ = 0.51 microns, spacecraft
NXANTC	λ = 0.84 microns, spacecraft
NXANTD	λ = 10.6 microns, spacecraft
NXANTF	λ = 13 cm, diameter burdens, spacecraft
NXANTG	λ = 13 cm, gain burdens, spacecraft

Receiver Antenna Burdens

NRANTA	λ = 0.51 microns, optical direct detection, earth
NRANTB	λ = 0.51 microns, optical heterodyne or homodyne detection, earth
NRANTC	λ = 0.84 microns, optical direct detection, earth
NRANTD	λ = 10.6 microns, optical direct detection, earth
NRANTE	λ = 10.6 microns, optical heterodyne or homodyne detection, earth
NRANTF	λ = 13 cm, diameter burdens, earth
NRANTG	λ = 13 cm, gain burdens, earth

TABLE IV-I (continued)
COMPLETE LISTING OF COPTRAN INSTRUCTION MNEMONICS

Transmitter Acquisition and Track Burdens	
NXACTA	Optical frequencies, spacecraft
NXACTB	Radio frequencies, spacecraft, diameter burdens
NXACTC	Radio frequencies, spacecraft, gain burdens
Receiver Acquisition and Track Burdens	
NRACTA	Optical frequencies, earth
NRACTB	Radio frequencies, earth, diameter burdens
NRACTC	Radio frequencies, earth, gain burdens
Modulation Equipment Burdens	
NMODEA	λ = 0.51 microns, CW laser, spacecraft
NMODEB	λ = 0.84 microns, CW laser, spacecraft
NMODEC	λ = 0.84 microns, pulsed laser, spacecraft
NMODED	λ = 10.6 microns, CW laser, spacecraft
NMODEE	λ = 13 cm, spacecraft
NMODEF	λ = 0.51 microns, CW laser, earth
NMODEG	λ = 0.84 microns, CW laser, earth
NMODEH	λ = 0.84 microns, pulsed laser, earth
NMODEI	λ = 10.6 microns, CW laser, earth
NMODEJ	λ = 13 cm, earth
Demodulation Equipment Burdens	
NDMODA	Optical direct detection, earth
NDMODB	Optical heterodyne detection, earth
NDMODC	Optical homodyne detection, earth
NDMODE	13 cm radio homodyne detection, earth
NDMODF	Optical direct detection, spacecraft
NDMODG	Optical heterodyne detection, spacecraft
NDMODH	Optical homodyne detection, spacecraft
NDMODI	13 cm radio direct detection, spacecraft
NDMODJ	13 cm radio homodyne detection, spacecraft

TABLE IV-I (continued)
COMPLETE LISTING OF COPTRAN INSTRUCTION MNEMONICS

	Transmitter Power Supply Burdens
NXPWSA	RTG, spacecraft
NXPWSB	Reactor, spacecraft
NXPWSC	Solar cell, Mars, Spacecraft
NXPWSD	Generator, earth
NXPWSE	Solar cell, satellite, spacecraft
NXPWSF	Solar cell, Venus, spacecraft
NXPWSG	Solar cell, Mercury, spacecraft
	Receiver Power Supply Burdens
NRPWSA	RTG, spacecraft
NRPWSB	Reactor, spacecraft
NRPWSC	Solar cell, Mars, spacecraft
NRPWSD	Generator, earth
NRPWSE	Solar cell, satellite, spacecraft
NRPWSF	Solar cell, Venus, spacecraft
NRPWSG	Solar cell, Mercury, spacecraft
	Transmitter Burdens
NXMTRA	λ = 0.51 microns, spacecraft
NXMTRB	λ = 0.51 microns, earth
NXMTRE	λ = 10.6 microns, spacecraft
NXMTRF	λ = 10.6 microns, earth
NXMTRG	λ = 13 cm, spacecraft
NXMTRH	λ = 13 cm, earth

TABLE IV-I (continued)
COMPLETE LISTING OF COPTRAN INSTRUCTION MNEMONICS

10. Computation Format — Choose one of each

RBFRQ___ — Number of information rate computations per decade, 1, 2, 4, 5, 8, 0 according to following table

RBFRQ1	RBFRQ2	RBFRQ4	RBFRQ5	RBFRQ8	RBFRQ0
10^n	10^n	10^n	10^n	10^n	10^n
10^{n-1}	0.5×10^n	0.75×10^n	0.8×10^n	0.875×10^n	0.9×10^n
	10^{n-1}	0.50×10^n	0.6×10^n	0.750×10^n	0.8×10^n
		0.25×10^n	0.4×10^n	0.625×10^n	0.7×10^n
		10^{n-1}	0.2×10^n	0.500×10^n	0.6×10^n
			10^{n-1}	0.375×10^n	0.5×10^n
				0.250×10^n	0.4×10^n
				0.125×10^n	0.3×10^n
				10^{n-1}	0.2×10^n
					10^{n-1}

RBINT___ — Initial information rate, exponent 0 to 8 (e.g., $R_B = 10^0, 10^1, \ldots, 10^8$)

RBFIN___ — Final information rate, exponent 1 to 9 (e.g., $R_B = 10^1, 10^2, \ldots, 10^9$) Note that final information rate must be greater than initial information rate

11. Print Format — Choose sets desired

PRTBUR — Print system burdens data

PRTSPD — Print system physical data

TABLE IV-I (continued)
COMPLETE LISTING OF COPTRAN INSTRUCTION MNEMONICS

PRTSNC	Print signal-to-noise ratio constants
PRTBRC	Print system burden constants
PRTSPC	Print parameter constraints
PRTOPT	Print optimum system parameters
PRTWGT	Print weight burdens for optimum system parameters
PRTPWP	Print power burdens for optimum system parameters
PRTFAB	Print fabrication cost burdens for optimum system parameters
PRTSYC	Print system cost burdens for optimum system parameters
PRTALL	Prints all of above data
PRTDAT	Print system burdens data, systems physical data, signal-to-noise ratio constants, system burden constants, and system parameter constraints.

12. Plot Format (Choose those desired)

PLTOPT	Plot optimum system parameters
PLTWA	Plot transmitter system weight
PLTCS	Plot total system cost

13. Instruction End (This card must be placed at the end of COPTRAN instructions)

ENDINS

14. Data End (This card must be placed at the end of COPTRAN data. It must appear after the "ENDINS" card if there is no data.)

ENDDAT

15. Case End (This card must physically be the last card of the COPTRAN deck, following all instructions and data for all cases run.)

ENDCAS

4.3.2 <u>COPTRAN data format</u>. – COPTRAN data is in two parts, a label consisting of up to six characters and a field consisting of up to fourteen characters in either fixed or floating point form. Small amounts of data are usually entered on COPTRAN Coding Sheet A (see Figure 4-3) by the user for subsequent key punching with the COPTRAN instructions. If a large amount of data is to be entered, COPTRAN Coding Sheets B and C shown in Figures 4-4 and 4-5 respectively may be utilized. These coding sheets contain preprinted data labels. Each data parameter will be punched on a single card, the total of these cards is the COPTRAN Data Deck. (Section 4.7 contains blank forms which are convenient for recoding large amounts of data.)

The data label must be justified left in columns 1 to 6 on the coding sheet. Columns 7, 8, 23, and 24 are left blank. The data value is entered in columns 9 to 22. Columns 25 to 80 may be employed for users comments.

Examples of fixed and floating point entries in the data field are given below. The decimal point in both cases is always in column 14.

Floating point entry: 7.5×10^{13}

7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
						7	.	5				E	+	1	3		

Fixed point entry: 0.95

7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
							.	9	5								

A control card with the characters ENDDAT in columns 1 to 6 must be placed at the end of the COPTRAN Data Deck. This card is required even if there are no new data entries. If any item of data is not included in the COPTRAN Data Deck by the user, the COPTRAN program automatically selects the value of the data item from the nominal value data bank. The labels and definitions of the COPTRAN data which may be used are listed in Table IV-II.

COPTRAN CODING SHEET B

NAME ________________ DATE ________ PROBLEM ________________

SYSTEM BURDENS DATA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	K	T	H	T										.										
2	K	D	T											.										
3	C	K	T											.										
4	W	K	T											.										
5	M	T												.										
6	N	T												.										
7																								
8	K	A	T											.										
9	K	W	A	T										.										
10	K	P	Q	T										.										
11	C	A	T											.										
12	W	B	T											.										
13	Q	T												.										
14																								
15	K	F	M											.										
16	K	M												.										
17	K	P	M											.										
18	C	K	M											.										
19	W	K	M											.										
20																								
21	K	S	T											.										
22	K	W	S	T										.										
23	C	K	E											.										
24	W	K	E											.										
25																								

SYSTEM BURDENS DATA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	K	T	H	R										.										
2	K	D	R											.										
3	C	K	R											.										
4	W	K	R											.										
5	M	R												.										
6	N	R												.										
7																								
8	K	A	R											.										
9	K	W	A	R										.										
10	K	P	Q	R										.										
11	C	A	R											.										
12	W	B	R											.										
13	Q	R												.										
14																								
15	K	F	D											.										
16	K	D												.										
17	K	P	D											.										
18	C	K	D											.										
19	W	K	D											.										
20																								
21	K	S	R											.										
22	K	W	S	R										.										
23	C	K	F											.										
24	W	K	F											.										
25																								

Figure 4-4. COPTRAN Coding Sheet B

COPTRAN CODING SHEET C

NAME ______________________ DATE ____________ PROBLEM ______________________________

SYSTEM BURDENS DATA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	K	P	T											.										
2	K	W	T											.										
3	K	H												.										
4	K	X												.										
5	K	E												.										
6	C	K	P											.										
7	C	K	H											.										
8	W	K	P											.										
9	W	K	H											.										
10	G	T												.										
11	H	T												.										
12	J	T												.										
13																								
14	K	S	A											.										
15	K	S	B											.										
16																								
17																								
18																								
19																								
20																								
21																								
22																								
23																								
24																								
25																								

SYSTEM PHYSICAL DATA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	R													.										
2	L	A	M	B	D	A								.										
3	S	N												.										
4	C	N												.										
5	U	S	B	R	E	Q								.										
6	T	A	U	T										.										
7	T	A	U	R										.										
8	T	A	U	A										.										
9	T	E												.										
10	E	T	A											.										
11	R	L												.										
12	L	M	B	D	I									.										
13	Q	B												.										
14																								
15																								
16																								
17																								
18																								
19																								
20																								
21																								
22																								
23																								
24																								
25																								

Figure 4-5. COPTRAN Coding Sheet C

TABLE IV-IIa
COPTRAN DATA

System Physical Data — Choose as desired

Label	Description
R	Transmission range
LAMBDA	Transmission wavelength
SN	Signal-to-noise power ratio
CN	Carrier-to-background radiation power ratio
USBREQ	Required signal photoelectron count per bit
TAUT	Transmitter transmissivity
TAUR	Receiver transmissivity
TAUA	Atmospheric transmissivity
RHOT	Transmitter antenna efficiency
RHOR	Receiver antenna efficiency
TE	Receiver equivalent temperature
ETA	Detector quantum efficiency
RL	Receiver output load resistance
LMBDI	Optical filter bandwidth
QB	Background radiation photon spectral radiance

TABLE IV-IIb
COPTRAN DATA

Systems Burdens Data   Choose as desired

Symbol	Description
KTHT	Constant Relating Transmitter Antenna Fabrication Cost to Transmitter Antenna Diameter
KDT	Constant Relating Transmitter Antenna Weight to Transmitter Antenna Diameter
CKT	Transmitter Antenna Fabrication Cost Independent of Transmitter Antenna Diameter
WKT	Transmitter Antenna Weight Independent of Transmitter Antenna Diameter
MT	Exponent Relating Transmitter Antenna Fabrication Cost to Transmitter Antenna Diameter
NT	Exponent Relating Transmitter Antenna Weight to Transmitter Antenna Diameter
KAT	Constant Relating Transmitter Acquisition – Track Equipment Fabrication Cost to Transmitter Beamwidth
KWAT	Constant Relating Transmitter Acquisition – Track Equipment Weight to Transmitter Antenna Weight
KPQT	Constant Relating Transmitter Acquisition – Track Equipment Power Requirement to Weight
CAT	Transmitter Acquisition – Track Equipment Fabrication Cost Independent of Transmitter Beamwidth
WBT	Transmitter Acquisition – Track Equipment Weight Independent of Transmitter Beamwidth
QT	Exponent Relating Transmitter Acquisition – Track Equipment Fabrication Cost to Transmitter Beamwidth
KFM	Constant Relating Modulation Equipment Fabrication Cost to Information Rate
KM	Constant Relating Modulation Equipment Weight to Information Rate
KPM	Constant Relating Modulation Equipment Power Requirement to Information Rate
CKM	Modulation Equipment Fabrication Cost Independent of Information Rate
WKM	Modulation Equipment Weight Independent of Information Rate
KST	Constant Relating Transmitter Power Supply Fabrication Cost to Power Requirement

TABLE IV-IIb (continued)
COPTRAN DATA

Systems Burdens Data	Choose as desired
Symbol	**Description**
KWST	Constant Relating Transmitter Power Supply Weight to Power Requirement
CKE	Transmitter Power Supply Fabrication Cost Independent of Power Requirement
WKE	Transmitter Power Supply Weight Independent of Power Requirement
KTHR	Constant Relating Receiver Antenna Fabrication Cost to Receiver Antenna Diameter
KDR	Constant Relating Receiver Antenna Weight to Receiver Antenna Diameter
CKR	Receiver Antenna Fabrication Cost Independent of Receiver Antenna Diameter
WKR	Receiver Antenna Weight Independent of Receiver Antenna Diameter
MR	Exponent Relating Receiver Antenna Fabrication Cost to Receiver Antenna Diameter
NR	Exponent Relating Receiver Antenna Weight to Receiver Antenna Diameter
KAR	Constant Relating Receiver Acquisition — Track Equipment Fabrication Cost to Receiver Beamwidth
KWAR	Constant Relating Receiver Acquisition — Track Equipment Weight to Receiver Antenna Weight
KPQR	Constant Relating Transmitter Acquisition — Track Equipment Power Requirement to Weight
CAR	Receiver Acquisition — Track Equipment Fabrication Cost Independent of Receiver Beamwidth
WBR	Exponent Relating Receiver — Track Equipment Fabrication Cost to Receiver Beamwidth
QR	Exponent Relating Receiver Track Equipment Fabrication Cost to Receiver Beamwidth
KFD	Constant Relating Demodulation Equipment Fabrication Cost to Information Rate
KD	Constant Relating Demodulation Equipment Weight to Information Rate
KPD	Constant Relating Demodulation Equipment Power Requirement to Information Rate

TABLE IV-IIb (continued)
COPTRAN DATA

Systems Burdens Data	Choose as desired
Symbol	Description
CKD	Demodulation Equipment Fabrication Cost Independent of Information Rate
WKD	Demodulation Equipment Weight Independent of Information Rate
KSR	Constant Relating Receiver Power Supply Fabrication Cost to Power Requirement
KWSR	Constant Relating Receiver Power Supply Weight to Power Requirement
CKF	Receiver Power Supply Fabrication Cost Independent of Power Requirement
WKF	Receiver Power Supply Weight Independent of Power Requirement
KPT	Constant Relating Transmitter Fabrication Cost to Transmitter Power
KWT	Constant Relating Transmitter Weight to Transmitter Power
KH	Constant Relating Transmitter Heat Exchanger Fabrication Cost to Transmitter Power Dissipation
KX	Constant Relating Transmitter Heat Exchanger Weight to Transmitter Power Dissipation
KE	Transmitter Power Efficiency
CKP	Transmitter Fabrication Cost Independent of Transmitter Power
CKH	Transmitter Heat Exchanger Fabrication Cost Independent of Transmitter Power
WKP	Transmitter Weight Independent of Transmitter Power
WKH	Transmitter Heat Exchanger Weight Independent of Transmitter Power
GT	Exponent Relating Transmitter Fabrication Cost to Transmitter Power
HT	Exponent Relating Transmitter Weight to Transmitter Power
JT	Exponent Relating Transmitter Power Supply-Heat Exchanger Burdens to Transmitter Power
KSA	Cost per Unit Weight for Spaceborne Transmitter System Equipment
KSB	Cost per Unit Weight for Spaceborne Receiver System Equipment

TABLE IV-IIc
COPTRAN DATA

Major System Parameter Constraints			Choose as indicated below
	Label	Description	
A.	DTM	Fixed value of transmitter antenna diameter	
A.	GTM	Fixed value of transmitter antenna gain	
B.	DRM	Fixed value of receiver antenna diameter	
B.	GRM	Fixed value of receiver antenna gain	
	PTM	Fixed value of transmitter power	
	THERM	Fixed value of receiver field of view	
A.	DTB	Stop value of transmitter antenna diameter	
A.	GTB	Stop value of transmitter antenna gain	
B.	DRB	Stop value of receiver antenna diameter	
B.	GRB	Stop value of receiver antenna gain	
	PTB	Stop value of transmitter power	
	THERB	Stop value of receiver field of view	
C.	DTI	Initial value of transmitter antenna diameter	
C.	GTI	Initial value of transmitter antenna gain	
C.	DRI	Initial value of receiver antenna diameter	
C.	GRI	Initial value of receiver antenna gain	
C.	PTI	Initial value of transmitter power	
	THERI	Initial value of receiver field of view	

A. Choose DTM (DTB) for transmitter antenna diameter optimization and GTM (GTB) for transmitter antenna gain optimization.

B. Choose DRM (DRB) for receiver antenna diameter optimization and GRM (GRB) for receiver antenna gain optimization.

C. Initial values of the system parameters may be chosen, if desired, to speed the convergence to a solution by the COPS program.

4.3.3 COPTRAN Multiple Runs. – Two additional features are available with the COPTRAN system as a programming aid. These are the REPEAT (repeat) and INCRMNT (increment) features. They are used when more than one job is to be run in which only a few variables are to be changed. Figure 4-6 summarizes the use of these features. Each is described in more detail below.

REPEAT – This instruction signals the COPTRAN processor that more data or instructions follow which will be used to modify the case just completed. The cards following the REPEAT and preceding the next REPEAT or ENDCAS card will affect only those variables or instructions mentioned. As in normal COPTRAN programming, instructions must be terminated by an ENDINS card and precede all data. Data must be terminated by an ENDDAT card. Refer to Figure 4-6 for an example of the use of this feature.

Instructions following a REPEAT override all instructions in the same category in previous runs. Here category is defined to mean a group of similar instructions such as those referring to transmission range (Category 3) or those referring to optimization basis (Category 7). (Refer to Table IV-I.) Data entries of the previous run remain in effect unless specifically named in the REPEAT sequence.

NCRMNT (mnemonic for increment) – This instruction set permits the user to specify a series of runs in which one data value is varied from an initial value to a final value in finite step sizes. Figure 4-7 shows the three instructions and their use. The sequence

NCRMNT	XXX E±XX
(DATA NAME)	XXX E±XX
FINALE	XXX E±XX

will cause a series of COPS runs to be made in which the variable named (DATA NAME) assumes the values from that on the (DATA NAME) card to that on the FINALE card in step sizes specified on the NCRMNT card. The variable (DATA NAME) will be incremented until its value is strictly greater than the final value specified. When this condition occurs, control returns to the COPTRAN processor and the case is finished.

NAME ______________ DATE ________ PROBLEM ______________

COPTRAN INSTRUCTIONS AND DATA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
1	S	P	X	M	T	R																			COPTRAN PROGRAM
2	E	A	R	C	V	R																			
3	•																								
4	•																								
5	•																								
6	E	N	D	D	A	T																			
7	R	E	P	E	A	T																			REPEAT
8	X	X	X	X	X	X																			(NEW INSTRUCTION(S)
9	E	N	D	I	N	S																			END OF NEW INSTRUCTIONS
10	X	X	X	X	X	X							Y	•	Y	Y			E		Y	Y			(NEW DATA)
11	E	N	D	D	A	T																			END OF NEW DATA
12	R	E	P	E	A	T																			REPEAT
13	X	X	X	X	X	X																			(NEW INSTRUCTION(S)
14	E	N	D	I	N	S																			END OF NEW INSTRUCTIONS
15	X	X	X	X	X	X							Y	•	Y	Y			E		Y	Y			(NEW DATA)
16	E	N	D	D	A	T																			END OF NEW DATA
17	•																								
18	•																								
19	•																								
20	E	N	D	C	A	S																			END OF CASES TO BE RUN
21																									
22																									
23																									
24																									
25																									

NOTE: Either new instructions or new data, or both, may follow a REPEAT.

Figure 4-6. "REPEAT" example.

NAME ____________ DATE ____________ PROBLEM ____________

COPTRAN INSTRUCTIONS AND DATA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
1	S	P	X	M	T	R																			
2	E	A	R	C	V	R																			
3	o																								
4	o																								
5	o																								COPTRAN INSTRUCTIONS AND DATA
6	E	N	D	I	N	S																			
7	o																								
8	o																								
9	o																								
10	N	C	R	M	N	T							Y	•	Y			E	±	Y	Y				(STEP SIZE)
11	(	D	A	T	A		N	A	M	E	)		Y	•	Y	Y		E	±	Y	Y				(INITIAL VALUE)
12	F	I	N	A	L	E							Y	•	Y			E	±	Y	Y				(FINAL VALUE)
13	E	N	D	C	A	S																			END OF DATA
14																									END OF CASES TO BE RUN
15																									
16																									
17																									
18																									
19																									
20																									
21																									
22																									
23																									
24																									
25																									

NOTE: Final value must be greater than initial value. All three cards must be present.

Figure 4-7. Increment (NCRMNT) Example.

4.3.4 Error Messages. – As mentioned before, certain COPTRAN instruction combinations are either invalid or not yet implemented in the COPTRAN system. When such combinations are encountered, appropriate messages will be printed for the user and the job will not be run. The error messages are listed below:

'nnnnnn' NOT YET IMPLEMENTD
where nnnnnn is the name of the illegal instruction mnemonic

THE ONLY BURDENS AVAILABLE WITH 'PCM/AM' and 'PCM/FM' ARE FOR 'LAM106'

THE ONLY BURDENS AVAILABLE WITH 'PCM/PL' ARE FOR 'LAM051'

THE ONLY BURDENS AVAILABLE WITH 'PCM/PM' ARE FOR 'LAM13C'

THE ONLY BURDENS AVAILABLE WITH 'OPTDIR' ARE FOR 'PCM/PL' AND 'LAM051'

THE ONLY BURDENS AVAILABLE WITH 'OPTHET' ARE FOR 'PCM/FM' AND 'LAM106'

THE ONLY BURDENS AVAILABLE WITH 'RADHOM' ARE FOR 'PCM/PM' AND 'LAM13C'

IF 'DRM' AND 'THERM' OR 'DTM' AND 'PTM' ARE NOT OPTIMIZED IN WEIGHT OR COST, FIXED VALUES MUST BE GIVEN

4.4 Program Examples

The following pages contain four examples of COPTRAN use. Each example contains a short description of the problem followed by a COPTRAN coding sheet as it might be coded for that problem. The output from that COPTRAN program concludes the data for a particular example.

Example A. Synchronous Satellite Transmitter to Earth Receiver Link

10.6 micron wavelength

PCM Intensity Modulation and Optical Direct Detection Receiver

Thermal Noise Limited Operation

Transmitter system weight and fabrication cost, and receiver fabrication cost jointly optimized.

Parameters to be optimized:

a. Transmitter antenna diameter
b. Receiver antenna diameter
c. Transmitter power

Fixed Parameters: Receiver field of view at 1 milliradian

Parameter Stops: None

NAME ____________ DATE ____________ PROBLEM EXAMPLE A

COPTRAN INSTRUCTIONS AND DATA

INSTRUCTION TYPE*	Line	Columns 1–6	Columns 7–24	
1	1	SPXMTR		SPACECRAFT TRANSMITTER
2	2	EARCVR		EARTH RECEIVER
3	3	RANSAT		SYNCHRONOUS SATELLITE RANGE
4	4	LAM106		10.6 MICRON TRANSMISSION WAVELENGTH
5	5	BKDSKY		DAY SKY BACKGROUND
6	6	PCM/AM		PCM INTENSITY MODULATION
6	7	OPTDIR		OPTICAL DIRECT DETECTION
7	8	XMWTOP		TRANSMITTER SYSTEM WEIGHT AND
7	9	XMFCOP		FABRICATION COST AND RECEIVER SYSTEM
7	10	RCFCOP		FABRICATION COST OPTIMIZATION
8	11	DTDROP		XMTR & RCVR ANT DIAMETER OPTIMIZATION
10	12	RBFRQ2		DATA POINTS AT $R_B = 10^2, 0.5 \times 10^3, 10^3, \ldots, 10^8$ BPS
10	13	RBINT2		
10	14	RBFIN8		
11	15	PRTALL		PRINT ALL DATA VALUES AND RESULTS OF OPT.
12	16	PLTOPT		PLOT RESULTS OF OPTIMIZATION
13	17	ENDINS		END OF COPTRAN INSTRUCTIONS
DATA	18	THERM	1.0 (cols 13–15), E-03 (cols 19–22)	1 MILLIRADIAN FIELD OF VIEW
14	19	ENDDAT		END OF COPTRAN DATA
15	20	ENDCAS		END OF COPTRAN CASES
	21			
	22			
	23			
	24			
	25			

SPACECRAFT TRANSMITTER
EARTH RECEIVER

SYNCHRONOUS SATELLITE RANGE(3.6E4 KM)
TRANSMISSION WAVELENGTH LAMBDA = 10.6 MICRONS

DAY SKY BACKGROUND
PCM AMPLITUDE MODULATION

OPTICAL DIRECT DETECTION
TRANSMITTER WEIGHT OPTIMIZATION

TRANSMITTER FABRICATION COST OPTIMIZATION
RECEIVER FABRICATION COST OPTIMIZATION

TRANSMITTER ANTENNA DIAMETER AND RECEIVER ANTENNA DIAMETER OPTIMIZATION

SYSTEM BURDENS DATA

TRANSMITTER ANTENNA	KTHT	14.00000	KDT	0.01000	CKT	20000.00	WKT	25.00	MT	2.00	NT	2.00000
RECEIVER ANTENNA	KTHR	8.75000	KDR	0.0230000	CKR	25000.00	WKR	20.00000	MR	2.00000	NR	2.00000
TRANSMITTER ACQUISITION AND TRACK SYSTEM	KAT	71000.	KWAT	0.46000	KPQT	0.48000	CAT	400000.	WBT	5.000	QT	0.30000
RECEIVER ACQUISITION AND TRACK SYSTEM	KAR	71000.	KWAR	0.46000	KPQR	0.48000	CAR	200000.	WBR	5.000	QR	0.30000
TRANSMITTER	KPT	1.43000	KWT	2.00000	KH	1.97000	KX	0.02500	KE	0.10000	CKP	2000.00
	CKH	13800.	WKP	25.000	WKH	0.	JT	1.000	G1	1.00000	HT	1.00000
MODULATION EQUIPMENT	KFM	0.00050	KM	0.00000	KPM	5.00000	CKM	15000.	WKM	10.00		
DEMODULATION EQUIPMENT	KFD	0.0000550	KD	0.00000011	KPD	3.33000	CKD	15000.	WKD	30.000		
TRANSMITTER POWER SUPPLY	KST	166.000	KWST	0.157000	CKE	0.	WKE	0.				
RECEIVER POWER SUPPLY	KSR	25.000	KWSR	0.	CKF	10000.	WKF	0.				
BOOSTER BURDENS	KSA	1640.000	KSB	1640.000								

****

SYSTEM PHYSICAL DATA

R	0.36000E 10	LAMBDA	0.10600E-02	S/N	0.26000E 02	C/N	0.60000E 01	USBREQ	0.30000E 02	TAU-T	0.80000E 00
TAU-R	0.70000E 00	TAU-A	0.80000E 00	TE	0.30000E 03	ETA	0.50000E 00	RL	0.10000E 03	LMBD-I	0.10000E-02
QB	0.	RHO-T	0.98000E 00	RHO-R	0.98000E 00						

****

****

SIGNAL-TO-NOISE RATIO CONSTANTS

K	0.	KN	0.	KM	0.36017E-06	KR	0.	KS	0.

****

****

SYSTEM BURDEN CONSTANTS

KMT	0.14000E 02	KNT	0.24879E 02	KQT	0.55420E 06	KMR	0.87500E 01	KNR	0.12696E 00	KQR	0.71000E 05
KGT	0.14300E 01	KHT	0.32800E 04	KJT	0.46215E 04						

****

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PARAMETER CONSTRAINTS

DTI	0.50000E 02	GTI	0.	DRI	0.50000E 03	GRI	0.	PTI	0.25000E 03	THERI	0.10000E-02
DTM	0.	GTM	0.	DRM	0.	GRM	0.	PTM	0.	THERM	0.10000E-02
DTB	0.10000E 03	GTB	0.	DRB	0.10000E 04	GRB	0.	PTB	0.50000E 03	THERB	0.10000E-02

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OPTIMIZATION RESULTS

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INFORMATION RATE,RB    0.10000E 09
OPTIMUM SYSTEM PARAMETERS            DTO   0.712299E 01  DRO   0.130764E 03  PTO   0.192065E 02  THERO   0.1000E-02

OPTIMUM WEIGHT BURDENS  WDT  0.255074E 02  WDR  0.413279E 03  WQT  0.523339E 01  WQR  0.185908E 03  WX   0.634130E 02
                        WH   0.432146E 01  WM   0.400000E 02  WD   0.410000E 02  WST  0.619485E 02  WSR  0.
                        WA   0.200424E 03  WB   0.640188E 03

OPTIMUM POWER BURDENS   PQT  0.251203E 01  PQR  0.892361E 02  PX   0.192065E 03  PM   0.200000E 03  PD   0.136530E 03
                        PA   0.394577E 03  PB   0.225766E 03

OPTIMUM FABRICATION COST BURDENS           CDT  0.207103E 05  CDR  0.174617E 06  CQT  0.139877E 07  CQR  0.763973E 06
                        CX   0.202747E 04  CH   0.141405E 05  CM   0.650000E 05  CD   0.205000E 05  CST  0.654997E 05
                        CSR  0.156442E 05  CA   0.156615E 07  CB   0.974734E 06

OPTIMUM SYSTEM COST BURDENS                CTO  0.100074E 07  CRO  0.151788E 06  CQO  0.563973E 06  CGO  0.151788E 06
                        CV   0.186829E 07  CS   0.391948E 07

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INFORMATION RATE,RB    0.50001E 08
OPTIMUM SYSTEM PARAMETERS            DTO   0.624660E 01  DRO   0.128047E 03  PTO   0.184167E 02  THERO   0.1000E-02

OPTIMUM WEIGHT BURDENS  WDT  0.253902E 02  WDR  0.397107E 03  WQT  0.517949E 01  WQR  0.178469E 03  WX   0.618334E 02
                        WH   0.414376E 01  WM   0.250003E 02  WD   0.355001E 02  WST  0.489298E 02  WSR  0.
                        WA   0.170477E 03  WB   0.611077E 03

OPTIMUM POWER BURDENS   PQT  0.248616E 01  PQR  0.856653E 02  PX   0.184167E 03  PM   0.125002E 03  PD   0.118215E 03
                        PA   0.311655E 03  PB   0.203881E 03

OPTIMUM FABRICATION COST BURDENS           CDT  0.205463E 05  CDR  0.168465E 06  CQT  0.136020E 07  CQR  0.763973E 06
                        CX   0.202634E 04  CH   0.141265E 05  CM   0.400006E 05  CD   0.177501E 05  CST  0.517347E 05
                        CSR  0.150970E 05  CA   0.148863E 07  CB   0.965285E 06

OPTIMUM SYSTEM COST BURDENS                CTO  0.961712E 06  CRO  0.145546E 06  CQO  0.563973E 06  CGO  0.145546E 06
                        CV   0.181678E 07  CS   0.373566E 07

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INFORMATION RATE,RB     0.10000E 08
OPTIMUM SYSTEM PARAMETERS             DTO   0.459875E 01  DRO   0.122039E 03  PTO   0.167290E 02  THERO   0.1000E-02

OPTIMUM WEIGHT BURDENS  WDT   0.252115E 02  WDR   0.362549E 03  WQT   0.509728E 01  WQR   0.162573E 03  WX   0.584580E 02
                         WH   0.376402E 01  WM    0.130000E 02  WD    0.311000E 02  WST   0.368536E 02  WSR  0.
                         WA   0.142384E 03  WB    0.556222E 03

OPTIMUM POWER BURDENS   PQT   0.244670E 01  PQR   0.780349E 02  PX    0.167290E 03  PM    0.649999E 02  PD   0.103563E 03
                         PA   0.234736E 03  PB    0.181598E 03

OPTIMUM FABRICATION COST BURDENS            CDT   0.202961E 05  CDR   0.155318E 06  CQT   0.127591E 07  CQR  0.763973E 06
                         CX   0.202392E 04  CH    0.140966E 05  CM    0.200000E 05  CD    0.155500E 05  CST  0.389663E 05
                        CSR   0.145399E 05  CA    0.137129E 07  CB    0.949381E 06

OPTIMUM SYSTEM COST BURDENS                 CTO   0.876731E 06  CRO   0.132208E 06  CQO   0.563973E 06  CGO  0.132208E 06
                         CV   0.170512E 07  CS    0.346639E 07

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INFORMATION RATE,RB     0.50001E 07
OPTIMUM SYSTEM PARAMETERS             DTO   0.402876E 01  DRO   0.119565E 03  PTO   0.160577E 02  THERO   0.1000E-02

OPTIMUM WEIGHT BURDENS  WDT   0.251623E 02  WDR   0.348804E 03  WQT   0.507466E 01  WQR   0.156250E 03  WX   0.571155E 02
                         WH   0.361299E 01  WM    0.115000E 02  WD    0.305500E 02  WST   0.346206E 02  WSR  0.
                         WA   0.137086E 03  WB    0.535604E 03

OPTIMUM POWER BURDENS   PQT   0.243584E 01  PQR   0.750000E 02  PX    0.160577E 03  PM    0.575002E 02  PD   0.101732E 03
                         PA   0.220513E 03  PB    0.176732E 03

OPTIMUM FABRICATION COST BURDENS            CDT   0.202272E 05  CDR   0.150089E 06  CQT   0.124182E 07  CQR  0.763973E 06
                         CX   0.202296E 04  CH    0.140847E 05  CM    0.175001E 05  CD    0.152750E 05  CST  0.366052E 05
                        CSR   0.144183E 05  CA    0.133226E 07  CB    0.943755E 06

OPTIMUM SYSTEM COST BURDENS                 CTO   0.842448E 06  CRO   0.126904E 06  CQO   0.563973E 06  CGO  0.126904E 06
                         CV   0.166023E 07  CS    0.337922E 07

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INFORMATION RATE,RB    0.10000E 07
OPTIMUM SYSTEM PARAMETERS              DTO   0.296094E 01  DRO   0.114052E 03  PTO   0.146110E 02  THERO   0.1000E-02

OPTIMUM WEIGHT BURDENS  WDT  0.250877E 02  WDR  0.319181E 03  WWT  0.504033E 01  WOR  0.142623E 03  WX   0.542220E 02
                        WH   0.328748E 01  WM   0.103000E 02  WD   0.301100E 02  WST  0.314046E 02  WSR  0.
                        WA   0.129342E 03  WB   0.491914E 03

OPTIMUM POWER BURDENS   PQT  0.241936E 01  PQR  0.684592E 02  PX   0.146110E 03  PM   0.515000E 02  PD   0.100266E 03
                        PA   0.200030E 03  PB   0.168725E 03

OPTIMUM FABPICATION COST BURDENS           CDT  0.201227E 05  CDR  0.138819E 06  CQT  0.116753E 07  CQR  0.763973E 06
                        CX   0.202089E 04  CH   0.140591E 05  CM   0.155000E 05  CD   0.150550E 05  CST  0.332049E 05
                        CSR  0.142181E 05  CA   0.125244E 07  CB   0.932065E 06

OPTIMUM SYSTEM COST BURDENS                CTO  0.767871E 06  CRO  0.115470E 06  CQO  0.563973E 06  CGO  0.115470E 06
                        CV   0.156278E 07  CS   0.320336E 07

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INFORMATION RATE,RB    0.50001E 06
OPTIMUM SYSTEM PARAMETERS              DTO   0.259263E 01  DRO   0.111769E 03  PTO   0.140318E 02  THERO   0.1000E-02

OPTIMUM WEIGHT BURDENS  WDT  0.250672E 02  WDR  0.307322E 03  WQT  0.503092E 01  WQR  0.137168E 03  WX   0.530637E 02
                        WH   0.315717E 01  WM   0.101500E 02  WD   0.300550E 02  WST  0.303769E 02  WSR  0.
                        WA   0.126846E 03  WB   0.474545E 03

OPTIMUM POWER BURDENS   PQT  0.241484E 01  PQR  0.658406E 02  PX   0.140318E 03  PM   0.507500E 02  PD   0.100083E 03
                        PA   0.193483E 03  PB   0.165924E 03

OPTIMUM FABRICATION COST BURDENS           CDT  0.200941E 05  CDR  0.134307E 06  CQT  0.113755E 07  CQR  0.763973E 06
                        CX   0.202007E 04  CH   0.140488E 05  CM   0.152500E 05  CD   0.150275E 05  CST  0.321182E 05
                        CSR  0.141481E 05  CA   0.122108E 07  CB   0.927456E 06

OPTIMUM SYSTEM COST BURDENS                CTO  0.737807E 06  CRO  0.110893E 06  CQO  0.563973E 06  CGO  0.110893E 06
                        CV   0.152357E 07  CS   0.313481E 07

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INFORMATION RATE,RB     0.10000E 06
OPTIMUM SYSTEM PARAMETERS                 DTO    0.190389E 01  DRO    0.106659E 03  PTO    0.127781E 02  THERO    0.1000E-02

OPTIMUM WEIGHT BURDENS   WDT    0.250362E 02   WDR    0.281650E 03   WQT    0.501667E 01   WQR    0.125359E 03   WX    0.505563E 02
                          WH    0.287508E 01   WM     0.100300E 02   WD     0.300110E 02   WST    0.283133E 02   WSR   0.
                          WA    0.121828E 03   WB     0.437020E 03

OPTIMUM POWER BURDENS    PQT    0.240800E 01   PQR    0.601723E 02   PX     0.127781E 03   PM     0.501500E 02   PD    0.999366E 02
                          PA    0.180339E 03   PB     0.160109E 03

OPTIMUM FABRICATION COST BURDENS               CDT    0.200507E 05   CDR    0.124541E 06   CQT    0.107229E 07   CQR   0.763973E 06
                          CX    0.201827E 04   CH     0.140266E 05   CM     0.150500E 05   CD     0.150055E 05   CST   0.299363E 05
                         CSR    0.140027E 05   CA     0.115338E 07   CB     0.917522E 06

OPTIMUM SYSTEM COST BURDENS                    CTO    0.672435E 06   CRO    0.100985E 06   CQO    0.563973E 06   CGO   0.100985E 06
                          CV    0.143838E 07   CS     0.298741E 07

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INFORMATION RATE,RB     0.50001E 05
OPTIMUM SYSTEM PARAMETERS                 DTO    0.166667E 01  DRO    0.104536E 03  PTO    0.122746E 02  THERO    0.1000E-02

OPTIMUM WEIGHT BURDENS   WDT    0.250278E 02   WDR    0.271339E 03   WQT    0.501278E 01   WQR    0.120616E 03   WX    0.495492E 02
                          WH    0.276178E 01   WM     0.100150E 02   WD     0.300055E 02   WST    0.275106E 02   WSR   0.
                          WA    0.119877E 03   WB     0.421960E 03

OPTIMUM POWER BURDENS    PQT    0.240613E 01   PQR    0.578957E 02   PX     0.122746E 03   PM     0.500750E 02   PD    0.999183E 02
                          PA    0.175227E 03   PB     0.157814E 03

OPTIMUM FABRICATION COST BURDENS               CDT    0.200389E 05   CDR    0.120618E 06   CQT    0.104598E 07   CQR   0.763973E 06
                          CX    0.201755E 04   CH     0.140176E 05   CM     0.150250E 05   CD     0.150028E 05   CST   0.290877E 05
                         CSR    0.139453E 05   CA     0.112617E 07   CB     0.913539E 06

OPTIMUM SYSTEM COST BURDENS                    CTO    0.646091E 06   CRO    0.970055E 05   CQO    0.563973E 06   CGO   0.970055E 05
                          CV    0.140408E 07   CS     0.292832E 07

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INFORMATION RATE,RB    0.10000E 05
OPTIMUM SYSTEM PARAMETERS              DTO    0.122344E 01  DRO    0.997762E 02  PTO    0.111822E 02  THERO    0.1000E-02

OPTIMUM WEIGHT BURDENS  WDT   0.250150E 02  WDR   0.248972E 03  WOT   0.500689E 01  WQR   0.110327E 03  WX   0.473645E 02
                        WH    0.251600E 01  WM    0.100030E 02  WD    0.300011E 02  WST   0.257858E 02  WSR  0.
                        WA    0.115691E 03  WB    0.389300E 03

OPTIMUM POWER BURDENS   PUT   0.240330E 01  PQR   0.529570E 02  PX    0.111822E 03  PM    0.500150E 02  PD   0.999037E 02
                        PA    0.164241E 03  PB    0.152861E 03

OPTIMUM FABRICATION COST BURDENS            CDT   0.200210E 05  CDR   0.112109E 06  CQT   0.988764E 06  CQR  0.763973E 06
                        CX    0.201599E 04  CH    0.139983E 05  CM    0.150050E 05  CD    0.150005E 05  CST  0.272639E 05
                        CSR   0.138215E 05  CA    0.106707E 07  CB    0.904904E 06

OPTIMUM SYSTEM COST BURDENS                 CTO   0.588822E 06  CRO   0.883727E 05  CQO   0.563973E 06  CGO  0.883727E 05
                        CV    0.132954E 07  CS    0.280016E 07

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INFORMATION RATE,RB    0.50001E 04
OPTIMUM SYSTEM PARAMETERS              DTO    0.107087E 01  DRO    0.977961E 02  PTO    0.107428E 02  THERO    0.1000E-02

OPTIMUM WEIGHT BURDENS  WDT   0.250115E 02  WDR   0.239974E 03  WOT   0.500528E 01  WQR   0.106188E 03  WX   0.464856E 02
                        WH    0.241713E 01  WM    0.100015E 02  WD    0.300005E 02  WST   0.250946E 02  WSR  0.
                        WA    0.114016E 03  WB    0.376162E 03

OPTIMUM POWER BURDENS   PQT   0.240253E 01  PQR   0.509702E 02  PX    0.107428E 03  PM    0.500075E 02  PD   0.999018E 02
                        PA    0.159838E 03  PB    0.150872E 03

OPTIMUM FABRICATION COST BURDENS            CDT   0.200161E 05  CDR   0.108686E 06  CQT   0.965702E 06  CQR  0.763973E 06
                        CX    0.201536E 04  CH    0.139905E 05  CM    0.150025E 05  CD    0.150003E 05  CST  0.265331E 05
                        CSR   0.137718E 05  CA    0.104326E 07  CB    0.901431E 06

OPTIMUM SYSTEM COST BURDENS                 CTO   0.565747E 06  CRO   0.848999E 05  CQO   0.563973E 06  CGO  0.848999E 05
                        CV    0.129952E 07  CS    0.274858E 07

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INFORMATION RATE,RB    0.10000E 04
OPTIMUM SYSTEM PARAMETERS          DTO   0.785941E 00  DRO   0.933518E 02  PTO   0.978858E 01  THERO   0.1000E-02

OPTIMUM WEIGHT BURDENS  WDT   0.250062E 02  WDR   0.220435E 03  WOT   0.500284E 01  WQR   0.972000E 02  WX   0.445772E 02
                        WH    0.220243E 01  WM    0.100003E 02  WD    0.300001E 02  WST   0.235953E 02  WSR  0.
                        WA    0.110384E 03  WB    0.347635E 03

OPTIMUM POWER BURDENS   PQT   0.240136E 01  PQR   0.466560E 02  PX    0.978858E 02  PM    0.500015E 02  PD   0.999004E 02
                        PA    0.150289E 03  PB    0.146556E 03

OPTIMUM FABRICATION COST BURDENS            CDT   0.200086E 05  CDR   0.101252E 06  CQT   0.915565E 06  CQR  0.763973E 06
                        CX    0.201400E 04  CH    0.139736E 05  CM    0.150005E 05  CD    0.150001E 05  CST  0.249479E 05
                        CSR   0.136639E 05  CA    0.991510E 06  CB    0.893889E 06

OPTIMUM SYSTEM COST BURDENS                 CTO   0.515589E 06  CRO   0.773588E 05  CQO   0.563973E 06  CGO  0.773588E 05
                        CV    0.123428E 07  CS    0.263655E 07

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INFORMATION RATE,RB    0.50001E 03
OPTIMUM SYSTEM PARAMETERS          DTO   0.687896E 00  DRO   0.915017E 02  PTO   0.940443E 01  THERO   0.1000E-02

OPTIMUM WEIGHT BURDENS  WDT   0.250047E 02  WDR   0.212569E 03  WOT   0.500218E 01  WQR   0.935816E 02  WX   0.438089E 02
                        WH    0.211600E 01  WM    0.100001E 02  WD    0.300001E 02  WST   0.229920E 02  WSR  0.
                        WA    0.108924E 03  WB    0.336150E 03

OPTIMUM POWER BURDENS   PQT   0.240104E 01  PQR   0.449192E 02  PX    0.940443E 02  PM    0.500007E 02  PD   0.999002E 02
                        PA    0.146446E 03  PB    0.144819E 03

OPTIMUM FABRICATION COST BURDENS            CDT   0.200066E 05  CDR   0.982599E 05  CQT   0.895363E 06  CQR  0.763973E 06
                        CX    0.201345E 04  CH    0.139667E 05  CM    0.150003E 05  CD    0.150000E 05  CST  0.243101E 05
                        CSR   0.136205E 05  CA    0.970660E 06  CB    0.890853E 06

OPTIMUM SYSTEM COST BURDENS                 CTO   0.495381E 06  CRO   0.743228E 05  CQO   0.563973E 06  CGO  0.743228E 05
                        CV    0.120800E 07  CS    0.259144E 07

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INFORMATION RATE,RB		0.10000E 03									
OPTIMUM SYSTEM PARAMETERS			DTO	0.504820E 00	DRO	0.873472E 02	PTO	0.856984E 01	THERO	0.1000E-02	
OPTIMUM WEIGHT BURDENS	WDT	0.250025E 02	WDR	0.195479E 03	WQT	0.500117E 01	WQR	0.857205E 02	WX	0.421397E 02	
	WH	0.192821E 01	WM	0.100000E 02	WD	0.300000E 02	WST	0.216816E 02	WSR	0.	
	WA	0.105753E 03	WB	0.311200E 03							
OPTIMUM POWER BURDENS	PQT	0.240056E 01	PQR	0.411458E 02	PX	0.856984E 02	PM	0.500001E 02	PD	0.999000E 02	
	PA	0.138099E 03	PB	0.141046E 03							
OPTIMUM FABRICATION COST BURDENS			CDT	0.200036E 05	CDR	0.917585E 05	CQT	0.851448E 06	CQR	0.763973E 06	
	CX	0.201225E 04	CH	0.139519E 05	CM	0.150000E 05	CD	0.150000E 05	CST	0.229245E 05	
	CSR	0.135261E 05	CA	0.925340E 06	CB	0.884258E 06					
OPTIMUM SYSTEM COST BURDENS			CTO	0.451458E 06	CRO	0.677271E 05	CQO	0.563973E 06	CGO	0.677271E 05	
	CV	0.115089E 07	CS	0.249340E 07							

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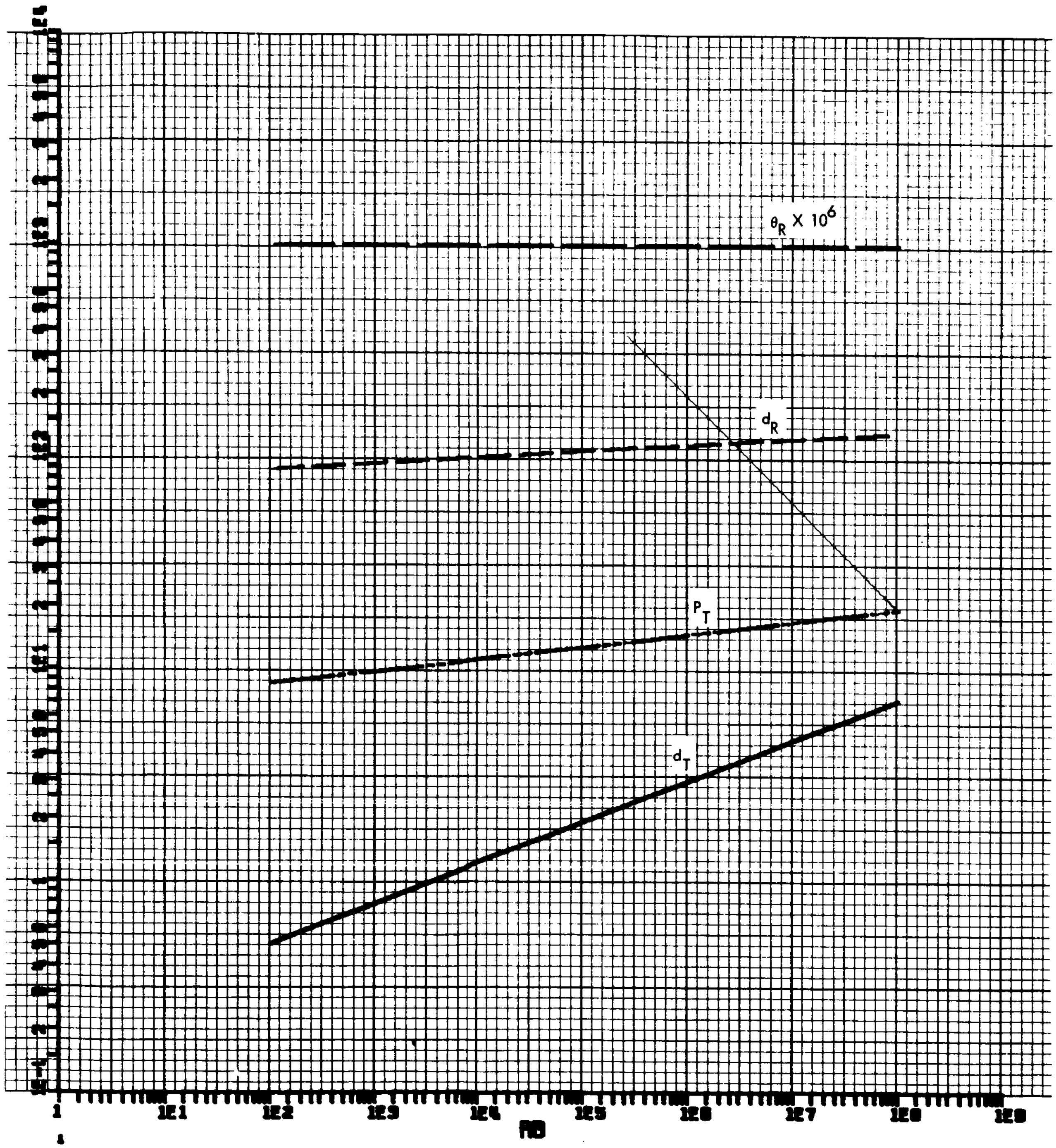

θ_R X 10^6
d_R
P_T
d_T
1
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
1E9

Example B: Mars Spacecraft Transmitter to Earth Receiver Link

0.51 micron wavelength

PCM polarization modulation

Shot Noise Limited Operation

Transmitter system weight and fabrication cost, and receiver fabrication cost jointly optimized.

Parameters to be optimized:

a. Transmitter antenna diameter

b. Receiver antenna diameter

c. Transmitter power

d. Receiver field of view

Fixed Parameters: None

Parameter Stops:

a. Transmitter antenna diameter at 50 cm

b. Receiver field of view at 2.5 microradians

NAME ______________ DATE ________ PROBLEM EXAMPLE B

COPTRAN INSTRUCTIONS AND DATA

INSTRUCTION TYPE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
1	1	S	P	X	M	T	R																			SPACECRAFT TRANSMITTER
2	2	E	A	R	C	V	R																			EARTH RECEIVER
3	3	R	A	N	M	A	R																			MARS RANGE
4	4	L	A	M	0	5	1																			0.51 MICRON TRANSMISSION WAVELENGTH
5	5	B	K	D	S	K	Y																			DAY SKY BACKGROUND
6	6	P	C	M	/	P	L																			PCM POLARIZATION MODULATION
6	7	O	P	T	D	I	R																			OPTICAL DIRECT DETECTION
7	8	X	M	W	T	O	P																			TRANSMITTER SYSTEM WEIGHT & FABRICATION
7	9	X	M	F	C	O	P																			COST AND RECEIVER SYSTEM FABRICATION
7	10	R	C	F	C	O	P																			COST JOINTLY OPTIMIZED
8	11	D	T	D	R	O	P																			TRANSMITTER & RECEIVER ANTENNA DIAMETEROPT.
10	12	R	B	F	R	Q	O																			DATA POINTS AT RB = 10°, 0.2 x 10',
10	13	R	B	I	N	T	O																			0.3 x 10', . . . , 10^8 BITS PER SECOND
10	14	R	B	F	I	N	8																			
11	15	P	R	T	D	A	T																			PRINT OUT ALL SYSTEM DATA
12	16	P	L	T	O	P	T																			PLOT VALUES OF OPT. SYSTEM PARAMETERS
13	17	E	N	D	I	N	S																			END OF COPTRAN INSTRUCTIONS
DATA	18	T	H	E	R	B								2	•	5			E	–	6					2.5 RAD STOPS ON RECEIVING FIELD OF VIEW
DATA	19	D	T	B									5	0	•											50 CM STOP ON TRANSMITTER ANT. DIAM.
DATA	20	D	T	I									4	5	•											INITIAL VALUE OF TRANSMITTER ANT. DIAM.
14	21	E	N	D	D	A	T																			END OF COPTRAN DATA DECK
15	22	E	N	D	C	A	S																			END OF COPTRAN CASES
	23																									
	24																									
	25																									

SPACECRAFT TRANSMITTER
EARTH RECEIVER

MARS RANGE (1.E8 KM)
TRANSMISSION WAVELENGTH LAMBDA = 0.51 MICRONS

DAY SKY BACKGROUND
PCM POLARIZATION MODULATION

OPTICAL DIRECT DETECTION
TRANSMITTER WEIGHT OPTIMIZATION

TRANSMITTER FABRICATION COST OPTIMIZATION
RECEIVER FABRICATION COST OPTIMIZATION

TRANSMITTER ANTENNA DIAMETER AND RECEIVER ANTENNA DIAMETER OPTIMIZATION

SYSTEM BURDENS DATA

TRANSMITTER ANTENNA	KTHT	14.00000	KDT	0.01000	CKT	20000.00	WKT	25.00	MT	2.00	NT	2.00000
RECEIVER ANTENNA	KTHR	8.75000	KDR	0.0230000	CKR	25000.00	WKR	20.00000	MR	2.00000	NR	2.00000
TRANSMITTER ACQUISITION AND TRACK SYSTEM	KAT	71000.	KWAT	0.46000	KPQT	0.48000	CAT	400000.	WBT	5.000	QT	0.30000
RECEIVER ACQUISITION AND TRACK SYSTEM	KAR	71000.	KWAR	0.46000	KPQR	0.48000	CAR	200000.	WBR	5.000	QR	0.30000
TRANSMITTER	KPT	150.00000	KWT	51.00000	KH	0.58000	KX	0.00700	KE	0.00100	CKP	3500.00
	CKH	13800.	WKP	40.000	WKH	0.	JT	1.000	GT	1.00000	HT	1.00000
MODULATION EQUIPMENT	KFM	0.00007	KM	0.00000	KPM	5.00000	CKM	7500.	WKM	5.00		
DEMODULATION EQUIPMENT	KFD	0.0000550	KD	0.00000011	KPD	3.33000	CKD	15000.	WKD	30.000		
TRANSMITTER POWER SUPPLY	KST	112.000	KWST	0.110000	CKE	0.	WKE	0.				
RECEIVER POWER SUPPLY	KSR	25.000	KWSR	0.	CKF	10000.	WKF	0.				
BOOSTER BURDENS	KSA	1640.000	KSB	1640.000								

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                                        SYSTEM PHYSICAL DATA

R       0.10000E 14  LAMBDA  0.51000E-04  S/N     0.12000E 02  C/N     0.30000E 01  USBREQ  0.15000E 02  TAU-T   0.80000E 00

TAU-R   0.70000E 00  TAU-A   0.80000E 00  TE      0.           ETA     0.20000E 00  RL      0.10000E 03  LMBD-I  0.10000E-02

QB      0.20000E 17  RHO-I   0.98000E 00  RHO-R   0.98000E 00

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                                   SIGNAL-TO-NOISE RATIO CONSTANTS

   K    0.26052E 13    KN    0.              KM    0.              KR    0.              KS    0.17679E-01

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                                      SYSTEM BURDEN CONSTANTS

  KMT   0.14000E 02    KNT   0.24590E 02    KQT   0.13772E 07 KMR      0.87500E 01    KNR   0.12696E 00    KQR   0.71000E 05

  KGT   0.15000E 03   KHT    0.83640E 05    KJT   0.30445E 06

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                                 PARAMETER CONSTRAINTS

DTI     0.45000E 02  GTI     0.           DRI     0.50000E 03  GRI     0.           PTI     0.25000E 02  THERI   0.20000E-04
DTM     0.           GTM     0.           DRM     0.           GRM     0.           PTM     0.           THERM   0.
DTB     0.50000E 02  GTB     0.           DRB     0.10000E 04  GRB     0.           PTB     0.50000E 02  THERB   0.10000E-04

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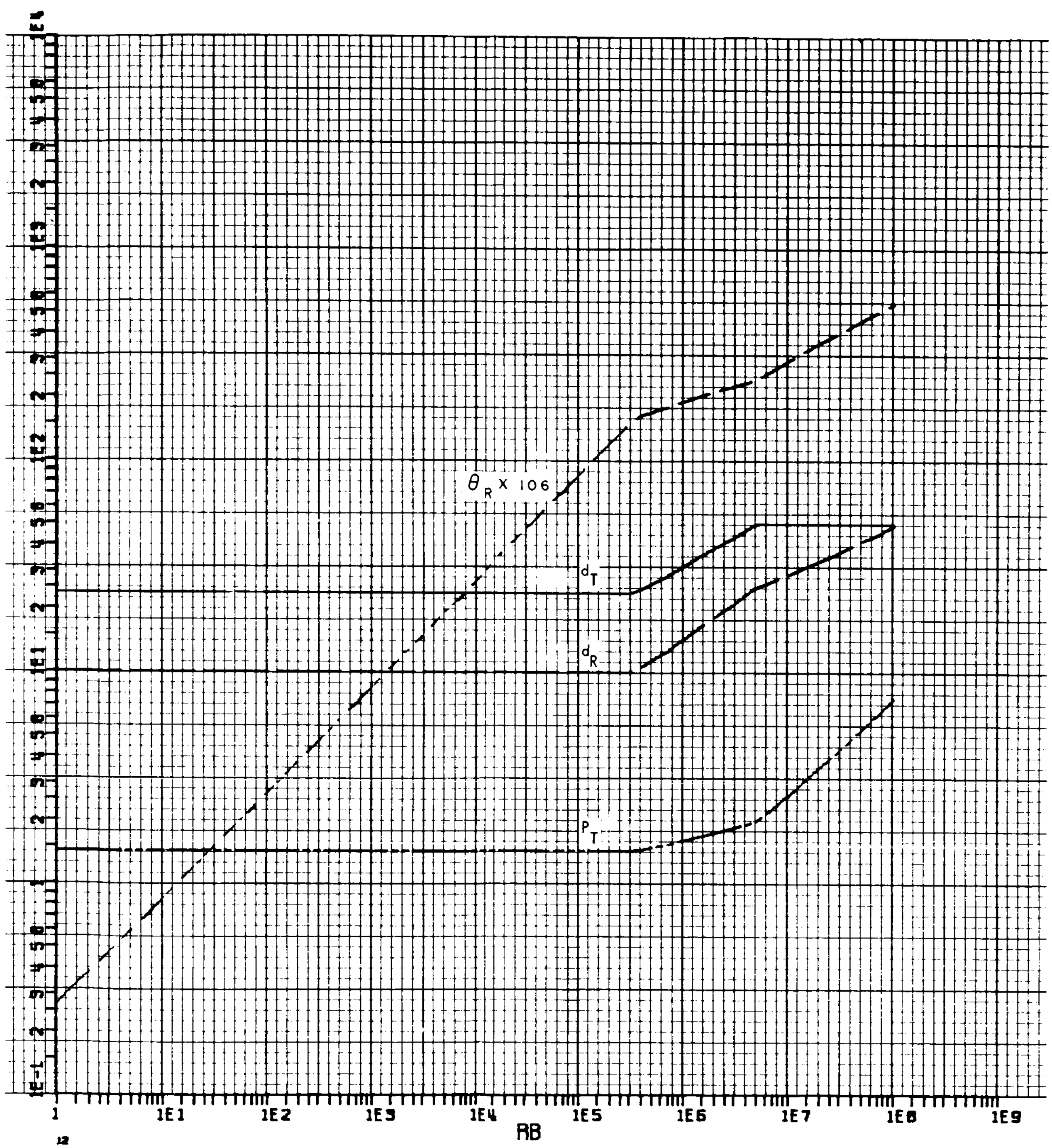

θ_R x 106
d_T
d_R
P_T
1
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
1E9
RB

Example C: Jupiter Spacecraft Transmitter to Earth Receiver Link

10.6 micron wavelength

PCM frequency shift keying

Shot noise limited operation

Transmitter system weight optimization

Parameters to be optimized:

a. Transmitter antenna diameter

b. Receiver antenna diameter

c. Transmitter power

Fixed Parameters

a. Receiver field of view at 1 milliradian

Parameter Stops

a. Transmitter power at 1 kw

b. Receiver antenna diameter at 1 meter

c. Receiver antenna diameter at 50 cm

NAME ______ DATE ______ PROBLEM EXAMPLE C

COPTRAN INSTRUCTIONS AND DATA

INSTRUCTION TYPE*		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
1	1	S	P	X	M	T	R																			SPACECRAFT TRANSMITTER
2	2	E	A	R	C	V	R																			EARTH RECEIVER
3	3	R	A	N	J	U	P																			JUPITER RANGE
4	4	L	A	M	1	0	6																			10.6 MICRON TRANSMISSION WAVELENGTH
5	5	B	K	D	S	K	Y																			DAY SKY BACKGROUND
6	6	P	C	M	/	F	M																			PCM FREQUENCY SHIFT KEYING
6	7	O	P	T	H	E	T																			OPTICAL HETERODYNE DETECTION
7	8	X	M	W	T	O	P																			TRANSMITTER SYSTEM WEIGHT OPTIMIZATION
8	9	D	T	D	R	O	P																			TRANSMITTER & RECEIVER ANTENNA WT. OPT.
10	10	R	B	F	R	Q	0																			DATA POINTS AT RB = 10°, 0.2 x 10', 0.3 x 10',
10	11	R	B	I	N	T	0																			. . . , 10^7 BPS
10	12	R	B	F	I	N	7																			
11	13	P	R	T	D	A	T																			PRINT SYSTEM DATA & CONSTANTS
12	14	P	L	T	O	P	T																			PLOT VALUES OF OPTIMUM SYSTEM PARAMETERS
13	15	E	N	D	I	N	S																			END OF COPTRAN INSTRUCTIONS
DATA	16	P	T	B										1	•	0				E	+	0	3			1 KW STOP ON XMTR POWER
DATA	17	D	R	M								1	0	0	•											1 METER STOP ON RECEIVER ANT. DIAMETER
DATA	18	D	T	B									5	0	•											50 CM STOP ON TRANSMITTER ANT. DIAMETER
DATA	19	T	H	E	R	M								1	•	0				E	–	0	3			1 MILLIRADIAN FIXED RECEIVER FIELD OF VIEW
14	20	E	N	D	D	A	T																			END OF COPTRAN DATA
REPEAT	21	R	E	P	E	A	T																			REPEAT PRECEDING CASE
13	22	E	N	D	I	N	S																			END OF COPTRAN INSTRUCTIONS
DATA	23	D	T	B									8	0	•											NEW XMTR ANT. DIAM. STOP = 80 CM
14	24	E	N	D	D	A	T																			END OF DATA
15	25	E	N	D	C	A	S																			END OF CASES
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	

SPACECRAFT TRANSMITTER
EARTH RECEIVER

JUPITER RANGE(7.5E8 KM)
TRANSMISSION WAVELENGTH LAMBDA - 10.6 MICRONS

DAY SKY BACKGROUND
PCM FREQUENCY MODULATION

OPTICAL HETERODYNE DETECTION
TRANSMITTER WEIGHT OPTIMIZATION

TRANSMITTER ANTENNA DIAMETER AND RECEIVER ANTENNA DIAMETER OPTIMIZATION

SYSTEM BURDENS DATA

TRANSMITTER ANTENNA	KTHT	14.00000	KDT	0.01000	CKT	20000.00	WKT	25.00	MT	2.00	NT	2.00000
RECEIVER ANTENNA	KTHR	8.75000	KDR	0.0230000	CKR	25000.00	WKR	20.00000	MR	2.00000	NR	2.00000
TRANSMITTER ACQUISITION AND TRACK SYSTEM	KAT	71000.	KWAT	0.46000	KPQT	0.48000	CAT	400000.	WBT	5.000	QT	0.30000
RECEIVER ACQUISITION AND TRACK SYSTEM	KAR	71000.	KWAR	0.46000	KPQR	0.48000	CAR	200000.	WBR	5.000	QR	0.30000
TRANSMITTER	KPT	1.43000	KWT	2.00000	KH	1.97000	KX	0.02500	KE	0.10000	CKP	2000.00
	CKH	13800.	WKP	25.000	WKH	0.	JT	1.000	GT	1.00000	HT	1.00000
MODULATION EQUIPMENT	KFM	0.00050	KM	0.00000	KPM	5.00000	CKM	15000.	WKM	10.00		
DEMODULATION EQUIPMENT	KFD	0.0001000	KD	0.00000020	KPD	3.33000	CKD	27500.	WKD	55.000		
TRANSMITTER POWER SUPPLY	KST	500.000	KWST	0.625000	CKE	1200000.	WKE	400.000				
RECEIVER POWER SUPPLY	KSR	25.000	KWSR	0.	CKF	10000.	WKF	0.				
BOOSTER BURDENS	KSA	1640.000	KSB	1640.000								

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SYSTEM PHYSICAL DATA

R	0.75000E 14	LAMBDA	0.10600E-02	S/N	0.15000E 02	C/N	0.	USBREQ	0.	TAU-T	0.80000E 00
TAU-R	0.60000E 00	TAU-A	0.80000E 00	TE	0.	ETA	0.50000E 00	RL	0.10000E 03	LMBD-I	0.10000E-02
QB	0.	RHO-T	0.98000E 00	RHO-R	0.98000E 00						

SIGNAL-TO-NOISE RATIO CONSTANTS

K	0.	KN	0.16202E-04	KM	0.	KR	0.	KS	0.

SYSTEM BURDEN CONSTANTS

KMT	0.	KNT	0.26207E 02	KOT	0.	KMR	0.	KNR	0.	KOR	0.
KGT	0.	KHT	0.32800E 04	KJT	0.10619E 05						

PARAMETER CONSTRAINTS

DTI	0.50000E 02	GTI	0.	DRI	0.10000E 03	GRI	0.	PTI	0.25000E 03	THERI	0.10000E-02
DTM	0.	GTM	0.	DRM	0.10000E 03	GRM	0.	PTM	0.	THERM	0.10000E-02
DTB	0.80000E 02	GTB	0.	DRB	0.10000E 03	GRB	0.	PTB	0.50000E 03	THERB	0.10000E-02

SPACECRAFT TRANSMITTER
EARTH RECEIVER

JUPITER RANGE(7.5E8 KM)
TRANSMISSION WAVELENGTH LAMBDA = 10.6 MICRONS

DAY SKY BACKGROUND
PCM FREQUENCY MODULATION

OPTICAL HETERODYNE DETECTION
TRANSMITTER WEIGHT OPTIMIZATION

TRANSMITTER ANTENNA DIAMETER AND RECEIVER ANTENNA DIAMETER OPTIMIZATION

SYSTEM BURDENS DATA

TRANSMITTER ANTENNA	KTHT	14.00000	KDT	0.01000	CKT	20000.00	WKT	25.00	MT	2.00	NT	2.00000
RECEIVER ANTENNA	KTHR	8.75000	KDR	0.0230000	CKR	25000.00	WKR	20.00000	MR	2.00000	NR	2.00000
TRANSMITTER ACQUISITION AND TRACK SYSTEM	KAT	71000.	KWAT	0.46000	KPQT	0.48000	CAT	400000.	WBT	5.000	QT	0.30000
RECEIVER ACQUISITION AND TRACK SYSTEM	KAR	71000.	KWAR	0.46000	KPQR	0.48000	CAR	200000.	WBR	5.000	QR	0.30000
TRANSMITTER	KPT	1.43000	KWT	2.00000	KH	1.97000	KX	0.02500	KE	0.10000	CKP	2000.00
	CKH	13800.	WKP	25.000	WKH	0.	JT	1.000	GT	1.00000	HT	1.00000
MODULATION EQUIPMENT	KFM	0.00050	KM	0.00000	KPM	5.00000	CKM	15000.	WKM	10.00		
DEMODULATION EQUIPMENT	KFD	0.0001000	KD	0.00000020	KPD	3.33000	CKD	27500.	WKD	55.000		
TRANSMITTER POWER SUPPLY	KST	500.000	KWST	0.625000	CKE	1200000.	WKE	400.000				
RECEIVER POWER SUPPLY	KSR	25.000	KWSR	0.	CKF	10000.	WKF	0.				
BOOSTER BURDENS	KSA	1640.000	KSB	1640.000								

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SYSTEM PHYSICAL DATA

R	0.75000E 14	LAMBDA	0.10600E-02	S/N	0.15000E 02	C/N	0.	USBREQ	0.	TAU-T	0.80000E 00
TAU-R	0.60000E 00	TAU-A	0.80000E 00	TE	0.	ETA	0.50000E 00	RL	0.10000E 03	LMBD-I	0.10000E-02
QB	0.	RHO-T	0.98000E 00	RHO-R	0.98000E 00						

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SIGNAL-TO-NOISE RATIO CONSTANTS

K	0.	KN	0.16202E-04	KM	0.	KR	0.	KS	0.

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SYSTEM BURDEN CONSTANTS

KMT	0.	KNT	0.26207E 02	KQT	0.	KMR	0.	KNR	0.	KQR	0.
KGT	0.	KHT	0.32800E 04	KJT	0.10619E 05						

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PARAMETER CONSTRAINTS

DTI	0.50000E 02	GTI	0.	DRI	0.10000E 03	GRI	0.	PTI	0.25000E 03	THERI	0.10000E-02
DTM	0.	GTM	0.	DRM	0.10000E 03	GRM	0.	PTM	0.	THERM	0.10000E-02
DTB	0.50000E 02	GTB	0.	DRB	0.10000E 03	GRB	0.	PTB	0.10000E 04	THERB	0.10000E-02

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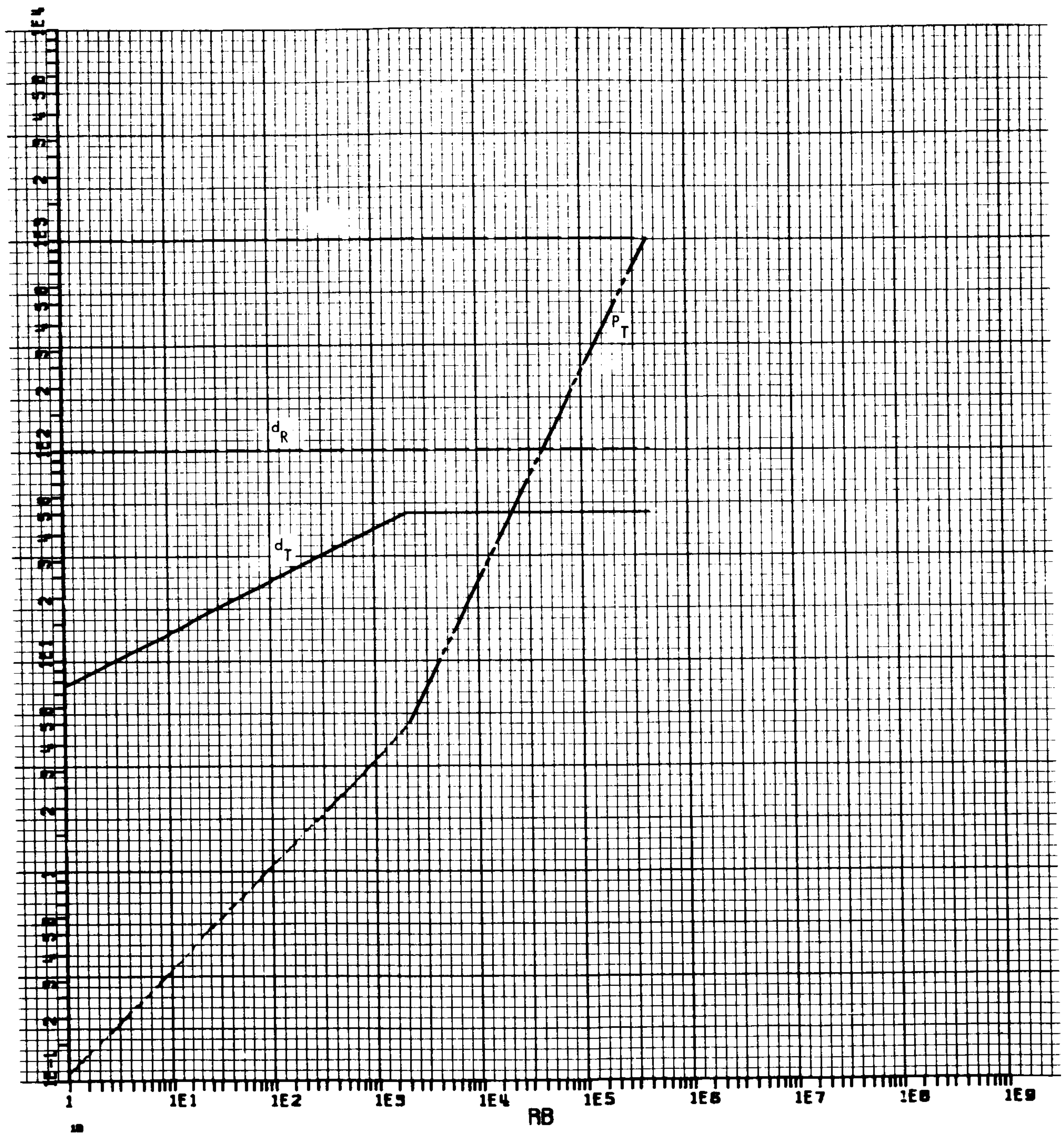
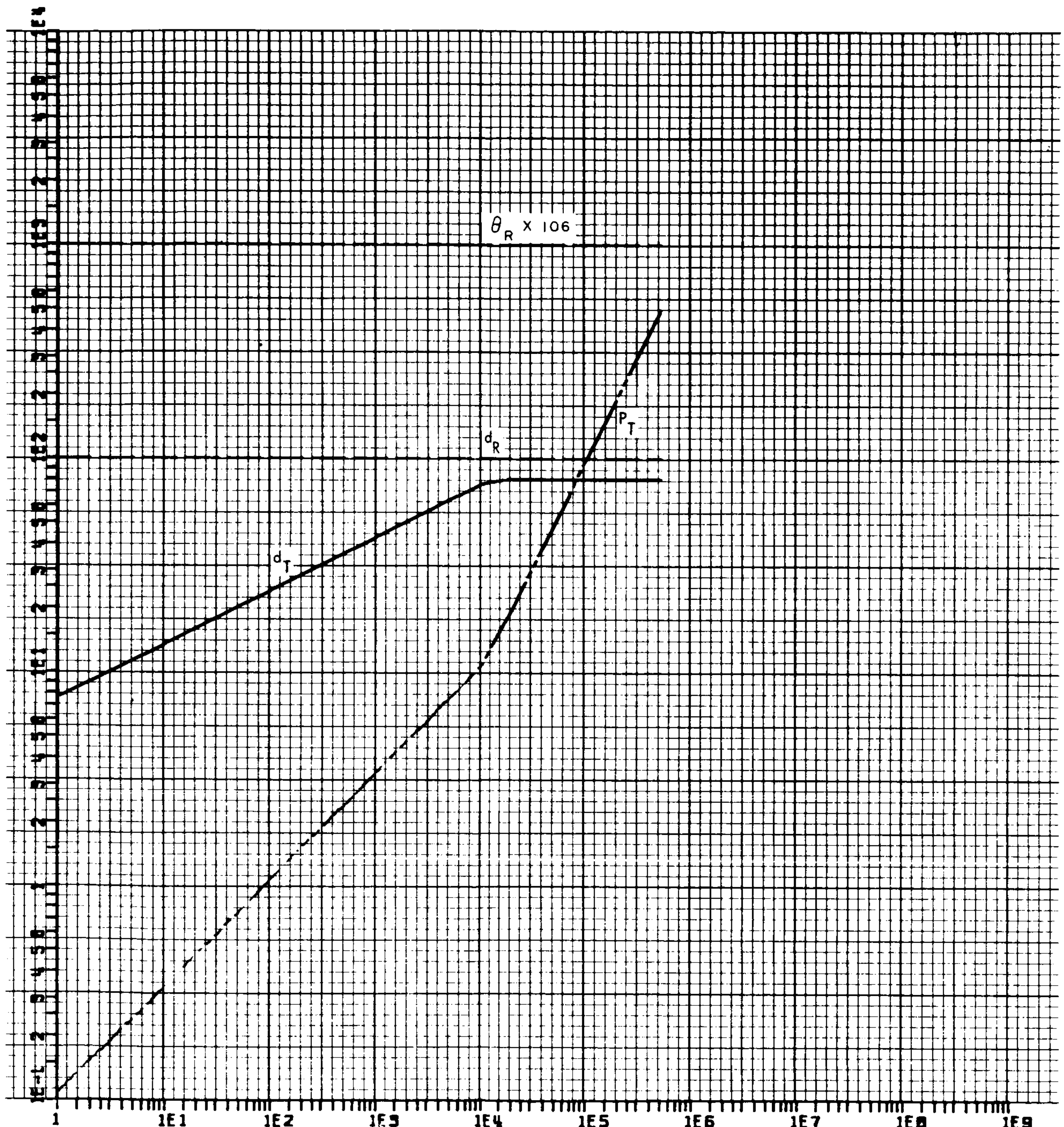


P_T
d_R
d_T
1
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
1E9
RB



θ_R X 106
d_R
P_T
d_T
1
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
1E9
RB

Example D: Mars Spacecraft Transmitter to Earth Receiver Link

13 cm wavelength

PCM phase shift keying

Thermal noise limited operation

Transmitter system weight and fabrication cost jointly optimized

Parameters to be optimized:

a. Transmitter antenna diameter

b. Transmitter power

Fixed Parameters:

a. Receiver antenna diameter at 64 meters

b. Receiver field of view of 1 milliradian

Parameter stops

a. Transmitter power at 1 kw

Data values:

a. Transmitter antenna efficiency = 60%

b. Revised transmitter burdens (1980 estimates)

NAME ______________ DATE __________ PROBLEM EXAMPLE D

COPTRAN INSTRUCTIONS AND DATA

INSTRUCTION TYPE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
1	1	S	P	X	M	T	R																			SPACECRAFT TRANSMITTER
2	2	E	A	R	C	V	R																			EARTH RECEIVER
3	3	R	A	N	M	A	R																			MARS RANGE
4	4	L	A	M	1	3	C																			13 CM TRANSMISSION WAVELENGTH
5	5	B	K	G	A	L	T																			GALACTIC BACKGROUND
6	6	P	C	M	/	P	M																			PCM PHASE SHIFT KEYING
6	7	R	A	D	H	O	M																			COHERENT RADIO HOMODYNE DETECTION
7	8	X	M	W	T	O	P																			XMTR SYSTEM WEIGHT AND XMTR SYSTEM
7	9	X	M	F	C	O	P																			FABRICATION COST JOINTLY OPTIMIZED
8	10	G	T	G	R	O	P																			TRANSMITTER & RECEIVER ANT GAIN OPTIMIZATION
9	11	N	X	P	W	S	A																			RTG XMTR POWER SUPPLY BURDENS
10	12	R	B	F	R	Q	0																			DATA POINTS AT $R_B = 10^0$, 0.2×10^1, 0.3×10^1,
10	13	R	B	I	N	T	0																			. . . , 10^7 BITS PER SECOND
10	14	R	B	F	I	N	7																			
11	15	P	R	T	D	A	T																			PRINT SYSTEM DATA AND CONSTANTS
12	16	P	L	T	O	P	T																			PLOT OPTIMUM SYSTEM PARAMETERS TOTAL COST, AND TRANSMITTER
12	17	P	L	T	C	S																				OPTIMUM WEIGHT
12	18	P	L	T	W	A																				END OF COPTRAN INSTRUCTIONS
13	19	E	N	D	I	N	S																			
	20																									
DATA	21	R	H	O	T										•	6	0									TRANSMITTER ANTENNA EFFICIENCY
DATA	22	K	P	T									9	6	•											
DATA	23	K	W	T											•	0	8									REVISED TRANSMITTER BURDENS
DATA	24	K	H												•	4	6									
DATA	25	K	X											5	•	6				E	—	0	3			

*See TABLE IV-I

NAME ____________ DATE ________ PROBLEM EXAMPLE D (continued)

COPTRAN INSTRUCTIONS AND DATA

INSTRUCTION TYPE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
DATA	1	K	E												•	2	5									REVISED TRANSMITTER BURDENS
DATA	2	C	X											8	•	7	5	0		E	+	0	3			
DATA	3	C	H											6	•	8	7	5		E	+	0	3			
DATA	4	W	K	P										2	•	5										
DATA	5	W	K	H											•	0										
DATA	6	G	T											1	•											
DATA	7	H	T											1	•											
DATA	8	J	T											1	•											
DATA	9	G	R	M										1	•	9				E	+	0	6			GAIN FOR 64 METER FIXED RECEIVER ANT. DIAM.
DATA	10	P	T	B										1	•					E	+	0	3			1 KW STOP ON XMTR POWER
DATA	11	T	H	E	R	M								1	•					E	–	0	3			1 MILLIRADIAN FIXED RECEIVER FIELD ON VIEW
INCREMENT SET	12	N	C	R	M	N	T						1	5	•											INCREMENT SN FROM 20 TO 50
	13	S	N										2	0	•											IN STEP SIZES OF 15
	14	F	I	N	A	L	E						5	0	•											
14	15	E	N	D	D	A	T																			END OF COPTRAN DATA
15	16	E	N	D	C	A	S																			END OF CASES
	17																									
	18																									
	19																									
	20																									
	21																									
	22																									
	23																									
	24																									
	25																									

*See TABLE IV-I

```
SPACECRAFT TRANSMITTER
EARTH RECEIVER
MARS RANGE (1.E8 KM)
TRANSMISSION WAVELENGTH LAMBDA = 13 CM
GALACTIC BACKGROUND
PCM PHASE MODULATION
RADIO HOMODYNE DETECTION
TRANSMITTER WEIGHT OPTIMIZATION
TRANSMITTER FABRICATION COST OPTIMIZATION
TRANSMITTER ANTENNA GAIN AND RECEIVER ANTENNA GAIN OPTIMIZATION


*** COPTRAN PROGRAM ***

SPXMTR
EARCVR
RANMAR
LAM13C
BKGALT
PCM/PM
RADHOM
XMWTOP
XMFCOP
GTGROP
NXPWSA
RBFRQ0
RBINT0
RBFIN7
PRTALL
PLTOPT
PLTCS
PLTWA
ENDINS
RHOT             0.600
KPT               96.0
KWT          0.800E-01
KH               0.460
KX           0.560E-02
KE               0.250
CX           0.875E 04
CH           0.688E 04
WKP               2.50
WKH          0.
GT                1.00
HT                1.00
JT                1.00
GRM          0.190E 07
PTB          0.100E 04
THERM        0.100E-02
NCRMNT            15.0
SN                20.0
FINALE            50.0
ENDDAT       0.
```

SYSTEM BURDENS DATA

TRANSMITTER ANTENNA	HTHT	520.00000	HDT	0.01350	CKT	5000.00	WKT	0.	MT	1.00	NT	1.00000
RECEIVER ANTENNA	HTHR	0.06600	HDR	0.	CKR	0.	WKR	0.	MR	1.35	NR	0.
TRANSMITTER ACQUISITION AND TRACK SYSTEM	KAT	71000.	KWAT	0.75000	KPQT	10.00000	CAT	140000.	WBT	10.000	QT	0.30000
RECEIVER ACQUISITION AND TRACK SYSTEM	KAR	0.	KWAR	0.	KPQR	0.	CAR	0.	WBR	0.	QR	0.
TRANSMITTER	KPT	96.00000	KWT	0.08000	KH	0.46000	KX	0.00560	KE	0.25000	CKP	17500.00
	CKH	23800.	WKP	2.500	WKH	0.	JT	1.000	GT	1.00000	HT	1.00000
MODULATION EQUIPMENT	KFM	0.	KM	0.	KPM	0.	CKM	0.	WKM	0.		
DEMODULATION EQUIPMENT	KFD	0.	KD	0.	KPD	0.	CKD	0.	WKD	0.		
TRANSMITTER POWER SUPPLY	KST	3000.000	KWST	0.700000	CKE	0.	WKE	0.				
RECEIVER POWER SUPPLY	KSR	25.000	KWSR	0.	CKF	10000.	WKF	0.				
BOOSTER BURDENS	KSA	1640.000	KSB	1640.000								

****

SYSTEM PHYSICAL DATA

R	0.10000E 14	LAMBDA	0.13000E 02	S/N	0.20000E 02	C/N	0.	USBREQ	0.	TAU-T	0.75000E 00
TAU-R	0.35000E 00	TAU-A	0.95000E 00	TE	0.27000E 02	ETA	0.	RL	0.	LMBD-I	0.
QB	0.	RHO-T	0.60000E 00	RHO-R	0.80000E 00						

****

****

SIGNAL-TO-NOISE RATIO CONSTANTS

K	0.	KN	0.	KM	0.	KR	0.89534E-07	KS	0.

****

****

SYSTEM BURDEN CONSTANTS

KMT	0.	KNT	0.	KOT	0.71000E 05	KMR	0.	KNR	0.	KOR	0.
KGT	0.96000E 02	KHT	0.13120E 03	KJT	0.16621E 05						

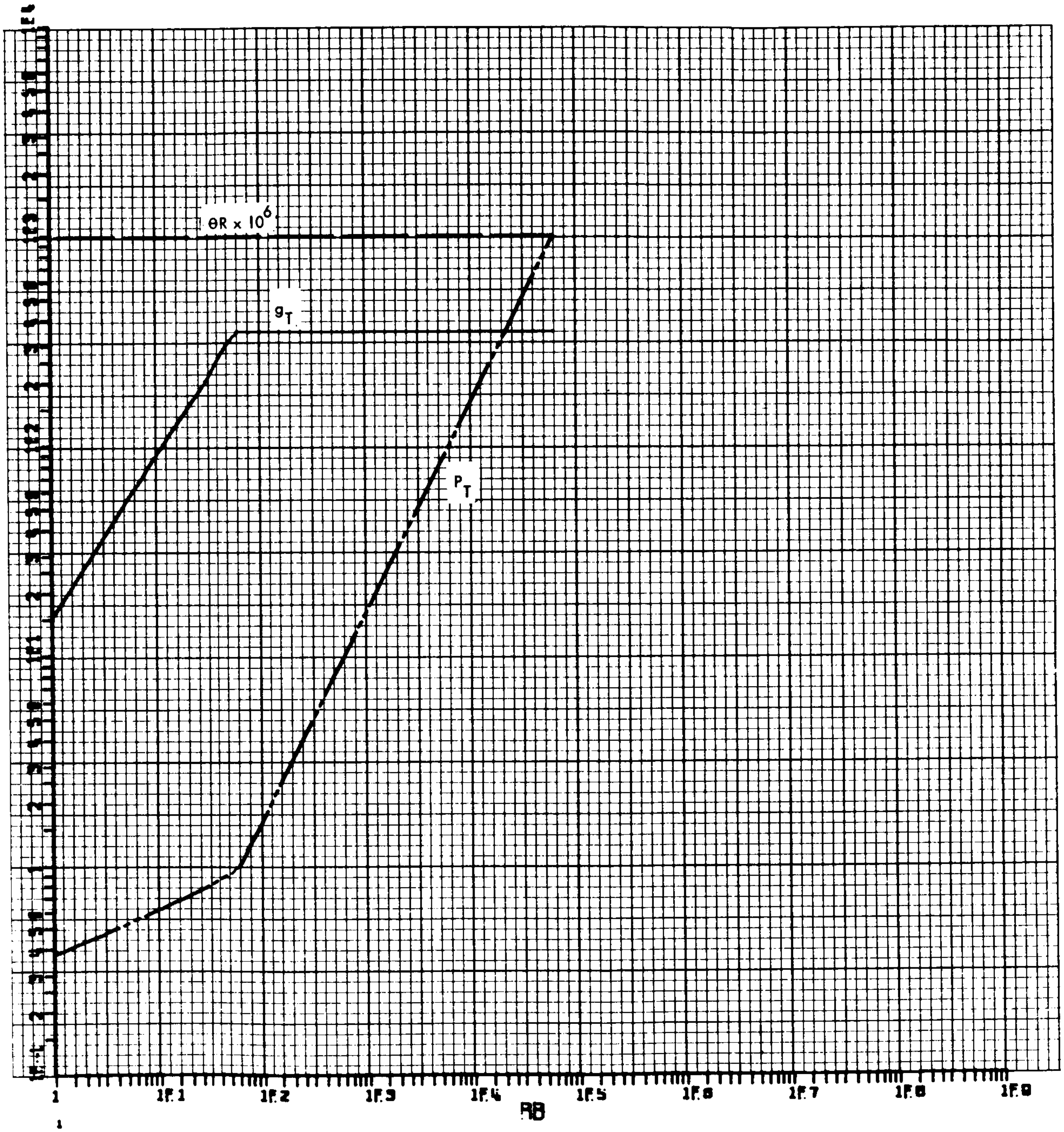
****

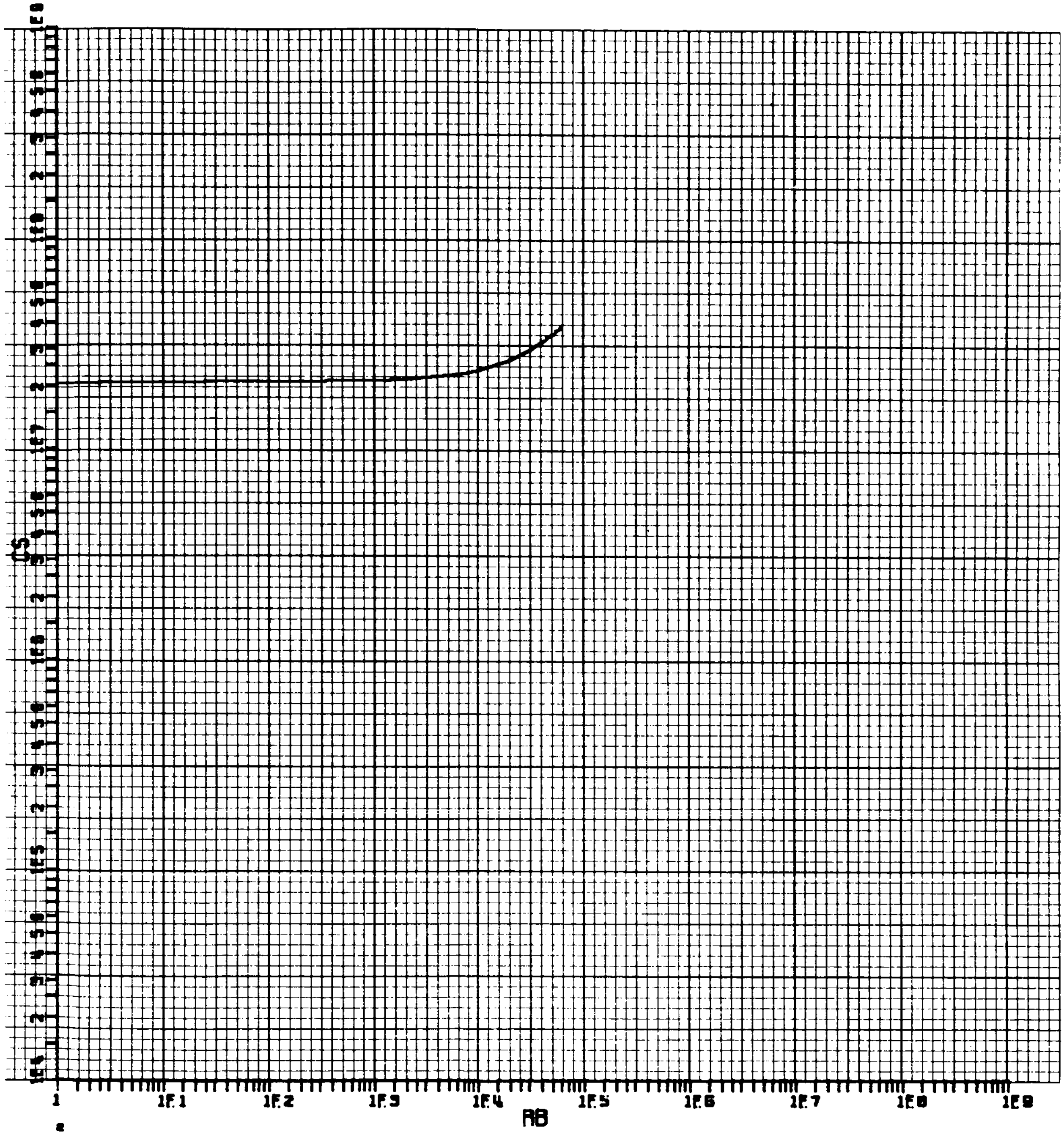
****

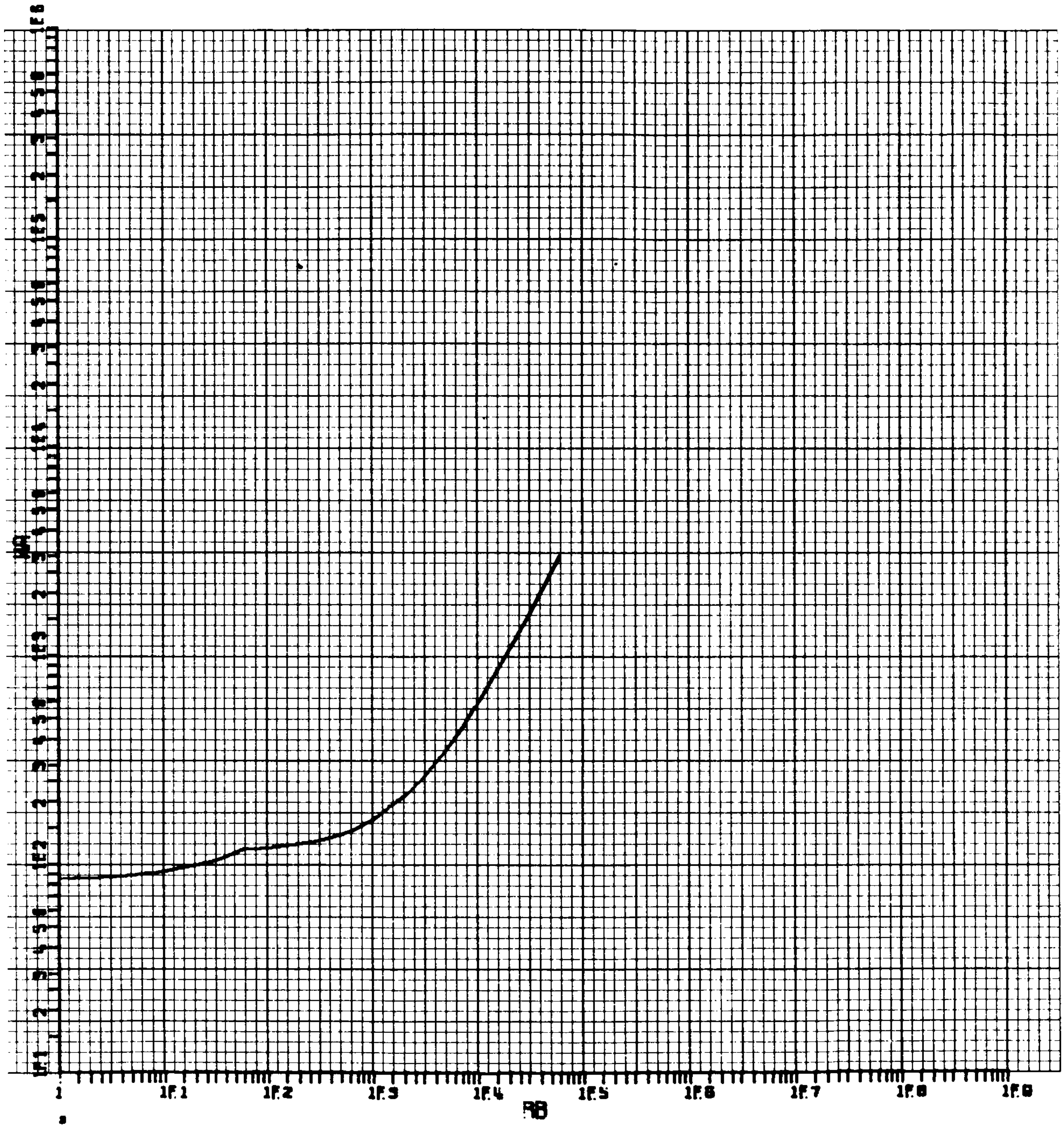
PARAMETER CONSTRAINTS

DTI	0.	GTI	0.17400E 03	DRI	0.	GRI	0.19000E 07	PTI	0.50000E 03	THERI	0.10000E-02
DTM	0.	GTM	0.	DRM	0.	GRM	0.19000E 07	PTM	0.	THERM	0.10000E-02
DTB	0.	GTB	0.34800E 03	DRB	0.	GRB	0.19000E 07	PTB	0.10000E 04	THERB	0.10000E-02

****


θR x 10^6
g_T
P_T
1
1E.1
1E.2
1E.3
1E.4
1E.5
1E.6
1E.7
1E.8
1E.9
RB


CS
RB
1
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
1E9



1
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
1E9
RB

```
SPACECRAFT TRANSMITTER
EARTH RECEIVER
MARS RANGE (1.E8 KM)
TRANSMISSION WAVELENGTH LAMBDA = 13 CM
GALACTIC BACKGROUND
PCM PHASE MODULATION
RADIO HOMODYNE DETECTION
TRANSMITTER WEIGHT OPTIMIZATION
TRANSMITTER FABRICATION COST OPTIMIZATION
TRANSMITTER ANTENNA GAIN AND RECEIVER ANTENNA GAIN OPTIMIZATION

*** COPTRAN PROGRAM ***

SPXMTR
EARCVR
RANMAR
LAM13C
BKGALT
PCM/PM
RADHOM
XMWTOP
XMFCOP
GTGROP
NXPWSA
RBFRQ0
RBINT0
RBFIN7
PRTALL
PLTOPT
PLTCS
PLTWA
ENDINS
RHOT            0.600
KPT              96.0
KWT         0.800E-01
KH              0.460
KX          0.560E-02
KE              0.250
CX          0.875E 04
CH          0.688E 04
WKP              2.50
WKH         0.
GT               1.00
HT               1.00
JT               1.00
GRM         0.190E 07
PTB         0.100E 04
THERM       0.100E-02
NCRMNT           15.0
SN               20.0
FINALE           50.0
ENDDAT      0.
```

SYSTEM BURDENS DATA

TRANSMITTER ANTENNA	HTHT	520.00000	HDT	0.01350	CKT	5000.00	WKT	0.	MT	1.00	NT	1.00000
RECEIVER ANTENNA	HTHR	0.06600	HDR	0.	CKR	0.	WKR	0.	MR	1.35	NR	0.
TRANSMITTER ACQUISITION AND TRACK SYSTEM	KAT	71000.	KWAT	0.75000	KPQT	10.00000	CAT	140000.	WBT	10.000	QT	0.30000
RECEIVER ACQUISITION AND TRACK SYSTEM	KAR	0.	KWAR	0.	KPQR	0.	CAR	0.	WBR	0.	QR	0.
TRANSMITTER	KPT	96.00000	KWT	0.08000	KH	0.46000	KX	0.00560	KE	0.25000	CKP	17500.00
	CKH	23800.	WKP	2.500	WKH	0.	JT	1.000	GT	1.00000	HT	1.00000
MODULATION EQUIPMENT	KFM	0.	KM	0.	KPM	0.	CKM	0.	WKM	0.		
DEMODULATION EQUIPMENT	KFD	0.	KD	0.	KPD	0.	CKD	0.	WKD	0.		
TRANSMITTER POWER SUPPLY	KST	3000.000	KWST	0.700000	CKE	0.	WKE	0.				
RECEIVER POWER SUPPLY	KSR	25.000	KWSR	0.	CKF	10000.	WKF	0.				
BOOSTER BURDENS	KSA	1640.000	KSB	1640.000								

****

SYSTEM PHYSICAL DATA

R	0.10000E 14	LAMBDA	0.13000E 02	S/N	0.35000E 02	C/N	0.	USBREQ	0.	TAU-T	0.75000E 00
TAU-R	0.35000E 00	TAU-A	0.95000E 00	TE	0.27000E 02	ETA	0.	RL	0.	LMBD-I	0.
QB	0.	RHO-T	0.60000E 00	RHO-R	0.80000E 00						

SIGNAL-TO-NOISE RATIO CONSTANTS

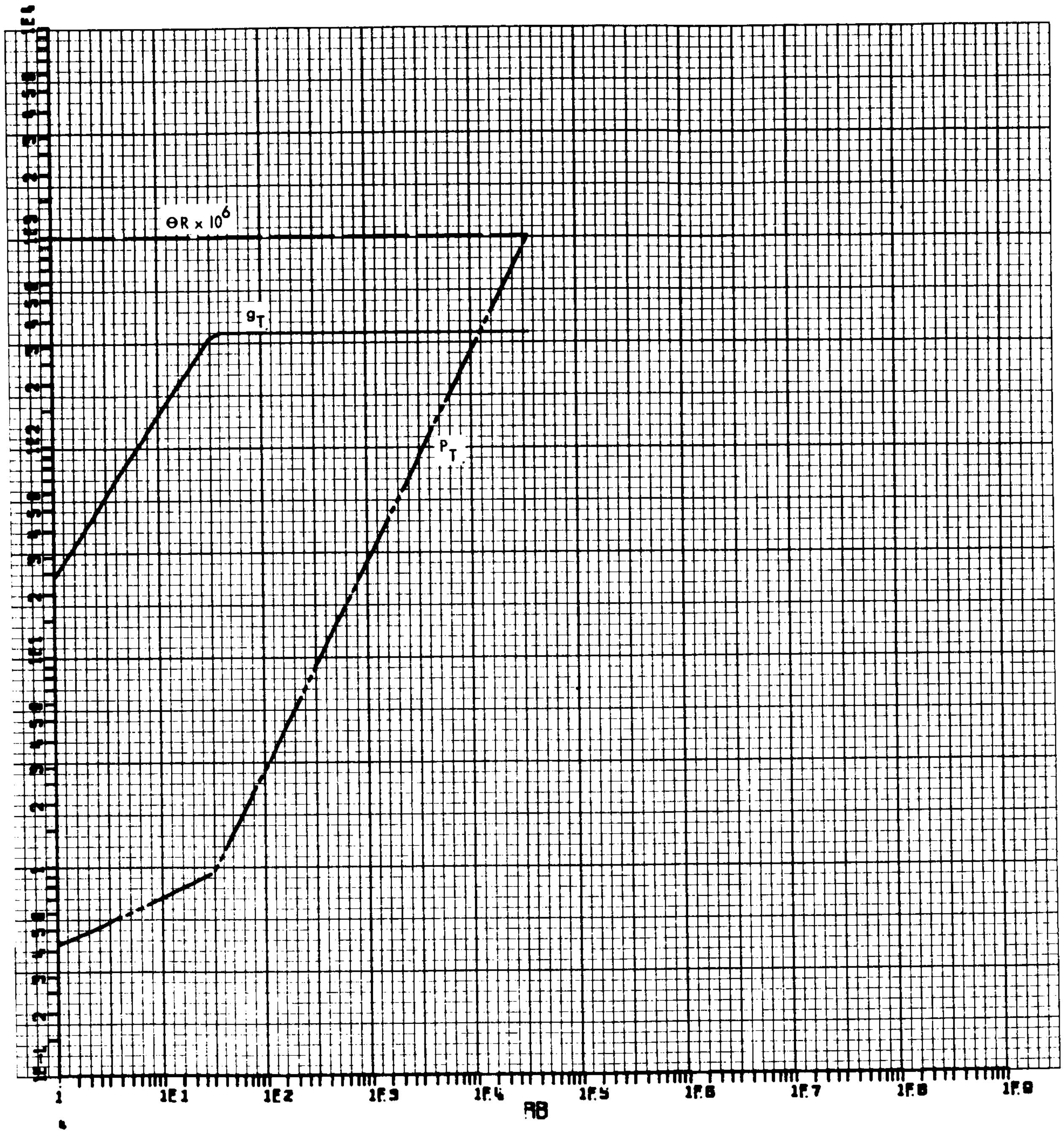
K	0.	KN	0.	KM	0.	KR	0.51162E-07	KS	0.

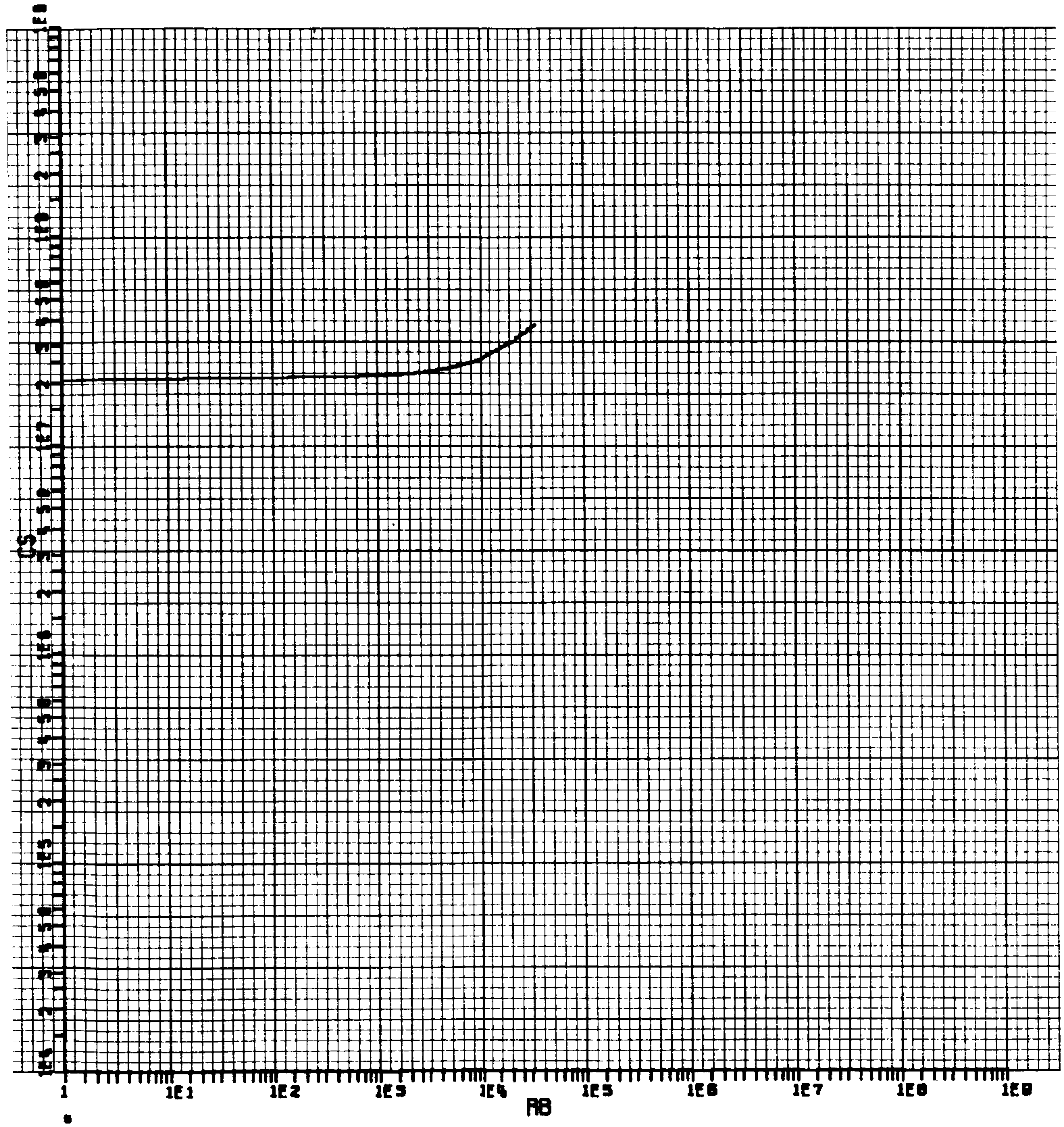
SYSTEM BURDEN CONSTANTS

KMT	0.	KNT	0.	KOT	0.71000E 05	KMR	0.	KNR	0.	KOR	0.
KGT	0.96000E 02	KHT	0.13120E 03	KJT	0.16621E 05						

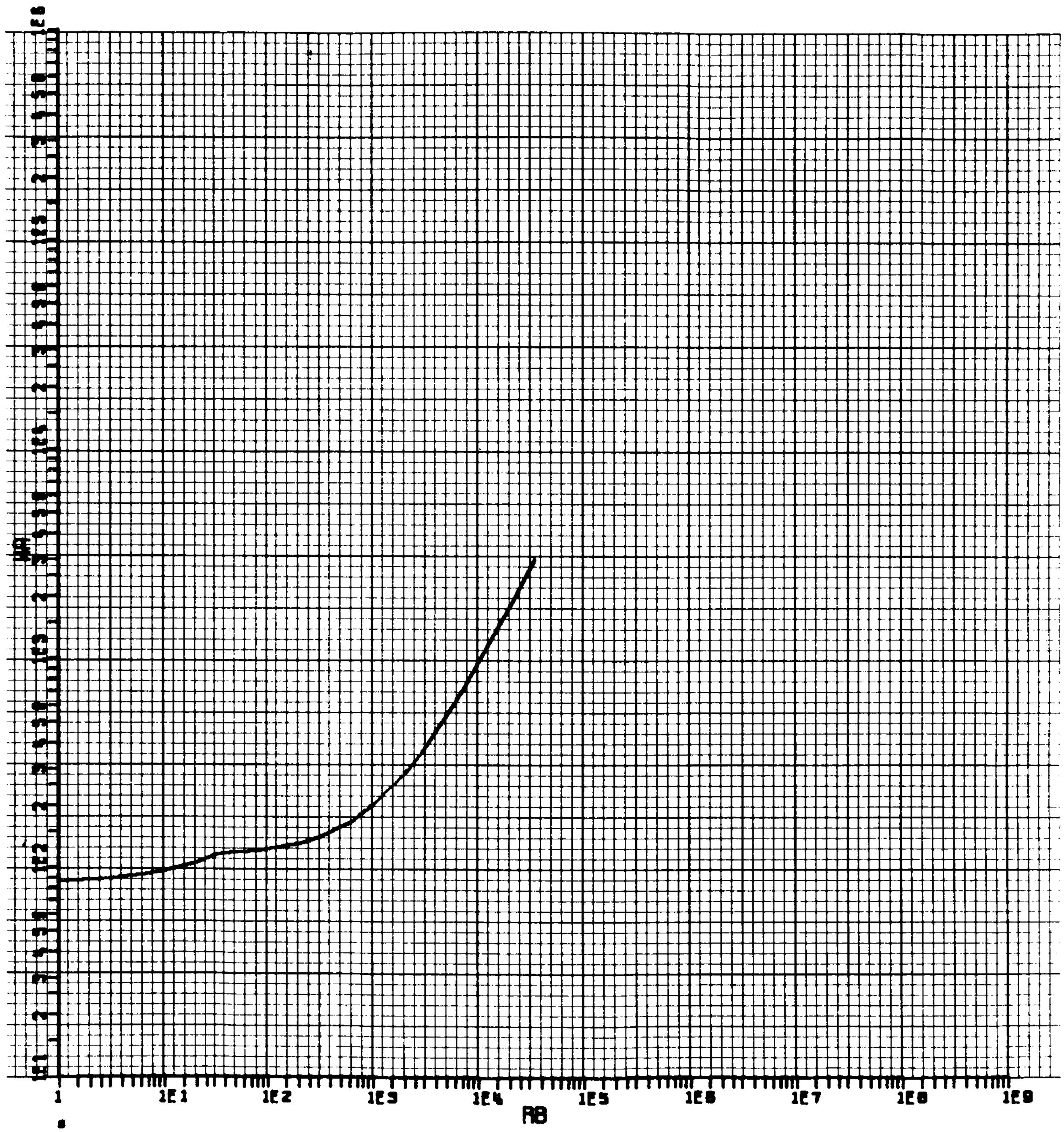
PARAMETER CONSTRAINTS

DTI	0.	GTI	0.17400E 03	DRI	0.	GRI	0.19000E 07	PTI	0.50000E 03	THERI	0.10000E-02
DTM	0.	GTM	0.	DRM	0.	GRM	0.19000E 07	PTM	0.	THERM	0.10000E-02
DTB	0.	GTB	0.34800E 03	DRB	0.	GRB	0.19000E 07	PTB	0.10000E 04	THERB	0.10000E-02


ΘR x 10^6
g_T
P_T
1
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
1E9
RB



CS
RB
1
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
1E9



1
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
1E9
RB

```
SPACECRAFT TRANSMITTER
EARTH RECEIVER
MARS RANGE (1.E8 KM)
TRANSMISSION WAVELENGTH LAMBDA = 13 CM
GALACTIC BACKGROUND
PCM PHASE MODULATION
RADIO HOMODYNE DETECTION
TRANSMITTER WEIGHT OPTIMIZATION
TRANSMITTER FABRICATION COST OPTIMIZATION
TRANSMITTER ANTENNA GAIN AND RECEIVER ANTENNA GAIN OPTIMIZATION


*** COPTRAN PROGRAM ***

SPXMTR
EARCVR
RANMAR
LAM13C
BKGALT
PCM/PM
RADHOM
XMWTOP
XMFCOP
GTGROP
NXPWSA
RBFRQ0
RBINT0
RBFIN7
PRTALL
PLTOPT
PLTCS
PLTWA
ENDINS
RHOT            0.600
KPT              96.0
KWT         0.800E-01
KH              0.460
KX          0.560E-02
KE              0.250
CX          0.875E 04
CH          0.688E 04
WKP              2.50
WKH         0.
GT               1.00
HT               1.00
JT               1.00
GRM         0.190E 07
PTB         0.100E 04
THERM       0.100E-02
NCRMNT           15.0
SN               20.0
FINALE           50.0
ENDDAT      0.
```

SYSTEM BURDENS DATA

TRANSMITTER ANTENNA	HTHT	520.00000	HDT	0.01350	CKT	5000.00	WKT	0.	MT	1.00	NT	1.00000
RECEIVER ANTENNA	HTHR	0.06600	HDR	0.	CKR	0.	WKR	0.	MR	1.35	NR	0.
TRANSMITTER ACQUISITION AND TRACK SYSTEM	KAT	71000.	KWAT	0.75000	KPOT	10.00000	CAT	140000.	WBT	10.000	QT	0.30000
RECEIVER ACQUISITION AND TRACK SYSTEM	KAR	0.	KWAR	0.	KPOR	0.	CAR	0.	WBR	0.	QR	0.
TRANSMITTER	KPT	96.00000	KWT	0.08000	KH	0.46000	KX	0.00560	KE	0.25000	CKP	17500.00
	CKH	23800.	WKP	2.500	WKH	0.	JT	1.000	GT	1.00000	HT	1.00000
MODULATION EQUIPMENT	KFM	0.	KM	0.	KPM	0.	CKM	0.	WKM	0.		
DEMODULATION EQUIPMENT	KFD	0.	KD	0.	KPD	0.	CKD	0.	WKD	0.		
TRANSMITTER POWER SUPPLY	KST	3000.000	KWST	0.700000	CKE	0.	WKE	0.				
RECEIVER POWER SUPPLY	KSR	25.000	KWSR	0.	CKF	10000.	WKF	0.				
BOOSTER BURDENS	KSA	1640.000	KSB	1640.000								

••

SYSTEM PHYSICAL DATA

R	0.10000E 14	LAMBDA	0.13000E 02	S/N	0.50000E 02	C/N	0.	USBREQ	0.	TAU-T	0.75000E 00
TAU-R	0.35000E 00	TAU-A	0.95000E 00	TE	0.27000E 02	ETA	0.	RL	0.	LMBD-I	0.
QB	0.	RHO-T	0.60000E 00	RHO-R	0.80000E 00						

****

****

SIGNAL-TO-NOISE RATIO CONSTANTS

K	0.	KN	0.	KM	0.	KR	0.35814E-07	KS	0.

****

****

SYSTEM BURDEN CONSTANTS

KMT	0.	KNT	0.	KQT	0.71000E 05	KMR	0.	KNR	0.	KQR	0.
KGT	0.96000E 02	KHT	0.13120E 03	KJT	0.16621E 05						

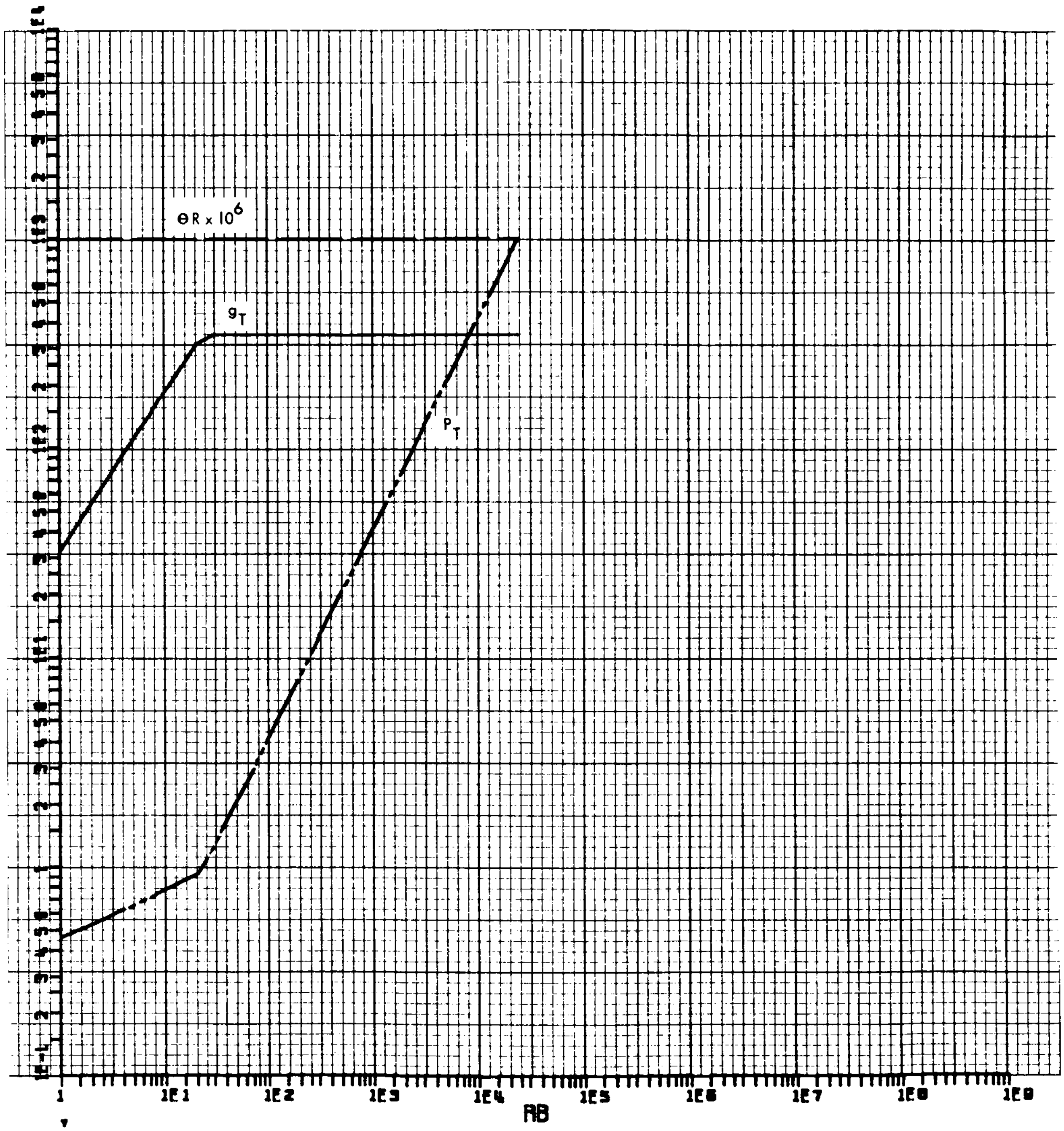
****

****

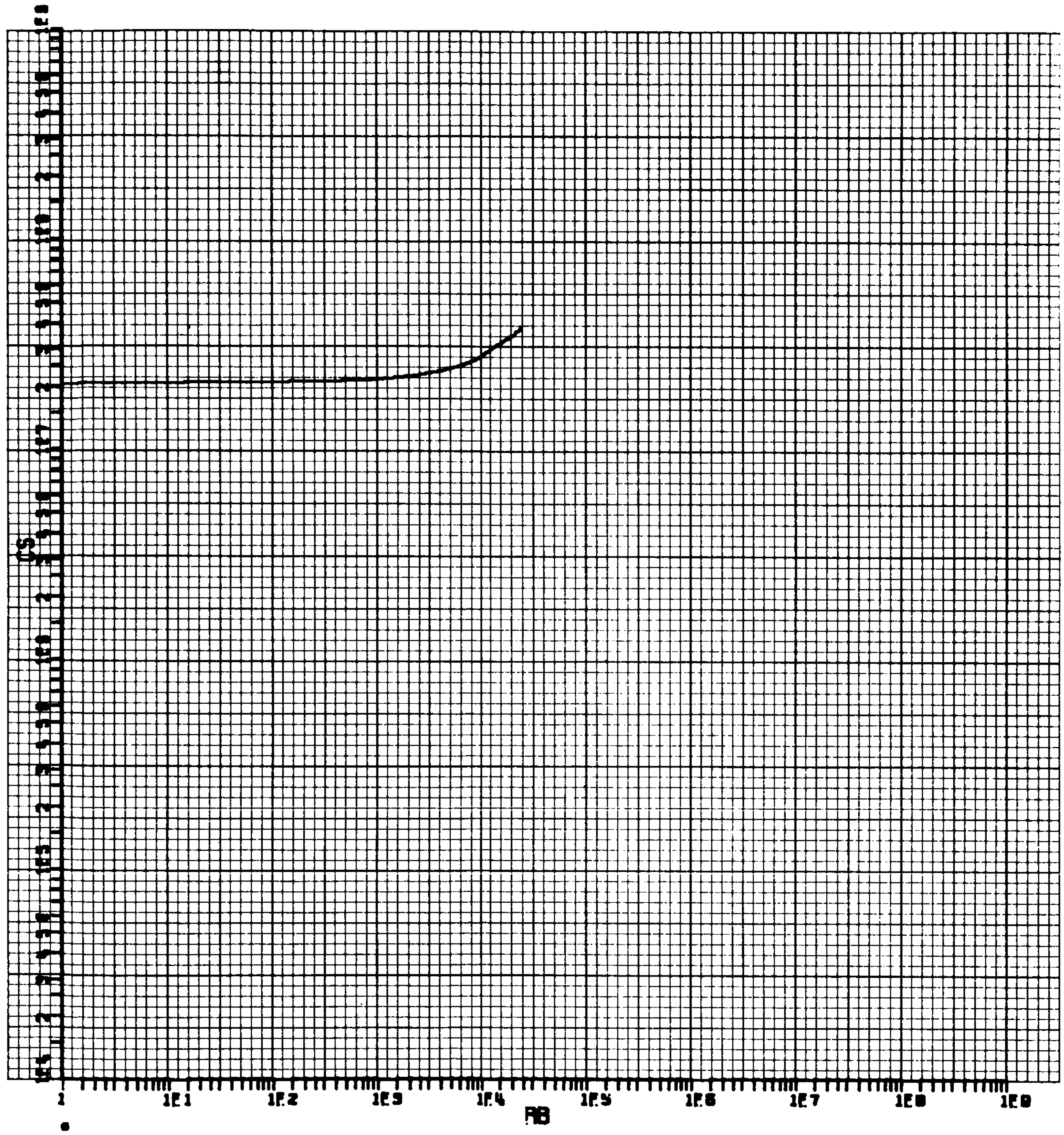
PARAMETER CONSTRAINTS

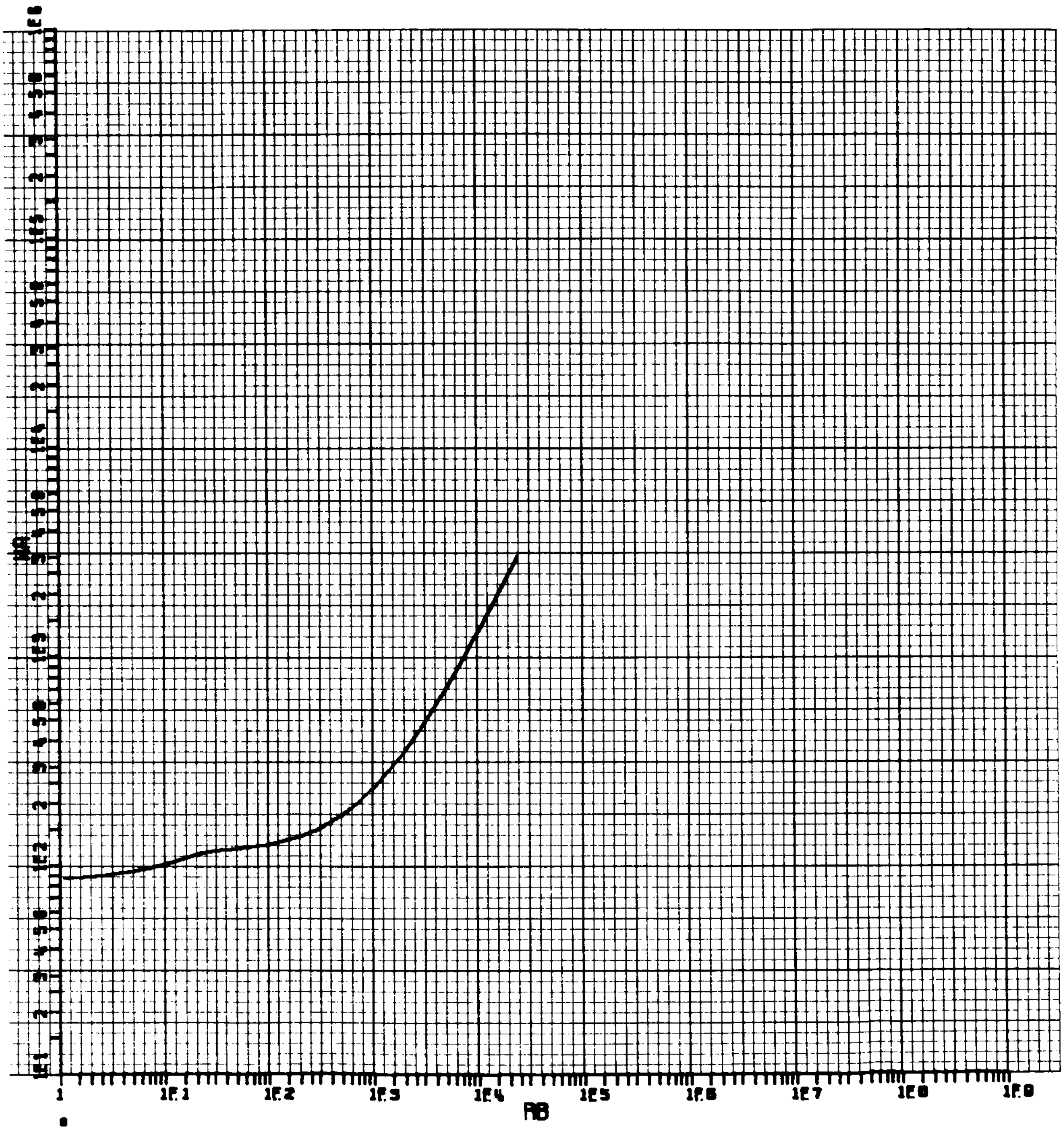
DTI	0.	GTI	0.17400E 03	DRI	0.	GRI	0.19000E 07	PTI	0.50000E 03	THERI	0.10000E-02
DTM	0.	GTM	0.	DRM	0.	GRM	0.19000E 07	PTM	0.	THERM	0.10000E-02
DTB	0.	GTB	0.34800E 03	DRB	0.	GRB	0.19000E 07	PTB	0.10000E 04	THERB	0.10000E-02

****



ΘR x 10^6
g_T
P_T
1
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
1E9
RB


CS
1
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
1E9
RB


1
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
1E9
RB

4.5 Library of Nominal System Burdens Data for COPTRAN

The following pages contain listings of the nominal System Burdens Data used in the COPTRAN program. (See Table IV-I, instruction No. 9.) Each of those detailed listings is summarized by a single COPTRAN instruction mnemonic.

NXANTA — XMTR ANT BURDENS, 0.51, SPACECRAFT

KTHT	14.		CONSTANT RELATING XMTR ANT FAB COST TO XMTR ANT DIAMETER
KDT	1.	E-02	CONSTANT RELATING XMTR ANT WEIGHT TO XMTR ANT DIAMETER
CKT	20.	E+03	XMTR ANT FAB COST INDEPENDENT OF XMTR ANT DIAMETER
WKT	25.		XMTR ANT WEIGHT INDEPENDENT OF XMTR ANT DIAMETER
MT	2.		EXPONENT RELATING XMTR ANT FAB COST TO XMTR ANT DIAMETER
NT	2.		EXPONENT RELATING XMTR ANT WEIGHT TO XMTR ANT DIAMETER

NXANTC — XMTR ANT BURDENS, 0.84, SPACECRAFT

KTHT	14.		CONSTANT RELATING XMTR ANT FAB COST TO XMTR ANT DIAMETER
KDT	1.	E-02	CONSTANT RELATING XMTR ANT WEIGHT TO XMTR ANT DIAMETER
CKT	20.	E+03	XMTR ANT FAB COST INDEPENDENT OF XMTR ANT DIAMETER
WKT	25.		XMTR ANT WEIGHT INDEPENDENT OF XMTR ANT DIAMETER
MT	2.		EXPONENT RELATING XMTR ANT FAB COST TO XMTR ANT DIAMETER
NT	2.		EXPONENT RELATING XMTR ANT WEIGHT TO XMTR ANT DIAMETER

NXANTD — XMTR ANT BURDENS, 10.6, SPACECRAFT

KTHT	14.		CONSTANT RELATING XMTR ANT FAB COST TO XMTR ANT DIAMETER
KDT	1.	E-02	CONSTANT RELATING XMTR ANT WEIGHT TO XMTR ANT DIAMETER
CKT	20.	E+03	XMTR ANT FAB COST INDEPENDENT OF XMTR ANT DIAMETER
WKT	25.		XMTR ANT WEIGHT INDEPENDENT OF XMTR ANT DIAMETER
MT	2.		EXPONENT RELATING XMTR ANT FAB COST TO XMTR ANT DIAMETER
NT	2.		EXPONENT RELATING XMTR ANT WEIGHT TO XMTR ANT DIAMETER

NXANTF — XMTR ANT BURDENS,13CM,DIAMETER BURDENS,SPACECRAFT

KTHT	16.7		CONSTANT RELATING XMTR ANT FAB COST TO XMTR ANT DIAMETER
KDT	4.32	E-04	CONSTANT RELATING XMTR ANT WEIGHT TO XMTR ANT DIAMETER
CKT	5.	E+03	XMTR ANT FAB COST INDEPENDENT OF XMTR ANT DIAMETER
WKT	0.		XMTR ANT WEIGHT INDEPENDENT OF XMTR ANT DIAMETER
MT	2.		EXPONENT RELATING XMTR ANT FAB COST TO XMTR ANT DIAMETER
NT	2.		EXPONENT RELATING XMTR ANT WEIGHT TO XMTR ANT DIAMETER

NXANTG — XMTR ANT BURDENS,13CM,GAIN BURDENS,SPACECRAFT

KTHT	5.2	E+02	CONSTANT RELATING XMTR ANT FAB COST TO XMTR ANT DIAMETER
KDT	1.35	E-02	CONSTANT RELATING XMTR ANT WEIGHT TO XMTR ANT DIAMETER
CKT	5.	E+03	XMTR ANT FAB COST INDEPENDENT OF XMTR ANT DIAMETER
WKT	0.		XMTR ANT WEIGHT INDEPENDENT OF XMTR ANT DIAMETER
MT	1.		EXPONENT RELATING XMTR ANT FAB COST TO XMTR ANT DIAMETER
NT	1.		EXPONENT RELATING XMTR ANT WEIGHT TO XMTR ANT DIAMETER

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NRANTA                          RCVR ANT BURDENS, 0.51, OPT DIRECT DETECTION, EARTH

KTHR         8.75               CONSTANT RELATING RCVR ANT FAB COST TO RCVR ANT DIAMETER
KDR           .023              CONSTANT RELATING RCVR ANT WEIGHT TO RCVR ANT DIAMETER
CKR         25.        E+03     RCVR ANT FAB COST INDEPENDENT OF RCVR ANT DIAMETER
WKR         20.                 RCVR ANT WEIGHT INDEPENDENT OF RCVR ANT DIAMETER
MR           2.                 EXPONENT RELATING RCVR ANT FAB COST TO RCVR ANT DIAMETER
NR           2.                 EXPONENT RELATING RCVR ANT WEIGHT TO RCVR ANT DIAMETER

NRANTB                          RCVR ANT BURDENS, 0.51, OPT HET OR HOM DETECTION, EARTH

KTHR         8.75               CONSTANT RELATING RCVR ANT FAB COST TO RCVR ANT DIAMETER
KDR           .023              CONSTANT RELATING RCVR ANT WEIGHT TO RCVR ANT DIAMETER
CKR         25.        E+03     RCVR ANT FAB COST INDEPENDENT OF RCVR ANT DIAMETER
WKR         20.                 RCVR ANT WEIGHT INDEPENDENT OF RCVR ANT DIAMETER
MR           2.                 EXPONENT RELATING RCVR ANT FAB COST TO RCVR ANT DIAMETER
NR           2.                 EXPONENT RELATING RCVR ANT WEIGHT TO RCVR ANT DIAMETER

NRANTC                          RCVR ANT BURDENS, 0.84, OPT DIRECT DETECTION, EARTH

KTHR         8.75               CONSTANT RELATING RCVR ANT FAB COST TO RCVR ANT DIAMETER
KDR           .023              CONSTANT RELATING RCVR ANT WEIGHT TO RCVR ANT DIAMETER
CKR         25.        E+03     RCVR ANT FAB COST INDEPENDENT OF RCVR ANT DIAMETER
WKR         20.                 RCVR ANT WEIGHT INDEPENDENT OF RCVR ANT DIAMETER
MR           2.                 EXPONENT RELATING RCVR ANT FAB COST TO RCVR ANT DIAMETER
NR           2.                 EXPONENT RELATING RCVR ANT WEIGHT TO RCVR ANT DIAMETER

NRANTD                          RCVR ANT BURDENS, 10.6, OPT DIRECT DETECTION, EARTH

KTHR         8.75               CONSTANT RELATING RCVR ANT FAB COST TO RCVR ANT DIAMETER
KDR           .023              CONSTANT RELATING RCVR ANT WEIGHT TO RCVR ANT DIAMETER
CKR         25.        E+03     RCVR ANT FAB COST INDEPENDENT OF RCVR ANT DIAMETER
WKR         20.                 RCVR ANT WEIGHT INDEPENDENT OF RCVR ANT DIAMETER
MR           2.                 EXPONENT RELATING RCVR ANT FAB COST TO RCVR ANT DIAMETER
NR           2.                 EXPONENT RELATING RCVR ANT WEIGHT TO RCVR ANT DIAMETER

NRANTE                          RCVR ANT BURDENS, 10.6, OPT HET OR HOM DETECTION, EARTH

KTHR         8.75               CONSTANT RELATING RCVR ANT FAB COST TO RCVR ANT DIAMETER
KDR           .023              CONSTANT RELATING RCVR ANT WEIGHT TO RCVR ANT DIAMETER
CKR         25.        E+03     RCVR ANT FAB COST INDEPENDENT OF RCVR ANT DIAMETER
WKR         20.                 RCVR ANT WEIGHT INDEPENDENT OF RCVR ANT DIAMETER
MR           2.                 EXPONENT RELATING RCVR ANT FAB COST TO RCVR ANT DIAMETER
NR           2.                 EXPONENT RELATING RCVR ANT WEIGHT TO RCVR ANT DIAMETER
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NRANTF			RCVR ANT BURDENS,13CM,DIAMETER BURDENS,EARTH
KTHR	6.4	E-04	CONSTANT RELATING RCVR ANT FAB COST TO RCVR ANT DIAMETER
KDR	.0		CONSTANT RELATING RCVR ANT WEIGHT TO RCVR ANT DIAMETER
CKR	0.		RCVR ANT FAB COST INDEPENDENT OF RCVR ANT DIAMETER
WKR	.0		RCVR ANT WEIGHT INDEPENDENT OF RCVR ANT DIAMETER
MR	2.7		EXPONENT RELATING RCVR ANT FAB COST TO RCVR ANT DIAMETER
NR	.0.		EXPONENT RELATING RCVR ANT WEIGHT TO RCVR ANT DIAMETER

NRANTG			RCVR ANT BURDENS,13CM,GAIN BURDENS,EARTH
KTHR	6.6	E-02	CONSTANT RELATING RCVR ANT FAB COST TO RCVR ANT DIAMETER
KDR			CONSTANT RELATING RCVR ANT WEIGHT TO RCVR ANT DIAMETER
CKR			RCVR ANT FAB COST INDEPENDENT OF RCVR ANT DIAMETER
WKR			RCVR ANT WEIGHT INDEPENDENT OF RCVR ANT DIAMETER
MR	1.35		EXPONENT RELATING RCVR ANT FAB COST TO RCVR ANT DIAMETER
NR			EXPONENT RELATING RCVR ANT WEIGHT TO RCVR ANT DIAMETER

NXACTA			XMTR ACQ AND TRACK BURDENS,OPTICAL FREQUENCY,SPACECRAFT
KAT	.71	E+05	CONSTANT RELATING XMTR TRACK EQUIP FAB COST TO XMTR BEAM
KWAT	.46		CONSTANT RELATING XMTR TRACK EQUIP WEIGHT TO XMTR ANT WT
KPQT	.48		CONSTANT RELATING XMTR ACQ-TRACK EQUIP PWR REQ TO WEIGHT
CAT	.4	E+06	XMTR ACQ-TRACK EQUIP FAB COST INDEPENDENT OF XMTR BEAM
WBT	5.		XMTR ACQ-TRACK EQUIP WEIGHT INDEPENDENT OF XMTR BEAM
QT	.3		EXPONENT RELATING XMTR TRACK EQUIP FAB COST TO XMTR BEAM
NXACTB			XMTR ACQ AND TRACK BURDENS,RADIO FREQUENCY,SPACE,DIAM
KAT	.71	E+05	CONSTANT RELATING XMTR TRACK EQUIP FAB COST TO XMTR BEAM
KWAT	.75		CONSTANT RELATING XMTR TRACK EQUIP WEIGHT TO XMTR ANT WT
KPQT	10.		CONSTANT RELATING XMTR ACQ-TRACK EQUIP PWR REQ TO WEIGHT
CAT	.14	E+06	XMTR ACQ-TRACK EQUIP FAB COST INDEPENDENT OF XMTR BEAM
WBT	10.		XMTR ACQ-TRACK EQUIP WEIGHT INDEPENDENT OF XMTR BEAM
QT	.3		EXPONENT RELATING XMTR TRACK EQUIP FAB COST TO XMTR BEAM
NXACTC			XMTR ACQ AND TRACK BURDENS,RADIO FREQUENCY,SPACE,GAIN
KAT	.71	E+05	CONSTANT RELATING XMTR TRACK EQUIP FAB COST TO XMTR BEAM
KWAT	.75		CONSTANT RELATING XMTR TRACK EQUIP WEIGHT TO XMTR ANT WT
KPQT	10.		CONSTANT RELATING XMTR ACQ-TRACK EQUIP PWR REQ TO WEIGHT
CAT	.14	E+06	XMTR ACQ-TRACK EQUIP FAB COST INDEPENDENT OF XMTR BEAM
WBT	10.		XMTR ACQ-TRACK EQUIP WEIGHT INDEPENDENT OF XMTR BEAM
QT	.3		EXPONENT RELATING XMTR TRACK EQUIP FAB COST TO XMTR BEAM

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NRACTA                      RCVR ACQ AND TRACK BURDENS,OPTICAL FREQUENCY,EARTH

KAR       .71   E+05        CONSTANT RELATING RCVR TRACK EQUIP FAB COST TO RCVR BEAM
KWAR      .46               CONSTANT RELATING RCVR TRACK EQUIP WEIGHT TO RCVR ANT WT
KPQR      .48               CONSTANT RELATING XMTR ACQ-TRACK EQUIP PWR REQ TO WEIGHT
CAR       .2    E+06        RCVR ACQ-TRACK EQUIP FAB COST INDEPENDENT OF RCVR BEAM
WBR      5.0                RCVR ACQ-TRACK EQUIP WEIGHT INDEPENDENT OF RCVR BEAM
QR        .3                EXPONENT RELATING RCVR TRACK EQUIP FAB COST TO RCVR BEAM

NRACTB                      RCVR ACQ AND TRACK BURDENS,RADIO FREQUENCY,EARTH,DIAM

KAR       .0                CONSTANT RELATING RCVR TRACK EQUIP FAB COST TO RCVR BEAM
KWAR      .0                CONSTANT RELATING RCVR TRACK EQUIP WEIGHT TO RCVR ANT WT
KPQR      .0                CONSTANT RELATING XMTR ACQ-TRACK EQUIP PWR REQ TO WEIGHT
CAR       .0                RCVR ACQ-TRACK EQUIP FAB COST INDEPENDENT OF RCVR BEAM
WBR       .0                RCVR ACQ-TRACK EQUIP WEIGHT INDEPENDENT OF RCVR BEAM
QR        .0                EXPONENT RELATING RCVR TRACK EQUIP FAB COST TO RCVR BEAM

NRACTC                      RCVR ACQ AND TRACK BURDENS,RADIO FREQUENCY,EARTH,GAIN

KAR       .0                CONSTANT RELATING RCVR TRACK EQUIP FAB COST TO RCVR BEAM
KWAR      .0                CONSTANT RELATING RCVR TRACK EQUIP WEIGHT TO RCVR ANT WT
KPQR      .0                CONSTANT RELATING XMTR ACQ-TRACK EQUIP PWR REQ TO WEIGHT
CAR       .0                RCVR ACQ-TRACK EQUIP FAB COST INDEPENDENT OF RCVR BEAM
WBR       .0                RCVR ACQ-TRACK EQUIP WEIGHT INDEPENDENT OF RCVR BEAM
QR        .0                EXPONENT RELATING RCVR TRACK EQUIP FAB COST TO RCVR BEAM
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NMODEA MODULATION EQUIP BURDENS, 0.51, CW LASER, SPACECRAFT

KFM	7.5	E-05	CONSTANT RELATING MOD EQUIP FAB COST TO INFORMATION RATE
KM	5.	E-08	CONSTANT RELATING MOD EQUIP WEIGHT TO INFORMATION RATE
KPM	5.		CONSTANT RELATING MOD EQUIP PWR REQ TO EQUIP WEIGHT
CKM	7.5	E+03	MOD EQUIP FAB COST INDEPENDENT OF INFORMATION RATE
WKM	5.		MOD EQUIP WEIGHT INDEPENDENT OF INFORMATION RATE

NMODEB MODULATION EQUIP BURDENS, 0.84, CW LASER, SPACECRAFT

KFM	7.5	E-05	CONSTANT RELATING MOD EQUIP FAB COST TO INFORMATION RATE
KM	5.	E-08	CONSTANT RELATING MOD EQUIP WEIGHT TO INFORMATION RATE
KPM	5.		CONSTANT RELATING MOD EQUIP PWR REQ TO EQUIP WEIGHT
CKM	7.5	E+03	MOD EQUIP FAB COST INDEPENDENT OF INFORMATION RATE
WKM	5.		MOD EQUIP WEIGHT INDEPENDENT OF INFORMATION RATE

NMODEC MODULATION EQUIP BURDENS, 0.84, PULSED LASER, SPACECRAFT

KFM	.5	E-03	CONSTANT RELATING MOD EQUIP FAB COST TO INFORMATION RATE
KM	.3	E-06	CONSTANT RELATING MOD EQUIP WEIGHT TO INFORMATION RATE
KPM	5.		CONSTANT RELATING MOD EQUIP PWR REQ TO EQUIP WEIGHT
CKM	15.	E+03	MOD EQUIP FAB COST INDEPENDENT OF INFORMATION RATE
WKM	10.		MOD EQUIP WEIGHT INDEPENDENT OF INFORMATION RATE

NMODED MODULATION EQUIP BURDENS, 10.6, CW LASER, SPACECRAFT

KFM	.5	E-03	CONSTANT RELATING MOD EQUIP FAB COST TO INFORMATION RATE
KM	.3	E-06	CONSTANT RELATING MOD EQUIP WEIGHT TO INFORMATION RATE
KPM	5.		CONSTANT RELATING MOD EQUIP PWR REQ TO EQUIP WEIGHT
CKM	15.	E+03	MOD EQUIP FAB COST INDEPENDENT OF INFORMATION RATE
WKM	10.		MOD EQUIP WEIGHT INDEPENDENT OF INFORMATION RATE

NMODEE MODULATION EQUIP BURDENS, 13CM, SPACECRAFT

KFM	.0		CONSTANT RELATING MOD EQUIP FAB COST TO INFORMATION RATE
KM	.0		CONSTANT RELATING MOD EQUIP WEIGHT TO INFORMATION RATE
KPM	.0		CONSTANT RELATING MOD EQUIP PWR REQ TO EQUIP WEIGHT
CKM	.0		MOD EQUIP FAB COST INDEPENDENT OF INFORMATION RATE
WKM	.0		MOD EQUIP WEIGHT INDEPENDENT OF INFORMATION RATE

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NMODEF                       MODULATION EQUIP BURDENS, 0.51, CW LASER, EARTH

KFM        7.5     E-05      CONSTANT RELATING MOD EQUIP FAB COST TO INFORMATION RATE
KM         5.      E-08      CONSTANT RELATING MOD EQUIP WEIGHT TO INFORMATION RATE
KPM        5.                CONSTANT RELATING MOD EQUIP PWR REQ TO EQUIP WEIGHT
CKM        7.5     E+03      MOD EQUIP FAB COST INDEPENDENT OF INFORMATION RATE
WKM        5.                MOD EQUIP WEIGHT INDEPENDENT OF INFORMATION RATE

NMODEG                       MODULATION EQUIP BURDENS, 0.84, CW LASER, EARTH

KFM        7.5     E-05      CONSTANT RELATING MOD EQUIP FAB COST TO INFORMATION RATE
KM         5.      E-08      CONSTANT RELATING MOD EQUIP WEIGHT TO INFORMATION RATE
KPM        5.                CONSTANT RELATING MOD EQUIP PWR REQ TO EQUIP WEIGHT
CKM        7.5     E+03      MOD EQUIP FAB COST INDEPENDENT OF INFORMATION RATE
WKM        5.                MOD EQUIP WEIGHT INDEPENDENT OF INFORMATION RATE

NMODEH                       MODULATION EQUIP BURDENS, 0.84, PULSED LASER, EARTH

KFM         .5     E-03      CONSTANT RELATING MOD EQUIP FAB COST TO INFORMATION RATE
KM          .3     E-06      CONSTANT RELATING MOD EQUIP WEIGHT TO INFORMATION RATE
KPM        5.                CONSTANT RELATING MOD EQUIP PWR REQ TO EQUIP WEIGHT
CKM       15.      E+03      MOD EQUIP FAB COST INDEPENDENT OF INFORMATION RATE
WKM       10.                MOD EQUIP WEIGHT INDEPENDENT OF INFORMATION RATE

NMODEI                       MODULATION EQUIP BURDENS, 10.6, CW LASER, EARTH

KFM         .5     E-03      CONSTANT RELATING MOD EQUIP FAB COST TO INFORMATION RATE
KM          .3     E-06      CONSTANT RELATING MOD EQUIP WEIGHT TO INFORMATION RATE
KPM        5.                CONSTANT RELATING MOD EQUIP PWR REQ TO EQUIP WEIGHT
CKM       15.      E+03      MOD EQUIP FAB COST INDEPENDENT OF INFORMATION RATE
WKM       10.                MOD EQUIP WEIGHT INDEPENDENT OF INFORMATION RATE

NMODEJ                       MODULATION EQUIP BURDENS, 13CM, EARTH

KFM         .0               CONSTANT RELATING MOD EQUIP FAB COST TO INFORMATION RATE
KM          .0               CONSTANT RELATING MOD EQUIP WEIGHT TO INFORMATION RATE
KPM         .0               CONSTANT RELATING MOD EQUIP PWR REQ TO EQUIP WEIGHT
CKM         .0               MOD EQUIP FAB COST INDEPENDENT OF INFORMATION RATE
WKM         .0               MOD EQUIP WEIGHT INDEPENDENT OF INFORMATION RATE
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NDMODA                         DEMODULATION EQUIP BURDENS, OPTICAL DIR DET, EARTH

KFD       5.5     E-05         CONSTANT RELATING DEMOD EQUIP FAB COST TO INFO RATE
KD        1.1     E-07         CONSTANT RELATING DEMOD EQUIP WEIGHT TO INFORMATION RATE
KPD       3.33                 CONSTANT RELATING DEMOD EQUIP PWR REQ TO EQUIP WEIGHT
CKD       15.     E+03         DEMOD EQUIP FAB COST INDEPENDENT OF INFORMATION RATE
WKD       30.                  DEMOD EQUIP WEIGHT INDEPENDENT OF INFORMATION RATE

NDMODB                         DEMODULATION EQUIP BURDENS, OPTICAL HET DET, EARTH

KFD       .1      E-03         CONSTANT RELATING DEMOD EQUIP FAB COST TO INFO RATE
KD        .2      E-06         CONSTANT RELATING DEMOD EQUIP WEIGHT TO INFORMATION RATE
KPD       3.33                 CONSTANT RELATING DEMOD EQUIP PWR REQ TO EQUIP WEIGHT
CKD       27.5    E+03         DEMOD EQUIP FAB COST INDEPENDENT OF INFORMATION RATE
WKD       55.                  DEMOD EQUIP WEIGHT INDEPENDENT OF INFORMATION RATE

NDMODC                         DEMODULATION EQUIPMENT BURDENS, OPTICAL HOM DET, EARTH

KFD       .1      E-03         CONSTANT RELATING DEMOD EQUIP FAB COST TO INFO RATE
KD        .2      E-06         CONSTANT RELATING DEMOD EQUIP WEIGHT TO INFORMATION RATE
KPD       3.33                 CONSTANT RELATING DEMOD EQUIP PWR REQ TO EQUIP WEIGHT
CKD       27.5    E+03         DEMOD EQUIP FAB COST INDEPENDENT OF INFORMATION RATE
WKD       55.                  DEMOD EQUIP WEIGHT INDEPENDENT OF INFORMATION RATE

NDMODE                         DEMODULATION EQUIPMENT BURDENS, 13CM RADIO HOM DET,EARTH

KFD       .0                   CONSTANT RELATING DEMOD EQUIP FAB COST TO INFO RATE
KD        .0                   CONSTANT RELATING DEMOD EQUIP WEIGHT TO INFORMATION RATE
KPD       .0                   CONSTANT RELATING DEMOD EQUIP PWR REQ TO EQUIP WEIGHT
CKD       .0                   DEMOD EQUIP FAB COST INDEPENDENT OF INFORMATION RATE
WKD       .0                   DEMOD EQUIP WEIGHT INDEPENDENT OF INFORMATION RATE

NDMODF                         DEMODULATION EQUIPMENT BURDENS, OPTICAL DIRECT DET,SPACE

KFD       5.5     E-05         CONSTANT RELATING DEMOD EQUIP FAB COST TO INFO RATE
KD        1.1     E-07         CONSTANT RELATING DEMOD EQUIP WEIGHT TO INFORMATION RATE
KPD       3.33                 CONSTANT RELATING DEMOD EQUIP PWR REQ TO EQUIP WEIGHT
CKD       15.     E+03         DEMOD EQUIP FAB COST INDEPENDENT OF INFORMATION RATE
WKD       30.                  DEMOD EQUIP WEIGHT INDEPENDENT OF INFORMATION RATE
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NXPWSA			XMTR POWER SUPPLY BURDENS,RTG,SPACECRAFT
KST	3.	E+03	CONSTANT RELATING XMTR PWR SUPPLY FAB COST TO PWR REQ
KWST	.7		CONSTANT RELATING XMTR PWR SUPPLY WEIGHT TO PWR REQ
CKE	0.		XMTR PWR SUPPLY FAB COST INDEPENDENT OF PWR REQ
WKE	0.		XMTR PWR SUPPLY WEIGHT INDEPENDENT OF PWR REQ
NXPWSB			XMTR POWER SUPPLY BURDENS,REACTOR,SPACECRAFT
KST	5.	E+02	CONSTANT RELATING XMTR PWR SUPPLY FAB COST TO PWR REQ
KWST	.625		CONSTANT RELATING XMTR PWR SUPPLY WEIGHT TO PWR REQ
CKE	1.2	E+06	XMTR PWR SUPPLY FAB COST INDEPENDENT OF PWR REQ
WKE	400.		XMTR PWR SUPPLY WEIGHT INDEPENDENT OF PWR REQ
NXPWSC			XMTR POWER SUPPLY BURDENS,SOLAR CELL,SPACECRAFT,MARS
KST	112.		CONSTANT RELATING XMTR PWR SUPPLY FAB COST TO PWR REQ
KWST	.11		CONSTANT RELATING XMTR PWR SUPPLY WEIGHT TO PWR REQ
CKE	0.		XMTR PWR SUPPLY FAB COST INDEPENDENT OF PWR REQ
WKE	0.		XMTR PWR SUPPLY WEIGHT INDEPENDENT OF PWR REQ
NXPWSD			XMTR POWER SUPPLY BURDENS,GENERATOR,EARTH
KST	25.		CONSTANT RELATING XMTR PWR SUPPLY FAB COST TO PWR REQ
KWST	.0		CONSTANT RELATING XMTR PWR SUPPLY FAB COST TO PWR REQ
CKE	10.	E+03	XMTR PWR SUPPLY FAB COST INDEPENDENT OF PWR REQ
WKE	.0		XMTR PWR SUPPLY WEIGHT INDEPENDENT OF PWR REQ
NXPWSE			XMTR POWER SUPPLY BURDENS,SOLAR CELL,SPACECRAFT,SAT
KST	166.		CONSTANT RELATING XMTR PWR SUPPLY FAB COST TO PWR REQ
KWST	.157		CONSTANT RELATING XMTR PWR SUPPLY WEIGHT TO PWR REQ
CKE	0.		XMTR PWR SUPPLY FAB COST INDEPENDENT OF PWR REQ
WKE	0.		XMTR PWR SUPPLY WEIGHT INDEPENDENT OF PWR REQ
NXPWSF			XMTR POWER SUPPLY BURDENS,SOLAR CELL,SPACECRAFT,VENUS
KST	38.		CONSTANT RELATING XMTR PWR SUPPLY FAB COST TO PWR REQ
KWST	.04		CONSTANT RELATING XMTR PWR SUPPLY WEIGHT TO PWR REQ
CKE	0.		XMTR PWR SUPPLY FAB COST INDEPENDENT OF PWR REQ
WKE	0.		XMTR PWR SUPPLY WEIGHT INDEPENDENT OF PWR REQ

NXPWSG XMTR POWER SUPPLY BURDENS,SOLAR CELL,SPACECRAFT,MERCURY

KST	43.	CONSTANT RELATING XMTR PWR SUPPLY FAB COST TO PWR REQ
KWST	.04	CONSTANT RELATING XMTR PWR SUPPLY WEIGHT TO PWR REQ
CKE	0.	XMTR PWR SUPPLY FAB COST INDEPENDENT OF PWR REQ
WKE	0.	XMTR PWR SUPPLY WEIGHT INDEPENDENT OF PWR REQ

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NRPWSA                            RCVR POWER SUPPLY BURDENS,RTG,SPACECRAFT

KSR          3.       E+03   CONSTANT RELATING RCVR PWR SUPPLY FAB COST TO PWR REQ
KWSR          .7             CONSTANT RELATING RCVR PWR SUPPLY WEIGHT TO PWR REQ.
CKF          0.              RCVR PWR SUPPLY FAB COST INDEPENDENT OF PWR REQ
WKF          0.              RCVR PWR SUPPLY WEIGHT INDEPENDENT OF PWR REQ

NRPWSB                            RCVR POWER SUPPLY BURDENS,REACTOR,SPACECRAFT

KSR          5.       E+02   CONSTANT RELATING RCVR PWR SUPPLY FAB COST TO PWR REQ
KWSR          .625           CONSTANT RELATING RCVR PWR SUPPLY WEIGHT TO PWR REQ.
CKF          1.2      E+06   RCVR PWR SUPPLY FAB COST INDEPENDENT OF PWR REQ
WKF        400.              RCVR PWR SUPPLY WEIGHT INDEPENDENT OF PWR REQ

NRPWSC                            RCVR POWER SUPPLY BURDENS,SOLAR CELL,SPACECRAFT,MARS

KSR        112.              CONSTANT RELATING RCVR PWR SUPPLY FAB COST TO PWR REQ
KWSR          .11            CONSTANT RELATING RCVR PWR SUPPLY WEIGHT TO PWR REQ.
CKF          0.              RCVR PWR SUPPLY FAB COST INDEPENDENT OF PWR REQ
WKF          0.              RCVR PWR SUPPLY WEIGHT INDEPENDENT OF PWR REQ

NRPWSD                            RCVR POWER SUPPLY BURDENS,GENERATOR,EARTH

KSR         25.              CONSTANT RELATING RCVR PWR SUPPLY FAB COST TO PWR REQ
KWSR                         CONSTANT RELATING RCVR PWR SUPPLY WEIGHT TO PWR REQ.
CKF         10.       E+03   RCVR PWR SUPPLY FAB COST INDEPENDENT OF PWR REQ
WKF                          RCVR PWR SUPPLY WEIGHT INDEPENDENT OF PWR REQ

NRPWSE                            RCVR POWER SUPPLY BURDENS,SOLAR CELL,SPACECRAFT,SAT

KSR        166.              CONSTANT RELATING RCVR PWR SUPPLY FAB COST TO PWR REQ
KWSR          .157           CONSTANT RELATING RCVR PWR SUPPLY WEIGHT TO PWR REQ.
CKF          0.              RCVR PWR SUPPLY FAB COST INDEPENDENT OF PWR REQ
WKF          0.              RCVR PWR SUPPLY WEIGHT INDEPENDENT OF PWR REQ

NRPWSF                            RCVR POWER SUPPLY BURDENS,SOLAR CELL,SPACECRAFT,VENUS

KSR         38.              CONSTANT RELATING RCVR PWR SUPPLY FAB COST TO PWR REQ
KWSR          .04            CONSTANT RELATING RCVR PWR SUPPLY WEIGHT TO PWR REQ.
CKF          0.              RCVR PWR SUPPLY FAB COST INDEPENDENT OF PWR REQ
WKF          0.              RCVR PWR SUPPLY WEIGHT INDEPENDENT OF PWR REQ
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NRPWSG		RCVR POWER SUPPLY BURDENS,SOLAR CELL,SPACECRAFT,MERCURY
KSR	43.	CONSTANT RELATING RCVR PWR SUPPLY FAB COST TO PWR REQ
KWSR	.04	CONSTANT RELATING RCVR PWR SUPPLY WEIGHT TO PWR REQ.
CKF	0.	RCVR PWR SUPPLY FAB COST INDEPENDENT OF PWR REQ
WKF	0.	RCVR PWR SUPPLY WEIGHT INDEPENDENT OF PWR REQ

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NXMTRA                        XMTR BURDENS,0.51 ,SPACECRAFT

KPT        150.               CONSTANT RELATING XMTR FAB COST TO XMTR PWR
KWT         51.               CONSTANT RELATING XMTR WEIGHT TO XMTR PWR
KH            .58             CONSTANT RELATING XMTR HEAT EX FAB COST TO XMTR PWR DIS
KX            .7     E-02     CONSTANT RELATING XMTR HEAT EX WEIGHT TO XMTR PWP DIS
KE            .001            XMTR PWR EFFICIENCY
CKP          3.5     E+03     XMTR FAB COST INDEPENDENT OF XMTR PWR
CKH         13.8     E+03     XMTR HEAT EX FAB COST INDEPENDENT OF XMTR PWR
WKP         40.               XMTR WEIGHT INDEPENDENT OF XMTR PWR
WKH          0.               XMTR HEAT EX WEIGHT INDEPENDENT OF XMTR PWR
GT           1.               EXPONENT RELATING XMTR FAB COST TO XMTR PWR
HT           1.               EXPONENT RELATING XMTR WEIGHT TO XMTR PWR
JT           1.               EXPONENT RELATING XMTR PWR SUP-HEAT EX BURD TO XMTR PWR

NXMTRB                        XMTR BURDENS,0.51 ,EARTH

KPT        150.               CONSTANT RELATING XMTR FAB COST TO XMTR PWR
KWT         51.               CONSTANT RELATING XMTR WEIGHT TO XMTR PWR
KH           0.               CONSTANT RELATING XMTR HEAT EX FAB COST TO XMTR PWR DIS
KX           0.               CONSTANT RELATING XMTR HEAT EX WEIGHT TO XMTR PWP DIS
KE            .001            XMTR PWR EFFICIENCY
CKP          3.5     E+03     XMTR FAB COST INDEPENDENT OF XMTR PWR
CKH          0.               XMTR HEAT EX FAB COST INDEPENDENT OF XMTR PWR
WKP         40.               XMTR WEIGHT INDEPENDENT OF XMTR PWR
WKH          0.               XMTR HEAT EX WEIGHT INDEPENDENT OF XMTR PWR
GT           1.               EXPONENT RELATING XMTR FAB COST TO XMTR PWR
HT           1.               EXPONENT RELATING XMTR WEIGHT TO XMTR PWR
JT           1.               EXPONENT RELATING XMTR PWR SUP-HEAT EX BURD TO XMTR PWR

NXMTRE                        XMTR BURDENS,10.6 ,SPACECRAFT

KPT          1.43             CONSTANT RELATING XMTR FAB COST TO XMTR PWR
KWT          2.               CONSTANT RELATING XMTR WEIGHT TO XMTR PWR
KH           1.97             CONSTANT RELATING XMTR HEAT EX FAB COST TO XMTR PWR DIS
KX           2.5     E-02     CONSTANT RELATING XMTR HEAT EX WEIGHT TO XMTR PWP DIS
KE            .1              XMTR PWR EFFICIENCY
CKP          2.      E+03     XMTR FAB COST INDEPENDENT OF XMTR PWR
CKH         13.8     E+03     XMTR HEAT EX FAB COST INDEPENDENT OF XMTR PWR
WKP         25.               XMTR WEIGHT INDEPENDENT OF XMTR PWR
WKH          0.               XMTR HEAT EX WEIGHT INDEPENDENT OF XMTR PWR
GT           1.               EXPONENT RELATING XMTR FAB COST TO XMTR PWR
HT           1.               EXPONENT RELATING XMTR WEIGHT TO XMTR PWR
JT           1.               EXPONENT RELATING XMTR PWR SUP-HEAT EX BURD TO XMTR PWR
```

NXMTRF XMTR BURDENS,10.6 ,EARTH

KPT	1.43		CONSTANT RELATING XMTR FAB COST TO XMTR PWR
KWT	2.		CONSTANT RELATING XMTR WEIGHT TO XMTR PWR
KH	0.		CONSTANT RELATING XMTR HEAT EX FAB COST TO XMTR PWR DIS
KX	0.		CONSTANT RELATING XMTR HEAT EX WEIGHT TO XMTR PWP DIS
KE	.1		XMTR PWR EFFICIENCY
CKP	2.	E+03	XMTR FAB COST INDEPENDENT OF XMTR PWR
CKH	0.		XMTR HEAT EX FAB COST INDEPENDENT OF XMTR PWR
WKP	25.		XMTR WEIGHT INDEPENDENT OF XMTR PWR
WKH	0.		XMTR HEAT EX WEIGHT INDEPENDENT OF XMTR PWR
GT	1.		EXPONENT RELATING XMTR FAB COST TO XMTR PWR
HT	1.		EXPONENT RELATING XMTR WEIGHT TO XMTR PWR
JT	1.		EXPONENT RELATING XMTR PWR SUP-HEAT EX BURD TO XMTR PWR

NXMTRG XMTR BURDENS,13CM,SPACECRAFT

KPT	120.		CONSTANT RELATING XMTR FAB COST TO XMTR PWR
KWT	.1		CONSTANT RELATING XMTR WEIGHT TO XMTR PWR
KH	.58		CONSTANT RELATING XMTR HEAT EX FAB COST TO XMTR PWR DIS
KX	.7	E-02	CONSTANT RELATING XMTR HEAT EX WEIGHT TO XMTR PWP DIS
KE	.25		XMTR PWR EFFICIENCY
CKP	17.5	E+03	XMTR FAB COST INDEPENDENT OF XMTR PWR
CKH	13.8	E+03	XMTR HEAT EX FAB COST INDEPENDENT OF XMTR PWR
WKP	5.		XMTR WEIGHT INDEPENDENT OF XMTR PWR
WKH	0.		XMTR HEAT EX WEIGHT INDEPENDENT OF XMTR PWR
GT	1.		EXPONENT RELATING XMTR FAB COST TO XMTR PWR
HT	1.		EXPONENT RELATING XMTR WEIGHT TO XMTR PWR
JT	1.		EXPONENT RELATING XMTR PWR SUP-HEAT EX BURD TO XMTR PWR

NXMTRH XMTR BURDENS,13CM,EARTH

KPT	120.		CONSTANT RELATING XMTR FAB COST TO XMTR PWR
KWT	.1		CONSTANT RELATING XMTR WEIGHT TO XMTR PWR
KH	0.		CONSTANT RELATING XMTR HEAT EX FAB COST TO XMTR PWR DIS
KX	0.		CONSTANT RELATING XMTR HEAT EX WEIGHT TO XMTR PWP DIS
KE	.25		XMTR PWR EFFICIENCY
CKP	17.5	E+03	XMTR FAB COST INDEPENDENT OF XMTR PWR
CKH	0.		XMTR HEAT EX FAB COST INDEPENDENT OF XMTR PWR
WKP	5.		XMTR WEIGHT INDEPENDENT OF XMTR PWR
WKH	0.		XMTR HEAT EX WEIGHT INDEPENDENT OF XMTR PWR
GT	1.		EXPONENT RELATING XMTR FAB COST TO XMTR PWR
HT	1.		EXPONENT RELATING XMTR WEIGHT TO XMTR PWR
JT	1.		EXPONENT RELATING XMTR PWR SUP-HEAT EX BURD TO XMTR PWR

4.6 Automatic COPTRAN Burden Data Selection Logic

Automatic burden data selection by the COPTRAN program is made according to the selection tables in the following sections. This selection will always be made unless other specific instructions or data are included. In such a case, the specific instructions or data over-ride the automatic selection logic.

4.6.1 Nominal Systems Burdens Selection Logic

TRANSMITTER ANTENNA

	0.51 μ	0.84 μ	10.6 μ	13 cm Diameter Burdens	13 cm Gain Burdens
Spacecraft Transmitter	NXANTA	NXANTC	NXANTD	NXANTF	NXANTG

RECEIVER ANTENNA

		0.51μ	0.84μ	10.6μ	13 cm Diameter Burdens	13 cm Gain Burdens
Earth Receiver	Direct Detection	NRANTA	NRANTC	NRANTD	NRANTF	NRANTG
	Het. or Hom. Detection	NRANTB	X	NRANTE		

X - Forbidden combination

TRANSMITTER ACQUISITION
AND TRACK SYSTEM

	Optical Frequency	Radio Freq. Diam. Burdens	Radio Freq. Gain Burdens
Spacecraft Transmitter	NXACTA	NXACTB	NXACTC

RECEIVER ACQUISITION
AND TRACK SYSTEM

	Optical Frequency	Radio Freq. Diam. Burdens	Radio Freq. Gain Burdens
Earth Receiver	NRACTA	NRACTB	NRACTC

MODULATION
EQUIPMENT - SPACE

	0.51μ	0.84μ	10.6μ	13 cm
PCM/AM	NMODEA	NMODEB	NMODED	NMODEE
PCM/PL	NMODEA	NMODEB	NMODED	X
PCM/FM	NMODEA	NMODEB	NMODED	NMODEE
PCM/PM	NMODEA	NMODEB	NMODED	NOMDEE
PPM/AM	NMODEA	NMODEC	NMODED	X

X - Forbidden combination

MODULATION
EQUIPMENT - EARTH

	0.51μ	0.84μ	10.6μ	13 cm
PCM/AM	NMODEF	NMODEG	NMODEI	NMODEJ
PCM/PL	NMODEF	NMODEG	NMODEI	X
PCM/FM	NMODEF	NMODEG	NMODEI	NMODEJ
PCM/PM	NMODEF	NMODEG	NMODEI	NMODEJ
PPM/AM	NMODEF	NMODEH	NMODEI	X

X - Forbidden combination

DEMODULATION
EQUIPMENT - EARTH

	Optical Direct Detection			Optical Heterodyne Detection			Optical Homodyne Detection			Radio Direct Detection 13 cm	Radio Homodyne Detection 13 cm
	0.51μ	0.84μ	10.6μ	0.51μ	0.84μ	10.6μ	0.51μ	0.84μ	10.6μ		
PCM/AM	NDMODA	NDMODA	NDMODA	X	X	X	X	X	X	X	NDMODE
PCM/PL	NDMODA	NDMODA	NDMODA	X	X	X	X	X	X	X	X
PCM/FM	X	X	X	NDMODB	NDMODB	NDMODB	X	X	X	X	NDMODE
PCM/PM	X	X	X	X	X	X	NDMODC	NDMODC	NDMODC	X	NDMODE
PPM/AM	NDMODA	NDMODA	NDMODA	X	X	X	X	X	X	X	X

X - Forbidden combination

DEMODULATION
EQUIPMENT - SPACE

	Optical Direct Detection			Optical Heterodyne Detection			Optical Homodyne Detection			Radio Direct Detection 13 cm	Radio Homodyne Detection 13 cm
	0.51μ	0.84μ	10.6μ	0.51μ	0.84μ	10.6μ	0.51μ	0.84μ	10.6μ		
PCM/AM	NDMODF	NDMODF	NDMODF	X	X	X	X	X	X	NDMODI	NDMODJ
PCM/PL	NDMODF	NDMODF	NDMODF	X	X	X	X	X	X	X	X
PCM/FM	X	X	X	NDMODG	NDMODG	NDMODG	X	X	X	NDMODI	NDMODJ
PCM/PM	X	X	X	X	X	X	NDMODH	NDMODH	NDMODH	NDMODI	NDMODJ
PPM/AM	NDMODF	NDMODF	NDMODF	X	X	X	X	X	X	X	X

X - Forbidden combination

TRANSMITTER SYSTEM
POWER SUPPLY

Spacecraft Transmitter						Earth Transmitter
RTG	Reactor	Solar Cell Mars	Solar Cell Satellite	Solar Cell Venus	Solar Cell Mercury	Generator
NXPWSA	NXPWSB	NXPWSC	NXPWSE	NXPWSF	NXPWSG	NXPWSD

RECEIVER SYSTEM
POWER SUPPLY

Spacecraft Receiver						Earth Transmitter
RTG	Reactor	Solar Cell Mars	Solar Cell Satellite	Solar Cell Venus	Solar Cell Mercury	Generator
NRPWSA	NRPWSB	NRPWSC	NRPWSE	NRPWSF	NRPWSG	NRPWSD

TRANSMITTER

	0.51 μ	0.84 μ	10.6 μ	13 cm
Spacecraft Transmitter	NXMTRA	X	NXMTRE	NXMTRG
Earth Transmitter	NXMTRB	X	NXMTRF	NXMTRH

4.6.2 System Physical Data Selection Logic

R, transmission range

RANMAR	1.0×10^{13} cm
RANJUP	7.5×10^{13} cm
RANSAT	3.6×10^{9} cm

λ, transmission wavelength

LAM051	0.51×10^{-4} cm
LAM084	0.84×10^{-4} cm
LAM106	10.6×10^{-4} cm
LAM13C	13 cm

S/N, signal-to-noise power ratio

	OPTDIR	OPTHET	OPTHOM	RADHET	RADHOM
PCM/AM	26	30	15	20	15
PCM/PL	12	X	X	X	X
PCM/FM	X	15	X	19	15
PCM/PM	X	X	7	X	8
PCM/AM	19	X	X	25	X

X - Forbidden Combination

C/N, carrier-to-background radiation power ratio

	OPTDIR
PCM/IM	6
PCM/PL	3
PPM/IM	1

$(u_s, \tau)_{REQ}$, required signal photoelectron count per time period τ

	OPTDIR
PCM/IM	30
PCM/PL	15
PPM/IM	20

τ_t, transmitter system transmissivity

	LAM051	LAM084	LAM106	LAM13C
PCM/AM	.8	.8	.8	.75
PCM/IM	.8	.8	.8	.75
PCM/PL	.8	.8	.8	.75
PCM/FM	.8	.8	.8	.75
PCM/PM	.8	.8	.8	.75
PPM/IM	.8	.8	.8	.75

τ_r, receiver system transmissivity

	LAM051	LAM084	LAM106	LAM13C
OPTDIR	.7	.7	.7	X
OPTHET or OPTHOM	.6	.6	.6	X
RADHET or RADDIR	X	X	X	.35

X — Forbidden Combination

τ_a, atmospheric transmissivity

	LAM051	LAM084	LAM106	LAM13C
SPXMTR and SPRCVR	.8	.8	.8	.95
SPXMTR and EARCVR or EAXMTR and SPRCVR	.8	.8	.8	.95
EAXMTR and EARCVR	.8	.8	.8	.95

ρ_T, transmitter antenna aperture efficiency

LAM051	0.98
LAM084	0.98
LAM106	0.98
LAM13C	0.60

ρ_R, receiver antenna aperture efficiency

LAM051	0.98
LAM084	0.98
LAM106	0.98
LAM13C	0.80

T_E, receiver equivalent temperature

	LAM13C	LAM084 or LAM106
BKGALT	27	X
OPTDIR	X	300

η, detector quantum efficiency

LAM051	.2
LAM084	.5
LAM106	.5

X – Forbidden Combination

R_L, receiver output load resistance

R_L = 100 ohms

λ_i, optical filter bandwidth

$\lambda_i = 10^{-3}$ microns

Q_B, background radiation photon spectral radiance

	LAM051
BKMARS	X
BKJUPT	X
BKMOON	X
BKERTH	X
BKDSKY	$.2 \times 10^{-17}$
BKNSKY	$.75 \times 10^{9}$
BKGALT	0.

d_{TB}, transmitter antenna diameter stop

	LAM051	LAM084	LAM106	LAM13C
SPXMTR	10	16	100	100
EAXMTR	10	16	210	1000

G_{TB}, transmitter antenna gain stop

	LAM13C
SPXMTR	348
EAXMTR	34,800

X — Forbidden Combination

d_{RB}, receiver antenna diameter stop

	LAM051	LAM084	LAM106	LAM13C
SPRCVR and OPTDIR	100	100	100	X
SPRCVR and either OPTHET or OPTHOM	10	16	100	X
SPRCVR and either RADDIR or RADHOM	X	X	X	1000
EARCVR and OPTDIR	1000	1000	1000	1000
EARCVR and either OPTHET or OPTHOM	10	16	100	X
EARCVR and either RADDIR or RADHOM	X	X	X	6400

G_{RB}, receiver antenna gain stop

	LAM13C
SPRCVR	46,500
EARCVR	1,900,000

P_{TB}, transmitter power stop

	LAM051	LAM084	LAM106	LAM13C
SPXMTR	50	5	500	1,000
EAXMTR	100	25	1000	10,000

θ_{RB}, receiver field of view stop

	LAM051	LAM084	LAM106	LAM13C
SPRCVR	10^{-5}	10^{-5}	10^{-5}	10^{-4}
EARCVR	10^{-5}	10^{-5}	10^{-5}	10^{-4}

X — Forbidden Combination

4.7 COPTRAN Coding Sheets and Data Forms

The following pages contain the blank sheets and forms which may be used in the preparation of COPTRAN programs. The sheets are: the COPTRAN Coding Sheet A, the COPTRAN Coding Sheet B, the COPTRAN Coding Sheet C, the System Burdens Data Sheet, the System Physical Data Sheet, and the System Parameter Constraints Sheet.

The COPTRAN Coding Sheet A is generally the only coding sheet needed. Its usage is described in Section 4.3.1 and 4.3.2, where it is noted that the COPTRAN Instruction mnemonics and the COPTRAN Data may be tabulated on this form. COPTRAN Coding Sheets B and C, described in Section 4.3.2, are used if many of the Systems Burdens Data values and the System Physical Data values are to be changed. COPTRAN Coding Sheets B and C list all the labels and indicate where the decimal point is to be placed, saving some effort in preparation.

The Systems Burdens Data Sheet, the Systems Physical Data Sheet, and the Systems Parameter Constraints Sheets are provided to enable the user to consider more conveniently changes he may wish to make. Their use is not required in any part of the COPTRAN program.

COPTRAN CODING SHEET A

NAME ______________________ DATE ____________ PROBLEM ______________________________

COPTRAN INSTRUCTIONS AND DATA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1																								
2																								
3																								
4																								
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25																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
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25																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

COPTRAN CODING SHEET B

NAME ______________________ DATE __________ PROBLEM ______________________________

SYSTEM BURDENS DATA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	K	T	H	T										.										
2	K	D	T											.										
3	C	K	T											.										
4	W	K	T											.										
5	M	T												.										
6	N	T												.										
7																								
8	K	A	T											.										
9	K	W	A	T										.										
10	K	P	Q	T										.										
11	C	A	T											.										
12	W	B	T											.										
13	Q	T												.										
14																								
15	K	F	M											.										
16	K	M												.										
17	K	P	M											.										
18	C	K	M											.										
19	W	K	M											.										
20																								
21	K	S	T											.										
22	K	W	S	T										.										
23	C	K	E											.										
24	W	K	E											.										
25																								

SYSTEM BURDENS DATA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	K	T	H	R										.										
2	K	D	R											.										
3	C	K	R											.										
4	W	K	R											.										
5	M	R												.										
6	N	R												.										
7																								
8	K	A	R											.										
9	K	W	A	R										.										
10	K	P	Q	R										.										
11	C	A	R											.										
12	W	B	R											.										
13	Q	R												.										
14																								
15	K	F	D											.										
16	K	D												.										
17	K	P	D											.										
18	C	K	D											.										
19	W	K	D											.										
20																								
21	K	S	R											.										
22	K	W	S	R										.										
23	C	K	F											.										
24	W	K	F											.										
25																								

COPTRAN CODING SHEET C

NAME ____________ DATE ____________ PROBLEM ____________

SYSTEM BURDENS DATA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	K	P	T											.										
2	K	W	T											.										
3	K	H												.										
4	K	X												.										
5	K	E												.										
6	C	K	P											.										
7	C	K	H											.										
8	W	K	P											.										
9	W	K	H											.										
10	G	T												.										
11	H	T												.										
12	J	T												.										
13																								
14	K	S	A											.										
15	K	S	B											.										
16																								
17																								
18																								
19																								
20																								
21																								
22																								
23																								
24																								
25																								

SYSTEM PHYSICAL DATA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	R													.										
2	L	A	M	B	D	A								.										
3	S	N												.										
4	C	N												.										
5	U	S	B	R	E	Q								.										
6	T	A	U	T										.										
7	T	A	U	R										.										
8	T	A	U	A										.										
9	T	E												.										
10	E	T	A											.										
11	R	L												.										
12	L	M	B	D	I									.										
13	Q	B												.										
14																								
15																								
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25																								

SYSTEM BURDENS DATA

TRANSMITTER LOCATION: ____________________ DATE: ______________

RECEIVER LOCATION: ____________________

TRANSMISSION WAVELENGTH: ____________________

COMPONENT	PARAMETER	UNIT	VALUE	USE
TRANSMITTER ANTENNA	$K_{\theta T}$	\$/		TF
	K_{dT}	LB/		TW
	C_{KT}	\$		TF
	W_{KT}	LB		TW
	m_T	– –		TF
	n_T	– –		TW
RECEIVER ANTENNA	$K_{\theta R}$	\$/		RF
	K_{dR}	LB/		RW
	C_{KR}	\$		RF
	W_{KR}	LB		RW
	m_R	– –		RF
	n_R	– –		RW
TRANSMITTER ACQUISITION AND TRACK SYSTEM	K_{AT}	\$/		TF
	K_{WAT}	LB/		TW
	K_{PQT}	WATT/LB		TWF
	C_{AT}	\$		TF
	W_{BT}	LB		TW
	q_T	– –		TF
RECEIVER ACQUISITION AND TRACK SYSTEM	K_{AR}	\$/		RF
	K_{WAR}	LB/		RW
	K_{PQR}	WATT/LB		RWF
	C_{AR}	\$		RF
	W_{BR}	LB		RW
	q_R	– –		RF
GENERAL	K_{SA}	\$/LB		TW
	K_{SB}	\$/LB		RW

COMPONENT	PARAMETER	UNIT	VALUE	USE
MODULATION EQUIPMENT	K_{FM}	\$/BIT		TF
	K_M	LB/BIT		TW
	K_{PM}	WATT/LB		TWF
	C_{KM}	\$		TF
	W_{KM}	LB		TW
DEMODULATION EQUIPMENT	K_{FD}	\$/BIT		RF
	K_D	LB/BIT		RW
	K_{PD}	WATT/LB		RWF
	C_{KD}	\$		RF
	W_{KD}	LB		RW
TRANSMITTER POWER SUPPLY	K_{ST}	\$/WATT		TF
	K_{WST}	LB/WATT		TW
	C_{KE}	\$		TF
	W_{KE}			TW
RECEIVER POWER SUPPLY	K_{SR}	\$/WATT		RF
	K_{WSR}	LB/WATT		RW
	C_{KF}	\$		RF
	W_{KE}	LB		RW
TRANSMITTER	K_{PT}	\$/		TF
	K_{WT}	LB/		TW
	K_H	\$/WATT		TF
	K_X	LB/WATT		TW
	k_e	– –		TWF
	C_{KP}	\$		TF
	C_{KH}	\$		TF
	W_{KP}	LB		TW
	W_{KH}	LB		TW
	g_T	– –		TF
	h_T	– –		TW
	i_T	– –		TWF

Use Code:
- TW – Data for transmitter weight optimization
- TF – Data for transmitter fabrication cost optimization
- RW – Data for receiver weight optimization
- RF – Data for receiver fabrication cost optimization
- TWF – Data for transmitter weight and fabrication cost optimization
- RWF – Data for receiver weight and fabrication cost optimization

SYSTEM PHYSICAL DATA

TRANSMITTER LOCATION: ______________________ DATE: __________

RECEIVER LOCATION: ______________________

PROGRAM				PARAMETER	NAME	UNITS	VALUE
SOP	TOP	HOP	ROP				
*	*	*	*	R	Range	cm	
*	*	*	*	λ	Transmission wavelength	cm	
	*	*	*	S/N	Signal-to-noise power ratio		
*				C/N	Signal to background radiation power ratio		
*				$(\mu_{S,\pi})_{Req.}$	Required signal photoelectron count per decision interval		
*	*	*	*	τ_t	Transmitter transmissivity		
*	*	*	*	τ_r	Receiver transmissivity		
*	*	*	*	τ_a	Atmospheric transmissivity		
*	*	*	*	ρ_t	Transmitter antenna aperture efficiency		
*	*	*	*	ρ_r	Receiver antenna aperture efficiency		
	*		*	T_E	Receiver temperature	°K	
*	*	*		η	Detector quantum efficiency		
	*			R_L	Receiver output load resistance	ohms	
*				$\lambda.$	Optical filter bandwidth	micron	
*				Q_B	Photon spectral radiance	photons per cm^2 micron steradian	

Rule: Parameter may be set equal to zero if asterisk is absent in program column.

SYSTEM PARAMETER CONSTRAINTS

PARAMETER	UNITS	INITIAL	FIXED	STOP
Transmitter antenna diameter	cm	d_{TI}	d_{TM}	d_{TB}
Transmitter antenna gain	–	G_{TI}	G_{TM}	G_{TB}
Receiver antenna diameter	cm	d_{RI}	d_{RM}	d_{RB}
Receiver antenna gain	–	G_{RI}	G_{RM}	G_{RB}
Transmitter power	watt	P_{TI}	P_{TM}	P_{TB}
Receiver field of view	rad.	θ_{RI}	θ_{RM}	θ_{RB}

Rules:

1. If a parameter is to be fixed, set the stop and initial values of the parameter to its fixed value
2. If a parameter is not to be fixed, set the fixed value equal to zero, and set the initial value to one half the stop value.
3. If a parameter is not to be optimized, nor fixed, its values may be set to zero.

5.0 INTERFACE EQUIPMENT SUMMARY

5.1 Introduction

The COPS digital computer program can be controlled using COPTRAN, an interpretive computer language. These programs at present operate in a pure batch processing mode. Program controls and data are input by means of a prepared card deck. The program operates on the input and produces a tabular and graphical output.

To fully utilize the computer as a design tool, an interactive console terminal should be provided. Then, with the appropriate conversational software, the designer will be able to communicate directly with the COPS program through his console. Results could be made available immediately and changes in input parameters could be made quickly to determine their effects. Additionally, the conversational software can be designed so that the user need have very little familiarity with computers and card preparation. He would be able to converse with the computer in terms familiar to him or merely supply information to the computer as required in a question-and-answer session. The prime objectives in converting to a remote conversational mode of operation are: ease of use, flexibility, and rapid production of results.

There is a wide spectrum of capability which can be made available to the user. The features which can be provided at a remote terminal include:

Input: Keyboard
Light pen graphics
Stylus graphics
Output: Printer (High- or Low-Speed)
Plotter
CRT Alpha-Numerics
CRT Display graphics

These features may be combined in various ways to achieve many different degrees of sophistication. Configurations might run from something as simple as a teletype and plotter to a general purpose graphic display terminal with independent software, central processing unit, light pen, high speed printer, and graphic hard copy capability.

The following is a survey of currently available equipment which could form a remote terminal. The assumptions are that the first computer used will be a Honeywell DDP 516, with possible conversion at a later date to a larger computer in the SDS Sigma 5 class. Input/Output capability should conform as closely as possible to the requirements of COPS and COPTRAN. FORTRAN IV is available on the DDP-516 and it is understood that, because COPS and COPTRAN are written in FORTRAN IV, remote terminals should be evaluated also on their ability to be driven by and be compatible with FORTRAN IV.

The present ERC configuration of the DDP-516 installation includes CRT graphics as well as a large memory and secondary storage for implementation of a graphics-oriented time-sharing system. The selection of the graphics system for the DDP-516 facility has already been made (Information Displays, Inc.). Although this seems to dictate the choice of terminals for a prospective user, consideration is given here to a variety of terminals and terminal manufacturers. This is to provide an insight into the capabilities available today at a remote terminal. It is also intended to provide a perspective in planning future interactive systems.

5.2 Possible Systems

There are several general configurations which are available for remote terminals. In almost all cases the equipment can communicate with the central processor either directly or through a standard "Data-Set" communications link. A direct path to the computer is a simpler approach but restricts the distance between the central processing unit and the terminal. By using "Data-Sets" and regular telephone lines greater flexibility is available.

In order to indicate the wide variety of options which can be made available at the remote terminal, three general configurations will be presented with their advantages and disadvantages.

The configuration shown in Figure 5-1 is certainly the most straightforward approach and probably the least costly. Conversational interaction takes place via the teletype and output is on the plotter and teletype. The chief drawback to this configuration is its slow speed. The information rate

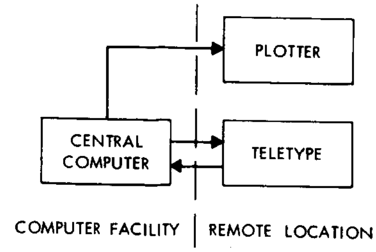

Figure 5-1. Teletype/Plotter Remote Station

for the available typewriter terminals is 10-12 characters/second. This means that the equivalent of one page of printer output would require on the order of 10 minutes to produce on the typewriter. The plotter shown is also a relatively slow device, a factor of importance if plots are to play an important role in the design process.

The configuration of Figure 5-2 has reduced the problem of low interactive speeds. Program output during the conversational mode of operation and throughout the intermediate design stages is on the CRT Alphanumeric display. Operator response is by means of the keyboard and graphic output is on the plotter at the remote location. Hard copy of the tabular results could be output on the line printer at the computer to be picked up later. As in the system shown in Figure 5-1, the design process can be hampered by slow interactive speeds if intermediate plotter output is required.

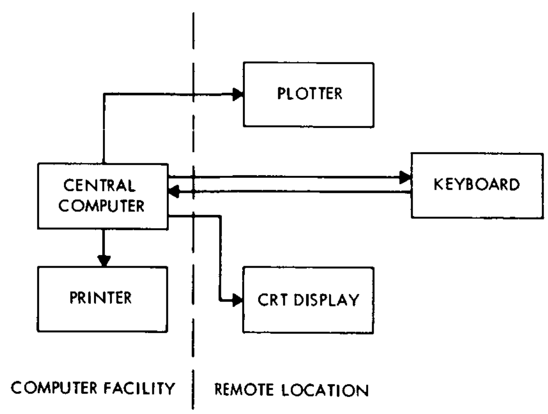

Figure 5-2. Keyboard/CRT Alphanumeric Output/ Plotter/Printer Remote Station

Figure 5-3 illustrates the most versatile and most costly of the possible terminal configurations. Because it has its own processor and memory, it can be programmed to do a large number of tasks independent of the central computer. A high rate of interaction can be maintained through the CRT alphanumeric and graphical displays, keyboard and light pen. Hard copy can be produced on the line printer and the plotter (or photographically from the CRT display (not shown here)). Additionally a system such as this provides graphical capability perhaps desirable in later system configurations.

5.3 Software Requirements

Three software packages should be considered in converting the COPS/ COPTRAN system into a remote, conversational system. They are: user (conversational) software, input/output software, and display software. These will now be described briefly.

Conversational software. — This programming effort would be proportional to the sophistication of the conversational language. It could require virtually no effort if user would input information in the present COPTRAN form. On the other hand, a relatively small amount of programming at the FORTRAN level will yield a system which is a great deal easier to use.

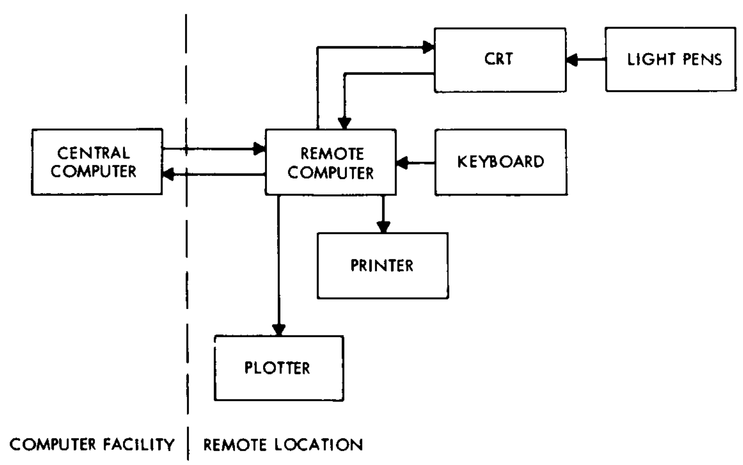

Figure 5-3. Complete Remote Graphic Processing Remote Terminal

Input/output software. – In all but the simplest configurations some amount of programming, probably at the assembly language level, will be required to interface the remote stations with the FORTRAN operating system. In some instances this will amount to routines to supply the control pulses to the devices which are not standard to the FORTRAN I/O package. In addition, encoding and decoding is required if the devices require a different bit code than that used by the DDP-516.

Display software. – Under this heading come the routines which drive the display device: CRT or plotter. They usually enable the user to specify the graphic entity to be displayed without regard to the actual control sequences which must be sent to the device. In some cases, this might also include display regeneration routines. In a large number of cases, this software can be provided by the manufacturer. In the case of the display terminal with its own self contained processor, this package can be very sophisticated.

5.4 Available Equipment

Table V-I gives a brief summary of the various terminals and terminal components considered. For each piece of equipment considered, Table V-I provides the following information:

1. Brief description of capabilities and drawbacks with regard to the DDP-516 system.
2. Approximate cost (where provided by the manufacturer).
3. Type of alphanumeric input provided.
4. Type of alphanumeric output provided.
5. Type of graphic input provided.
6. Type of graphic output provided.
7. Whether or not hard copy is provided.
8. Whether software support is provided by the manufacturer.
9. Whether terminal has its own programmable central processor (thus providing a great deal of flexibility).

TABLE V-I
EQUIPMENT SUMMARY

Name	1. Description	2. Approximate Cost	3. Alpha-numeric Input	4. Alpha-numeric Output	5. Graphic Input	6. Graphic Output	7. Produces Hard Copy	8. Software Supplied	9. Programmable Remote Processor
AGT/10 AGT/30 AGT/50	This is a family of highly sophisticated graphics terminals – very flexible and expensive. Extensive software is provided for remote processor. AGT/10 probably sufficient for conversational COPS – later version.	60 K 125 K 175 K	KBD	a. PRT b. CRT	LPEN	CRT	Yes	Yes Extended	Yes
Grafacon	Highly sophisticated. A major item is the graphic stylus which is probably unnecessary for COPS. Does include CRT, keyboard.	N/A	KBD	CRT	Stylus	CRT	–	–	–
CALCOMP	Incremental plotter. S16 interface available but manufacturer does not yet have S16 plotting routines. These may be available from other DDP S16/ CALCOMP installations.	$4500	None	None	None	Plotter	Yes	No	No
CC-30	Modular remote system designed for data phone use. Uses standard TV set for alphanumeric and graphic output.	$12 K minimum	KBD	TV, PTR	LPEN	TV	Yes	No	Yes, limited
DEC-338	Provides remote graphic capability. PDP-8 computer serves as remote processor – much software available with it.	$56 K	KBD	CRT, PTR	LPEN	CRT	Yes	Yes	Yes
Friden 7100	Typewriter terminal. 130 characters/ line. Up to 12 characters/second.	$3200	KBD	TYP	None	None	Yes	No	No
Gerber 22	Smallest of Gerber line is 4 by 5-foot drafting table. Provides fairly high accuracy.	N/A	None	None	None	Plotter	Yes	–	No
ASR 33	Teletype unit supplied with Honeywell computers. Easiest to interface. 72 characters/line, 12 characters/ second maximum.	$1200	KBD	TYP	None	None	Yes	Yes	No
S54-00	Honeywell's alphanumeric CRT remote terminal.	N/A	KBD	CRT	None	None	No	No	No
IBM-2740	IBM selectric remote terminal. Uses 6 bit code. 130 characters/line.	N/A	KBD	TYP	None	None	Yes	Some	No
IBM-2250	IBM's sophisticated remote graphic terminal. Probably interface problems. 6-bit code.	N/A	KBD	CRT	LPEN	CRT	Optional	Some	Limited
IDIIOM	Sophisticated graphics terminal. Versatile.	N/A	KBD	CRT/ TYP	LPEN	CRT	Yes	Yes	Yes
TEC-LITE	Small CRT alphanumeric terminal. Keyboard and function displays. Character display capability somewhat limited – to be increased this year (1968).	N/A	KBD	CRT	None	None	No	–	No

Abbreviations used in Table V-I are as follows:

CRT	Cathode ray tube
KBD	Keyboard
LPEN	Light pen
N/A	Not available
PTR	Line printer – usually 300-600 lines/minute
STYLUS	Graphic stylus
TYP	Typewriter or teletype printer

Table V-II provides the manufacturer's name and address for each device listed in Table V-I.

The equipment included in this survey does not constitute an exhaustive list. Rather, it is intended to be representative of the available hardware most suited for a conversational COPS/COPTRAN system.

TABLE V-II
LIST OF MANUFACTURERS

Equipment Name	Manufacturer
AGT/10 AGT/30 AGT/50	Adage, Inc. 1079 Commonwealth Ave. Boston, Massachusetts 02115 (617) 783-1100
GRAFACON	Bolt Beranek and Newman, Inc. Data Equipment Division 2126 South Lyon Street Santa Ana, California 92705 (714) 546-5300
CALCOMP	California Computer Products, Inc. 305 Muller Anaheim, California 92803 (714) 774-9141
CC-30	Computer Communications, Inc. 701 West Manchester Boulevard Inglewood, California 90301 (213) 674-5300
DEC-338	Digital Equipment Corporation Maynard, Massachusetts (617) 897-8821
FRIDEN 7100	Friden, Inc. 1720 Beverly Boulevard Los Angeles 26, California (213) 483-4800
GERBER 22	The Gerber Scientific Instrument Co. 16024 Ventura Boulevard Suite 110 Encino, California (213) 981-2044
ASR-33 S54-00	Honeywell Computer Control Division 9171 Wilshire Boulevard Suite 610 Beverly Hills, California 90210 (213) 278-1901

TABLE VII (continued)
LIST OF MANUFACTURERS

Equipment Name	Manufacturer
IBM 2740 IBM 2250	IBM 1031 North Brand Boulevard Glendale, California 91202 (213) 246-1651
IDIIOM	Information Displays, Inc. 333 North Bedford Road Mount Kisco, New York 10549 (914) 666-2936
TEC-LITE	Transistor Electronics Corporation Box 6191 Minneapolis, Minnesota 55424 (612) 941-1100

5.5 Conclusions

Considering the stage of development of the COPS/COPTRAN system, the scale of the DDP-516, and the wide range of remote terminal accessories, it seems evident that an evolutionary approach to the conversational COPTRAN mode is the most advisable. Before examining the options for the first system, there are several general observations which should be made. First, the desired interactive rate of the system should be given careful consideration. If the design process for which COPS was designed involves a large number of iterations before a final solution is reached, then a CRT graphics system would provide results — both tabular and graphical — very rapidly. This would allow much more interaction between COPS and the designer than would a system which was typewriter/plotter oriented. On the other hand, if the terminal is primarily to provide convenience and ease of use to the engineer with few iterations in the design process, then the slower systems will suffice. The tradeoff here is cost. CRT display systems are bigger, more versatile, and much more expensive. Future demands on the terminal should not be ignored in making this decision.

Only two of the typewriter consoles and none of the CRT displays considered provided 130 character/line capability. For this reason, compatibility with present COPS output format places serious limitations on the options available. The cost of reprogramming the COPS output format statements would be small compared to that of attempting to interface an otherwise unsuitable terminal.

Almost all of the terminal equipment considered had the capability of interfacing to at least one of the Data-Sets commercially available. The DDP-516 also has that capability. Taking advantage of this fact, where possible, can reduce some of the hardware interface requirements. (This in essence makes the Data-phone line the common denominator between two dissimilar devices. Depending on the locale, however, the charge for Data-phone service may not be insignificant.)

While the COPS/COPTRAN conversational system is under development, perhaps the most prudent approach is with a terminal similar to that given in Figure 5-1: a typewriter or teletype with a plotter. There are two reasons for this choice: 1) Cost and ease of interfacing, and 2) with a small initial investment an operational conversational mode can be made operational allowing further study regarding future development of COPS systems and its remote terminal requirements.

The most logical unit to serve as the interactive device is Honeywell's ASR 33. It undoubtedly would present the least interfacing problem and could be either the existing console teletype or logically be made to appear the same. This unit does not have the ability to output 130 characters per line. If printer format compatibility is to be maintained, the Friden 7100 is probably best. There would be some interfacing problems: an interface could cost up to $10,000 to develop. As mentioned above, the format changes to the program appear to be a relatively easy task compared to that of interfacing the Friden 7100. Hard copy graphic output would be produced on a Cal Comp plotter. The present DDP-516 system configuration does not include a plotter. A standard interface to the 516 does exist, however, and there is a strong possibility that a plotter will be added to the ERC computer installation.

Because the DDP-516 system is at the outset a graphics oriented system another option well worth considering is the use of an IDI display device (at a cost of about $15,000). The 516 facility will have the capability to drive eight such devices. If the software and hardware are available at an early date, this could provide high interactive and display capability at the start of the development of conversational COPTRAN.

It should be pointed out that until some sort of system software is provided, program loading from a remote location will be a problem.

Full use of the computer's capability and utilization of conversational COPTRAN will be realized in a time-shared environment with the ability to service more than one COPTRAN user at a time. In deciding which directions COPTRAN development should take in the future, the following considerations should be studied using early conversational COPTRAN and the first COPTRAN terminal:

1. Optimal or desirable degree of interaction
2. Type of graphic output
3. Permanent record requirements
4. Graphic input requirements
5. Possible use for related future design needs

Judicious selection of terminal capabilities and COPS system design can result in a very powerful and easy to use design tool for communications systems.

6.0 CONTRACT END ITEM

6.1 Introduction

A required end item for contract NAS 12-566 is as follows:

"Item 3 Evaluate and determine the follow-on mathematical analysis for the next generation of communication systems models with respect to the following factors:

a. Optimization criteria
b. Required degree of model versatility
c. Identify the parameters and their rating of importance
d. Determine the applicability and specifications for future remote and batch-type computer mathematical analyses."

The purpose of Item 3 was to place in perspective the analysis which yet needs to be done with that which has been completed under the present contract phase. The documentation of Item 3 is broken into three portions, Contract NAS 12-566 Statement of Work, a list of potential tasks for a continuing phase and a potential phase III. The phase II task listing is intended to satisfy the requirements of Item 3 above.

6.2 Phase I (NAS 12-566 Statement of Work)

The Hughes Aircraft Company shall supply the necessary personnel, facilities, services and materials to accomplish the work set forth below:

1. Apply and extend the mathematical analysis, the technical approach, and the supporting information generated under the two (2) referenced contracts of paragraph 2 above, to the specific Electronics Research Center requirements listed below:
   a. The mathematical analysis shall have a dual capability of providing management with a comprehensive technique for evaluating and selecting future research efforts and to provide the scientists with a detailed analysis of the value and effect of their specific research to overall space communication systems.

b. Extension of the present analytical model and corresponding computer program to include additional parameter stops, the necessary detection methods, and fixed value parameters. Deliverable items will include the analytical model and a computer implementation in the form of a FORTRAN IV printout and card deck.

c. The analytical model will be continually verified as best possible using experimental data such as that of Mariner IV.

d. The mathematical analysis must have a flexible input/output capability to optimize its utility to both management and the researchers and to fully exploit the latest technology of computer graphics and dynamic presentation.

e. The specific parameters for optimization by the mathematical analysis shall be determined to provide the maximum utilization by both management and the researchers.

f. A sensitivity analysis shall be performed concurrent with the primary mathematical analysis. The sensitivity of the systems response to each parameter variation is to be analyzed and, if possible, this sensitivity analysis is to be integrated into the mathematical model such that it will be an additional feature aiding in the identification of the most fruitful parameters upon which to work. Graphs of the effects of the more sensitive parameter variations will be included in a special report.

2. Investigation of an executive model will be done. The essential ingredients of this investigation will be tailoring the model to the equipment and personnel who will be making use of it. This requires substantial analysis of the variety of forms which the output might take. The steps required for implementation of the executive-decision making model will be delineated. This task will consist of examining a number of possible methods of implementation with appropriate recommendations included in the final contract report. A specific task will include the investigation of the desirability and the significant factors of remote computer applications in the control of the mathematical analysis, and determination of the

interface with a batch-type analysis. This investigation is to consider the following factors:

a. Technical management usage

b. Engineering and scientific usage

3. Evaluate and determine the follow-on mathematical analysis for the next generation of communication systems models with respect to the following factors:

   a. Optimization criteria

   b. Required degree of model versatility

   c. Identify the parameters and their rating of importance

   d. Determine the applicability and specifications for future remote and batch-type computer mathematical analyses.

6.3 Proposed Phase II

1. Model Refinement, Versatility

   The following items of model refinement and versatility apply to the existing deep space communications system analysis. In general, they add to, and build upon that which has already been documented and put to use.

   a. Inclusion of PPM

      Pulse position modulation (PPM) for laser communications represents an attractive implementation for transmitting data from deep space. This is due to the high efficiency of detectors available at frequencies where this type of modulation might be used (near IR and visible spectra) and the transmissivity of the atmosphere at these frequencies. In addition, this means of transmission is effective since all the energy of the laser beam, is transmitted in a very narrow time interval during which there is very little background radiation.

      The present COPS program is partially implemented to perform the type of communication analysis needed for PPM, in the subroutine known as SOPS. However, further refinement is needed to assure a true optimization is performed in this subprogram.

b. Documentation of Basic Program Mathematics

The basic concept used for deep space communication optimization programs have been partially documented in previous reports completed under contract NAS 5-9637. A complete documentation has not yet been made. Since a great deal of building has been done upon this foundation, it is felt wise that an adequate documentation be made such that future investigators may be able to follow the original derivations.

c. Visit Recognized Authorities to Check Burden Values

The burden values used are the result of literature searches and personal contacts of those who are recognized to have significant information on particular communication parameters. In order to have an "unbiased and agreed upon" set of parameters, it is proposed that a series of personal contacts be made to those in industry and NASA. Once these parameter values have been included in the present program, this program can be called upon to provide unbiased outputs.

d. Implement a Discrete Point Input Program

Burden relationships for the various communication parameters are presently represented by an equation describing their relationship against the given parameter. An alternate form of providing the burden data to the computer would be to provide discrete points relating burdens and the parameter value. This task would implement such an input program.

e. Program "As a Function of Frequency"

It is desirable to know the frequency relationship of various levels of performance in the communications optimization program. While it is not possible to represent such a program on a continuous frequency basis, due to the discrete limitations of certain parameter values, it may well be possible to represent many parametric relationships as a function of frequency and to express other frequency dependencies over a limited frequency range. This task will investigate these several possibilities.

f. Represent Parameter Burden by More Than Three Constants

The basic parameter burden relationship consists of expressing the burden in terms of a fixed constant, a multiplicative constant, and an exponential constant. This representation is undoubtedly an over-simplification in many of the parameter values. For instance, the acquisition and tracking weight is not a simple function of the diameter of the aperture used, for fine pointing and coarse pointing may provide accuracies which are relatively independent of their weight. The importance of representing parameters by more than three constants may be seen in the case of a rather complicated parameter such as, the cost of a large ground array. If a more representative burden model is made it may well show that one feature of the large array is a dominant feature in the overall burden. This would allow this isolated feature to be examined in greater detail before committing a large development effort to the complete receiving array. This task would analyze several parameter burden relationships.

g. Investigate Certain Promising Techniques

The sensitivity analysis completed during the first quarter of contract NAS 12-566 has shown several areas which are sensitive to inaccuracies of the burden constants. In addition, certain promising techniques have been proposed to implement various parameters. It is proposed that several of these be investigated further. Those technology areas to be investigated are: solid state microwave sources, antenna arrays, and power supplies.

2. Executive Model

Contract NAS 12-566 has developed an executive model for the existing program. This model is in the form of a simple user's handbook and batch computer processing (see Section 4.0). The proposed Phase II effort will include the following.

a. Develop a Specific Executive Model No. 1

Executive Model No. 1 is envisioned as the on-line remote teletypewriter used with the COPTRAN Program.

b. Develop a Specific Executive Model No. 2

The Executive Model No. 2 is envisioned as a means of using the deep space communications optimization program with greater facility than that developed in Executive Model No. 1. It is also expected that this model will be designed to be used in conjunction with a specialized console. Such a console will form the interface between a user, who is not familiar with computer programming or computer language, and the computer program.

c. Develop an Executive Check

The present computer program optimizes parameter values on the basis of minimizing the cost of the system or minimizing the weight of the spaceborne components. The cost optimization, in effect, provides the cost of developing a certain system. In many cases only relative cost values are important to the user. However, in many cases absolute values are of definite concern. It is recommended, therefore, that a method of checking these optimized values be determined. Such a method could be implemented by having a commercial company perform a pricing task for the check. Since this pricing is only a check and is not a bona fide request for proposal, it would be incumbent to have this clearly understood and have appropriate remuneration be made to the company making such a check.

3. Console for Executive/Computer Interface

The deep space communication optimization program represents a very complex and detailed computer implementation. It has been a major purpose of contract NAS 12-566 to enable a person with a minimal amount of computer implementation and user knowledge to use this analysis effectively to solve problems of direct interest. Some features of the executive model and model refinement have been previously mentioned. These include such features as implementation of discrete input points and the use of a simplified user's guide. There seems, however, a highly desirable step which may yet be taken. This step is that of implementing a specialized console with appropriate input and output displays and with appropriate controls to modify easily various parameter values. In addition, this console would enable any portion of the program (such as a particular burden relationship) to be recalled and be displayed appropriately. It is proposed that a design of such a console for executive/computer interface be included in the Proposed Phase II schedule.

4. Review Optimization Criteria

The present optimization criteria is one of weight optimization for spaceborne components or of cost optimization for the entire data link. Other criteria have been suggested but none have seemed immediately amenable to either the stated desires of the user or the present implementation of the optimization.

A proposed optimization criteria that may be useful is that of a reliability/cost interrelationship. Since reliability may always be increased by increasing cost, it, by itself, does not have an optimum value. However, by relating reliability to cost, an optimization may well be achieved which is meaningful both in view of the program and in view of the user's desires. A second factor which should be considered in the optimization review criteria task is that of expected response from the user during the first portion of the Proposed Phase II. Once users have begun to use the program they will undoubtedly request other types of criteria. These criteria suggestions will have to be evaluated for their general usage and worth to the overall objectives of the program. For these reasons this task has been included.

5. Deviation Analysis

The cost burden of individual parameter values has been delineated. If certain "stops" are included, the overall system cost has been found to increase as expected. A sample of this type of analysis has been given in the paper by Ross E. Graves titled "Techniques for Planning R&D for Deep Space Communications" and included as Appendix C of the Interim Technical Report of contract NAS 12-5'6. A similar type of analysis could be given on other parameter values to determine the relative merit of extending the state of the art these parameters. Such is the purpose of this task.

6.4 Potential Phase III

1. Study Antenna Arrays

   The implementation of large antenna arrays, whether they be flat arrays or parabolic dishes connected as arrays, is an extremely complicated task. It includes interrelationships of area and antenna temperature, as well as other technical and economic considerations. A detailed task description for the study of antenna arrays is presently being prepared. This will be forwarded to NASA-ERC by February 16, 1968.

2. Studies of Individual Parameter Representation

   This potential task represents an extension of a similar task mentioned in Task 1f of Proposed Phase II above. At the completion of the Proposed Phase II tasks, it is anticipated that further study of this nature would be in order.

3. Console for Executive/Computer Interface

   The purpose and general design concepts for a console for executive/computer interface has been described under Proposed Phase II Task 3 above. The purpose of the task being listed in Potential Phase III is that of actually constructing the console.

4. Develop Certain Components

   As a result of the deviation analysis (see Task 5 of Proposed Phase II) several components will undoubtedly be isolated as those whose further development would significantly extend the communication capability for deep space. It is proposed that these components then be developed in individual development efforts.

TABLE VI-I
ANALYSIS FOR DEEP SPACE COMMUNICATIONS

Phase I NAS 12-566	Proposed Phase II	Potential Phase III
1. <u>Extend Math Model</u> a. Method of evaluating and selecting future work b. Additional stops, detection, fixed values, deliver a FORTRAN deck c. Use actual experimental data d. Flexible input/output e. Optimization criteria f. Sensitivity analysis 2. <u>Investigate Executive Models</u> Look at possible output forms, list steps for getting an executive program. Recommended approach Investigate remote computer usage Investigate batch usage 3. <u>Evaluate Follow-on Math Analysis</u> a. Optimization criteria b. Model versatility required c. Parameters and their importance d. Applicability and specifications of future remote and batch analysis	1. <u>Model Refinement, Versatility</u> a. Inclusion of PPM (1.06, 0.84, 0.51μ) b. Documentation of basic mathematics c. Visit recognized authorities to check values used d. Implement discrete point input program e. Represent parameter burden by more than three constants f. Investigate certain promising techniques Solid state microwave sources Antenna arrays Power supplies 2. <u>Executive Model</u> a. Develop a specific executive model No. 1 b. Develop a specific executive model No. 2 c. Develop an executive model check 3. <u>Console for Executive/Computer Interface</u> Design a console for executive/computer interface for executive model No. 2 4. Review optimization criteria 5. Deviation Analysis – What it is worth to extend state of the art in certain technology areas ?	1. Study ground antenna arrays 2. Studies of individual parameter representation 3. Console for executive/computer interface 4. Develop certain components