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# MT's Algorithm: A New Algorithm to Search for the Optimum Set of Modulation Indices for Simultaneous Range, Command, and Telemetry Operations

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## ABSTRACT

MT's algorithm has been developed as an aid in the design of space telecommunications systems when utilized with simultaneous range/command/telemetry operations. This algorithm provides selection of modulation indices for: (1) suppression of undesired signals to achieve desired link performance margins and/or to allow for a specified performance degradation in the data channel (command/telemetry) due to the presence of undesired signals (interferers); and (2) optimum power division between the carrier, the range, and the data channel.

A software program, using this algorithm, has been developed for use with MathCAD software. This software program, called the MT program, provides the computation of optimum modulation indices for all possible cases that are recommended by the Consultative Committee on Space Data Systems (CCSDS) (with emphasis on the square-wave, NASA/JPL ranging system).

## ACKNOWLEDGMENTS

The author wishes to express his deep appreciation to Mr. W. L. Martin, Chairman of the Consultative Committee for Space Data Systems (CCSDS), Subpanel 1E, for his unflagging encouragement, support, and expert advice on ranging measurements; and to Mr. C. Westfall of the Spectrum Engineering Group for his expert advice on computer programming and his assistance in preparing Section 2.2. The author also wishes to thank Mr. W. Schwarz, Head of Section, Communication Techniques, German Space Operation Center (GSOC), Mr. F. W. Exter, GSOC, and Dr. M. Otter, European Space Operations Center, for their review of some of the computer programs presented in this report. Finally, the author wishes to thank Dr. R. De Gaudenzi for his careful review of this report.

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APPENDIXES (CONT'D)

# SECTION 1

## INTRODUCTION

The problem of selecting a set of modulation indices for optimum power division between the carrier, the range, and the data is of paramount importance to the designer. An optimum power division between carrier, data, and range will result in either a maximized distance over which the link will operate for a fixed power level, or the minimum power necessary for a fixed distance of transmission. In practice, the optimization of the simultaneous range/command/telemetry link is always desirable due to transmitter power limitations and possible interference from the ranging channel to the data channel. Maximum system efficiency will be attained by giving a required data bit rate, a desired ranging accuracy, required Signal-to-Noise ratio (SNR) in each channel, and a specified transmission system.

The purpose of this report is twofold: (1) to present the algorithm for selection of optimum modulation indices; (2) to describe the software program using MathCAD language for selection of modulation indices.

The report is subdivided into three remaining sections. Section 2 discusses the algorithm and flow chart for selection of modulation indices. Equations representing the calculation of the channel threshold requirements and the computation of the required ranging suppression relative to the data power level for a specified degradation in the data channel are included.

Section 3 describes the MT software program and contains a detailed explanation of how to use this software for selecting a proper set of optimum modulation indices. Included are instructions for how to run the MT program using MathCAD software.

Section 4 illustrates the hard copy of the MT program and demonstrator programs. The demonstrator programs include all the input parameters necessary to run the MT program for selecting the set of optimum modulation indices; the user supplies none.

## SECTION 2

## DESCRIPTION OF MT'S ALGORITHM

### 2.1. MT'S ALGORITHM

This section describes the sequence of instructions that search for the optimum set of modulation indices when simultaneous range/command/telemetry operations are employed. The theory behind this algorithm will not be discussed here, since it has been discussed elsewhere (Reference 1).

Step 1: Calculate the threshold requirements.

Threshold requirement for the carrier is:

$(SNR)_C$(dB-Hz) = PLL noise bandwidth, 2BLO (dB-Hz) + required operating threshold in 2BLO, $(SNR)_{2BLO}$ (dB)

Threshold requirement for the data channel is:

$(SNR)_D$(dB-Hz) = required bit SNR (Signal-to-Noise Ratio) to achieve a desired BER (Bit Error Rate), $E_b/N_o$ (dB) + $10.\log_{10}$(required bit rate, BR) + SNR degradation due to receiver hardware, $(SNR)_{\Delta D}$ (dB)

Threshold requirement for the ranging channel is:

$(SNR)_R$(dB-Hz) = ranging bandwidth (two-sided), $BW_R$ (dB-Hz) + required SNR in the specified bandwidth, $(SNR)_{BW}$ (dB) + SNR degradation due to ranging receiver hardware, $(SNR)_{\Delta R}$ (dB)

Step 2: Using the results from Step 1, calculate $A_1$ and $A_2$. Where $A_1$ and $A_2$ are given by:

$$A_1 = \frac{(SNR)_D}{(SNR)_C}$$

$$A_2 = \frac{(SNR)_D}{(SNR)_R}$$

Step 3: Specify the desired BER degradation $\Delta_D$(dB) in the data channel due to interference from the ranging channel, the required BER, $(SNR)_{REQ}$ and calculate the maximum ranging power level $P_I$(dB) which falls in the data channel.

Step 4: Calculate the ranging suppression, $\Delta_S$, relative to the data channel for the specified $\Delta_D$:

$$\Delta_S(\mathrm{dB}) = A_5(\mathrm{dB}) - [(SNR)_{REQ} + P_I(\mathrm{dB})]$$

Where

$$A_5(\mathrm{dB}) = 10.\log_{10}[10^{\{\Delta_D(\mathrm{dB})/10\}} - 1]$$

Step 5: Using the result from Step 4, calculate the design factor k:

$$k = \left[\frac{(SNR)_R}{(SNR)_D}\right] . \left[\frac{1}{\Delta_S}\right]$$

Step 6: Calculate $A_3$ and $A_4$. Check that k satisfies the condition $A_3 < k < A_4$. If this condition is not satisfied then we know that either too much power is being allocated to the data ($k > A_4$) or to the ranging channel ($k < A_3$) for the specified degradation $\Delta_D$. Where $A_3$ and $A_4$ are given by:

$$A_3 = \frac{(SNR)_R}{(SNR)_D} = \frac{1}{A_2}$$

$$A_4 = (SNR)_R$$

Step 7: For a particular modulation scheme, develop the expressions for the power in each channel as a function of the modulation indices.

Step 8: Using the expression:

$$\frac{P_D}{P_R} = k.A_2,$$

and the relation found in Step 7, plot the ranging modulation index as a function of the data modulation index. A specific set of modulation indices can now be obtained. Where,

$P_D$ = the recoverable power in the first-order sideband of the data channel (command or telemetry), and

$P_R$ = the recoverable power in the first-order sideband of the ranging signal.

Step 9: Find the values of the power ratios $(P_D/P_T)$ and $(P_R/P_T)$ corresponding to particular set of modulation indices; plot these power ratios as a function of the data modulation index in the same plot described in Step 8. Note that $P_T$ denotes the total transmitted power $(P_T = P_D + P_C + P_R)$.

Step 10: Solve

$$\frac{P_D}{P_C} \leq A_1$$

for the equality condition and bound the values of the modulation indices of the data and ranging channels, observing that these modulation indices are mutually dependent. Where,

$P_C$ = the power remaining in the carrier after phase modulation.

Step 11: Select the set of modulation indices for the data and ranging channels that correspond to the largest values of $(P_D/P_T)$ $(P_R/P_T)$ curves which satisfy the specified degradation $\Delta_D$, constraining these values to within the boundary set established in Step 10 above.

Step 12: Use this selected set of modulation indices in the computation of the communications link performance margins.

Step 13: Compare the calculated performance margins (from Step 12) with the required performance margins. If the calculated performance margins are greater than or equal to the required performance margins, then the set of modulation indices selected in Step 11 is indeed the optimum set. If not, go back to Step 3 and assign a new value for $\Delta_D$. Repeat all the above steps until a set of optimum modulation indices is found. It is possible that the optimum set of modulation indices does not exist for a given set of required performance margins. This means that the required performance margins will not be achieved under these threshold requirements.

The use of this set of modulation indices will: (1) achieve a specified performance degradation in the data channel due to the presence of undesired signals, (2) achieve a desired link performance margin, and (3) provide optimum power division between the carrier, the range, and the data channel.

## 2.2. SPECIFICATION OF MT'S ALGORITHM

The sequence of instructions that search for the optimum modulation indices described in Subsection 2.1 can be expressed in **pseudocode.** Pseudocode is a program design tool which is used frequently by professional programmers. It expresses the logic required in the solution of a problem using English-like phrases. This subsection will use both pseudocode and flowchart to specify the MT's algorithm.

The structure of the MT's algorithm can be mapped out by using a pseudocode, as follows:

**Begin**

Optimum-set-found := False;

**Read input data:** 2BLO, $(SNR)_{2BlO}$, BR (Bit Rate), $(SNR)_{\Delta D}$, $BW_R$ (BandWidth), $(SNR)_{BW}$, $(E_b/N_o)$, $(SNR)_{\Delta D}$;

**Repeat**

**Repeat**

Input a (desired/new) value for $\Delta_D$(dB);
Calculate the threshold requirements: $(SNR)_C$, $(SNR)_D$, $(SNR)_R$;
Calculate $A_1$, $A_2$, $A_3$, $A_4$;
Calculate the maximum ranging power level $P_I$ which falls in the data channel;
Calculate $A_5$;
Calculate ranging suppression $\Delta_S$;
Calculate the design factor K

**Until** $A_3 < K < A_4$;

Form the ratio $(P_D/P_R)$, the data power to the ranging power ratio;
Set $(P_D/P_R) = K.A_2$, and calculate the set of modulation indices that satisfies this relationship;
Output these sets of modulation indices;
Form the ratios $(P_D/P_T)$, $(P_R/P_T)$, the data power, and the ranging power to total transmitted power ratios, respectively;
Calculate $(P_D/P_T)$, $(P_R/P_T)$ using the values of modulation indices found from the previous step;

```
Output the set of modulation indices (mDo, mRo) that
maximizes (PD/PT), and (PR/PT);
Form the ratio (PD/PC), the data power to the carrier power
ratio;
Set (PD/PC) = A1 and solve for the upper bound value for the
data modulation index, mDB;
Output mDB;
Substitute mDB into (PD/PR) = K.A2 and solve for the upper
bound value for the ranging modulation index, mRB;
Output mDB, mRB;

If mDo < mDB and mRo < mRB then

  Output the selected set of modulation indices: (mDo, mRo)
Else

  Output the selected set of modulation indices: (mDB, mRB);

If there are no requirements on the link performance margins
then

  Begin

    Output the selected set of modulation indices as the
    optimum set of modulation indices;
    Optimum-set-found := True

  End

Else

  Begin

    Input the selected set of modulation indices;
    Input the required performance margins: CMReq (Required
    Carrier Margin), DMReq (Required Data Margin), RMReq
    (Required Ranging Margin);
    Calculate the performance margin for the carrier: CMc;
    Output the carrier performance margin, CMc;

    If CMc > CMReq then

      Begin

        Calculate the performance margin of the data: DMc;
        Output the data performance margin, DMc;

        If DMc > DMReq then

          Begin
```

```
                Calculate the performance margin for the
                range:RMc;
                Output the range performance margin, RMc;

                If RMc > RMReq then

                  Begin

                    Output the optimum set of modulation indices;
                    Optimum-set-found := True
                  End
              End
           End
       End
   Until optimum-set-found

End.
```

A drawing of this algorithm is illustrated in Figure 1. This flowchart shows the logic of the program to search for a set of modulation indices for simultaneous command/range/telemetry operations.

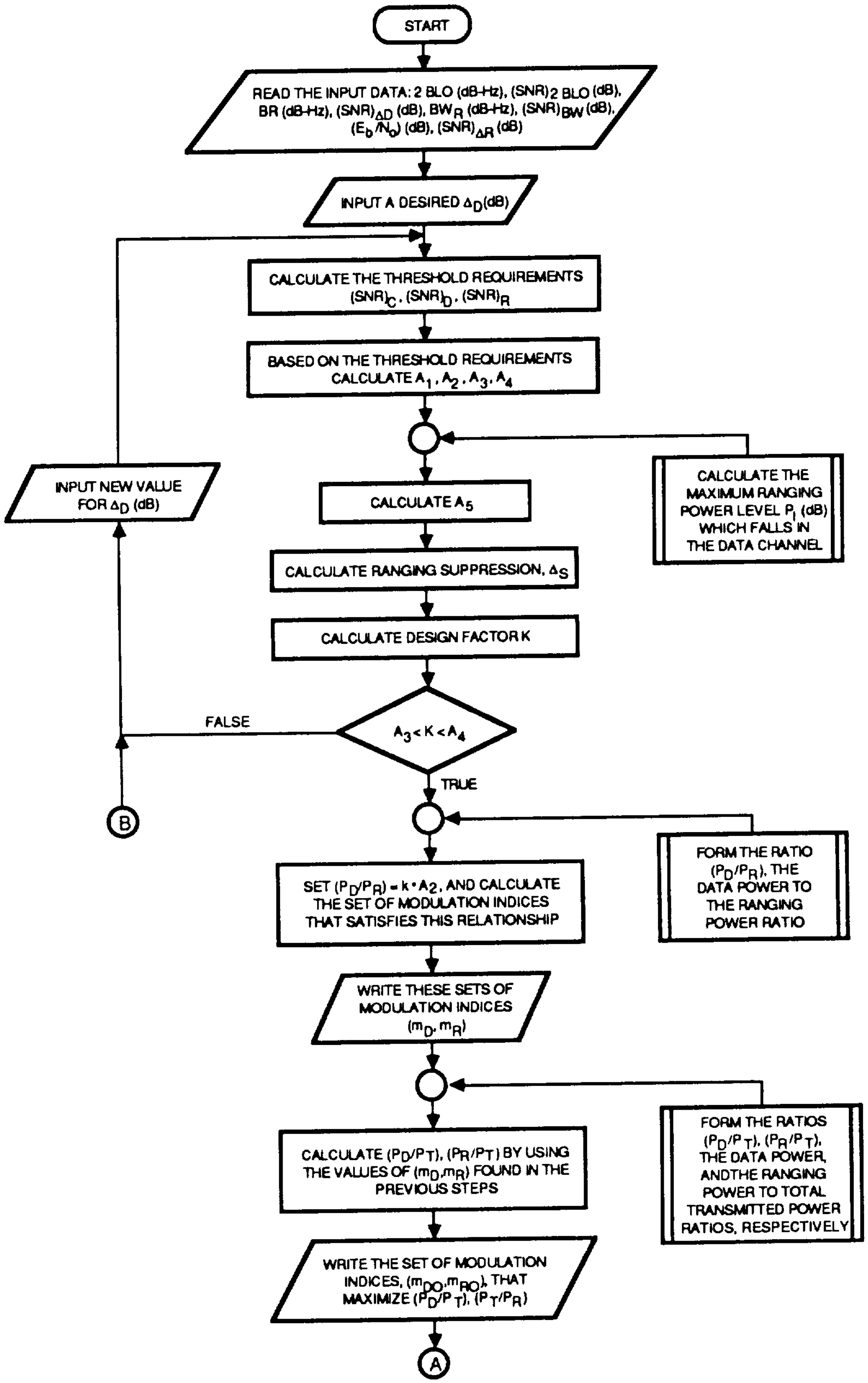
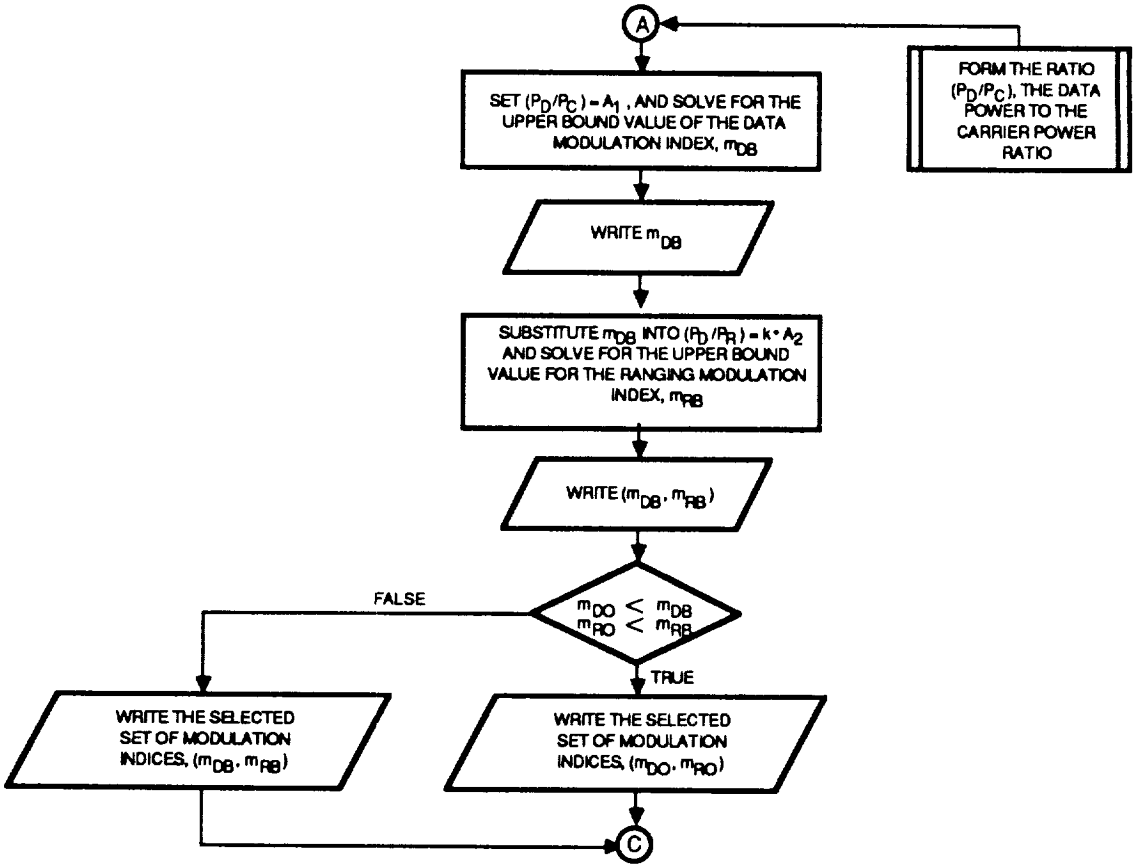



Figure 1. MT's Algorithm: an Algorithm to Search for a Set of Optimum Modulation Indices for Simultaneous Command/ Range/Telemetry Operations.




LEGEND:

| | |
|---|---|
| $(E_b/N_o)$ (dB) | = REQUIRED BIT SNR TO ACHIEVE A DESIRED BER IN dB |
| 2 BLO (dB-Hz) | = TWO-SIDED PLL NOISE BANDWIDTH IN dB-Hz |
| $(SNR)_{2\,BLO}$(dB) | = REQUIRED OERATING THRESHOLD IN dB |
| BR (dB-Hz) | = REQUIRED DATA BIT RATE IN dB-Hz |
| $(SNR)_{\Delta D}$ (dB) | = SNR DEGRADATION DUE TO RECEIVER HARDWARE IN dB |
| $BW_R$ (dB-Hz) | = RANGING BANDWIDTH IN dB-Hz (2-SIDED) |
| $(SNR)_{BW}$ (dB) | = REQUIRED RANGING SNR $BW_R$, EXPRESSED IN dB |
| $(SNR)_{\Delta R}$ (dB) | = SNR DEGRADATION DUE TO RANGING RECEIVER HARDWARE IN dB |
| $\Delta_S$ | = RANGING SUPPRESSION RELATIVE TO DATA POWER LEVEL IN dB |
| K | = DESIGN FACTOR |
| $\Delta_D$ (dB) | = DEGRADATION IN THE DATA CHANNEL DUE TO THE INTERFERENCE FROM THE RANGING CHANNEL |
| $m_D$ | = DATA CHANNEL MODULATION INDEX IN RADIAN |
| $m_R$ | = RANGING CHANNEL MODULATION INDEX IN RADIAN |
| $P_D$ | = THE RECOVERABLE POWER IN THE FIRST-ORDER SIDEBAND OF THE DATA CHANNEL |
| $P_R$ | = THE RECOVERABLE POWER IN THE FIRST-ORDER SIDEBAND OF THE RANGING CHANNEL |
| $P_T$ | = TOTAL TRANSMITTED POWER |
| $P_C$ | = THE RECOVERABLE POWER IN THE CARRIER CHANNEL |
| $CM_C$ | = CALCULATED CARRIER PERFORMANCE MARGIN |
| $DM_C$ | = CALCULATED DATA PERFORMANCE MARGIN |
| $RM_C$ | = CALCULATED RANGING MARGIN |
| $CM_{req}$ | = REQUIRED CARRIER PERFORMANCE MARGIN |
| $DM_{req}$ | = REQUIRED DATA PERFORMANCE MARGIN |
| $RM_{req}$ | = REQUIRED RANGING PERFORMANCE MARGIN |

Figure 1. (Cont'd)

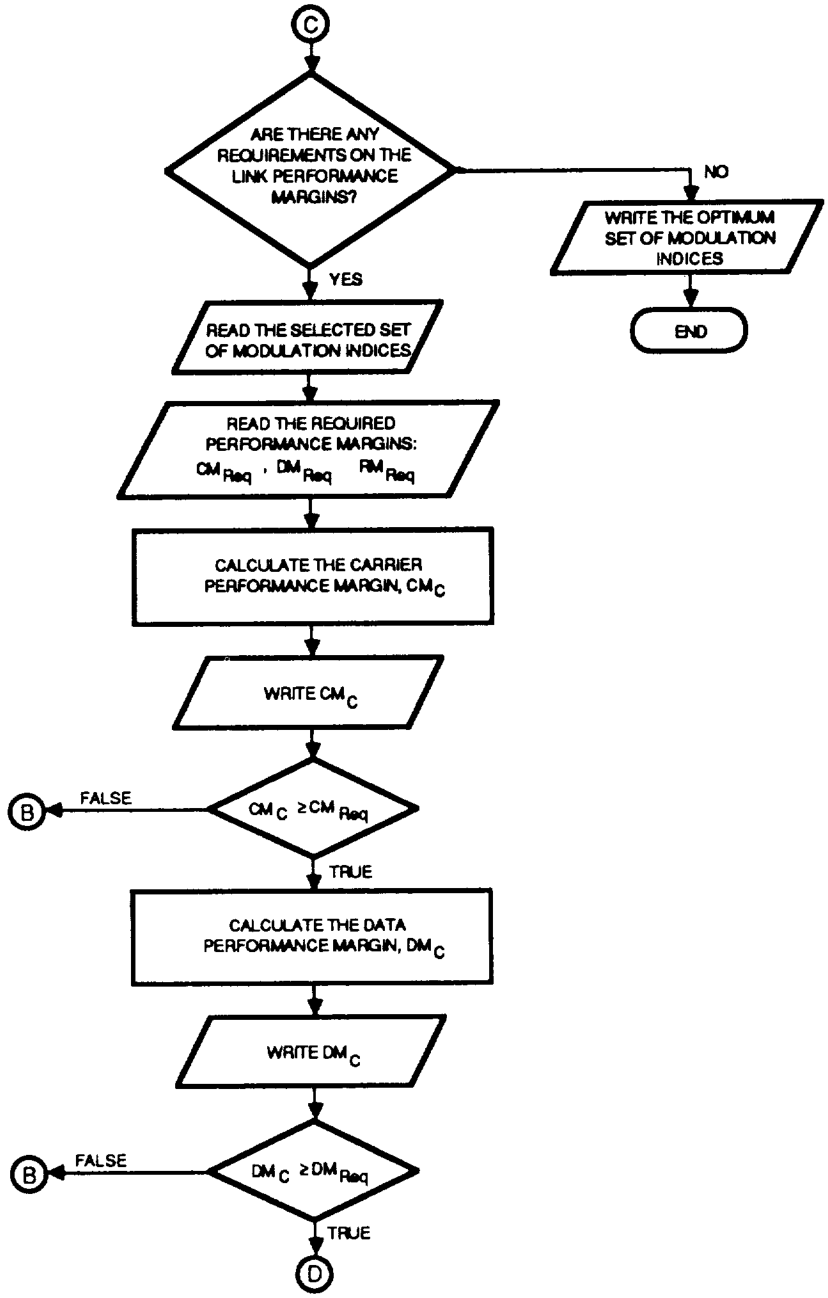



Figure 1. (Cont'd)

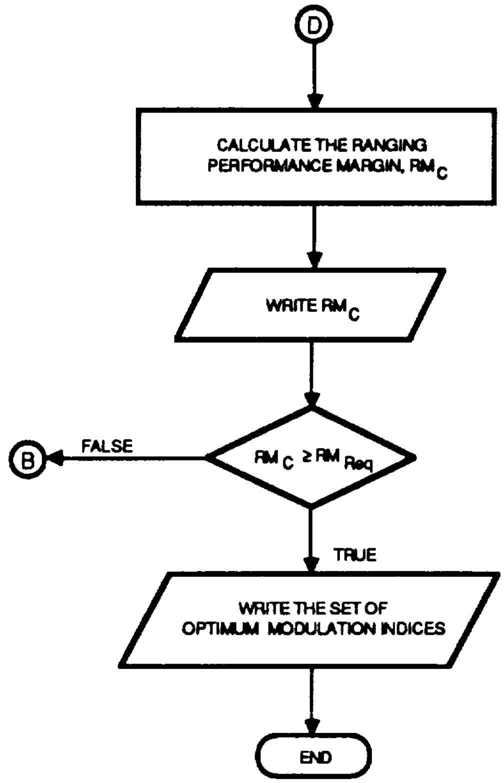



Figure 1. (Cont'd)

# SECTION 3

# DESCRIPTION OF THE MT SOFTWARE PROGRAM

## 3.1. INTRODUCTION AND CAPABILITIES OF THE MT SOFTWARE PROGRAM

The inherent problems in finding the optimum set of modulation indices are: (1) to solve the nonlinear equation found in Step 8; (2) to find the root of the nonlinear equation expressed in Step 10; and (3) to find the maximum points for the power curves described in Step 11. These nonlinear equations are comprised of Bessel and or trigonometric functions. Hence, they cannot be solved in closed form. One way to solve the equation in Step 8 is to assume the value of one modulation index and solve for the other. This process will yield corresponding pairs of modulation indices, and then use these pairs to look for the pair that maximizes the power curves described in Step 11. The Newton-Raphson method (Newton's method of tangents) can be used to approximate the root of the expression in Step 10. In addition to solving these complicated mathematical problems, the algorithm also required some engineering judgments on how-to-specify $\Delta_D$, the degradation in the data channel due to the presence of undesired signals. Thus, implementing this technique will require a computer language or software program that permits considerable interaction between the users and the computer, yet is friendly and powerful. A new software, the MathCAD software program, has all of these features. It is a new programming language that allows the user to interact with the formulas and the plots directly. This MathCAD software also has built-in functions and special features that can be used to solve and find the roots of the nonlinear equations. In addition to these, the MathCAD software can operate on personal computers such as IBM PC, XT, and AT, or compatibles, including the PS/2 series. It is these features that make the MathCAD software very attractive for implementing the MT's algorithm.

The MT program, using the MathCAD language, is completely interactive and user friendly due to the nature of the MathCAD software. There are seven subprograms contained in the MT software program. These subprograms provide the computation of modulation indices for both uplink and downlink, Categories A and B missions (for the definition of Categories A and B, see Reference 2). The NASA/JPL/DSN ranging system is taken in this software program for the computation of modulation indices. For the European Space Agency (ESA) ranging system, some modifications are needed due to different ranging wave-forms and ranging codes. Following is the list of the subprograms contained in the MT software program.

(1) UPSICMDN: Selection of modulation indices for the Uplink with the Sine-wave Command subcarrier, NASA/JPL ranging system (Square-wave ranging).

(2) DSICDONB: Selection of modulation indices for the Downlink with the Sine-wave Command subcarrier activated on the uplink, NASA/JPL ranging system, Category B missions.

(3) DSICDOFB: Selection of modulation indices for Downlink with the Sine-wave Command subcarrier turned Off on the uplink, NASA/JPL ranging system, Category B missions.

(4) DSICDONA: Selection of modulation indices for Downlink with the Sine-wave Command subcarrier activated on the uplink, NASA/JPL ranging system, Category A missions.

(5) DSICDOFA: Selection of modulation indices for Downlink with the Sine-wave Command subcarrier turned Off on the uplink, NASA/JPL ranging system, Category A missions.

(6) PINTBIPH: Computation of the maximum ranging Power level which falls into the telemetry data channel for Bi-Phase telemetry data modulated directly on the carrier with the command turned On.

(7) PINTSQSU: Computation of the maximum ranging Power level which falls into the telemetry data channel for both Square-wave and Sine-wave Subcarriers telemetry data PM modulated on the carrier with the command turned On.

There is, at the start of every subprogram, an interactive session where the MT program gathers the inputs necessary to compute the optimum modulation indices. This session makes the job of entering the input parameters as easy as possible. For instance, due to the nature of the MathCAD software, the inputs can be entered directly into the program by moving the cursor (using the arrow keys) directly beneath the input parameters that we wish to enter.

The first five MT subprograms listed above provide the computation and selection of the optimum modulation indices. These subprograms always consist of two distinct parts. The first part is the computation of modulation indices that maximize the power curves. The second part is the computation of the performance margins using the set of modulation indices found in the first part.

Each part consists of three distinct sessions. The first session is the interactive session, the user input data session. During this session the user inputs all parameter values necessary for the computation of optimum modulation indices.

The second session is the computation session. In this session, all of the calculation required for the selection of modulation indices is performed. The numerical results are displayed by using tables and plots. This allows the user to select a proper set of modulation indices to maximize the power contained in both the range and data channels.

The selection of modulation indices is presented in the last session. This session dictates how the user can choose a set of optimum modulation indices for a specific set of requirements.

The last two subprograms listed above provide computation of the maximum interference power that falls into the downlink telemetry data channel. This computation is required for the selection of the downlink modulation indices for (1) optimum power division between the carrier, the range, and the data channel; and (2) suppression of undesired signals to achieve a specified performance degradation in the data channel.

### 3.2. RUNNING THE MT PROGRAM

The MathCAD software is required in order to run the MT program. Load the MathCAD on your system. (See the MathCAD manual for instructions on how to install the MathCAD on your hard disk). This subsection describes how to run the MT program with the MathCAD installed on your hard disk. For floppy disk users, the procedure is slightly different. The users are referred to the MathCAD manual for instructions on how to run the MathCAD.

Before you run the MT program, you must change to the disk and directory containing the MathCAD program. Make sure you have installed MathCAD in the MCAD directory. At the DOS prompt, type (assuming the hard disk is identified by drive C):

```
C:\>CD MCAD
```

You are now in the MCAD directory, you can run the MCAD program. At the DOS prompt, type:

```
C:\MCAD>MCAD/M
```

If MathCAD can run on your system, you should see the "start up screen." You are now in the position to load the MT program. To load the MT program, press the load key, [F5]. Insert the MT program in disk drive A, and type:

A:\, then press the [Enter] key.

After you have pressed the [Enter] key, MathCAD shows a list of all the subprograms in the MT program. You can move the cursor up and down by using the arrow keys. **To select** a subprogram, move the cursor to the desired subprogram and press [Enter]. The screen now shows the MT subprogram that you wish to run. Note that all the initial input data are zeros. As indicated earlier, the first session of each subprogram is the interactive session, the user input data session. It is this session that you enter all the necessary input parameters required for the computation of modulation indices. **To enter** a desired value for a specified parameter, move the cursor to the initial value zero of that particular parameter and press the [Delete] key to erase the value zero before typing the desired input value. After all the required input parameters have been entered, you can press the [Esc] key and type in **"Automatic"** to **execute** the selected subprogram. It is important to note here that only the **"Arrow"** keys should be used while entering the input data. Any other keys used in moving the cursor may **destroy** the program. You can use the [Delete] key to erase the unwanted character or number when you accidentally press the undesired key. If something happens and the [Delete] key does not work, it is recommended that you clear the screen and reload the desired subprogram. To clear the screen, press the [Esc] key, then type **Clear**. To reload the program, again press the load key, [F5], and repeat the above steps.

After each run you can save the file by pressing the **save** key, [F6]. The last filename loaded (or saved) appears as the current filename. MathCAD uses this filename as a default. To save the document under the default filename, press [Enter] key. To save it under another name, hold down the [Backspace] key to erase the current filename and enter the new filename. MathCAD also allows you to print the results from the MT program. To print the results, type the following command:

[Esc] select [Enter].

This command allows you to select a printer type. After you have selected the printer, press the **print** key, [Ctrl]O (Control O). MathCAD responds to this key with a prompt for the print area. Since you wish to print only part of the program where the results are shown, you must specify these areas by editing the numbers on the message line. Use the arrow keys and the [Backspace] key to erase the numbers shown and enter new numbers that represent the upper left and lower right corners of the desired region to be printed. For more discussion on how-to-print a file, the user is referred to the MathCAD manual, Chapter 5.

The MT program is self-contained and self-explanatory. It is suggested that the user read all the instructions and notes in the MT program carefully. These instructions and notes describe in detail how to execute the program and select a proper set of modulation indices for optimum power division. It is also recommended that the user run the demonstrator programs before executing the MT program.

# SECTION 4

# HARD COPY OF THE MT PROGRAM AND DEMONSTRATOR SUBPROGRAMS

## 4.1. HARD COPY OF THE MT PROGRAM

This subsection presents the hard copy of the subprograms contained in the MT software program. As described earlier, the MT program consists of seven subprograms. These subprograms compute the optimum modulation indices for all possible cases that are recommended by the CCSDS. The hard copy of the MT program is shown in Appendix A.

## 4.2. DEMONSTRATOR SUBPROGRAMS

This subsection illustrates the capabilities of the MT program. Three demonstrator subprograms are supplied. They are: UPDEMO, DOWNDEMO, and PINTDEMO. These subprograms include all the parameter values necessary for computation and selection of the optimum modulation indices for both uplink (UPDEMO) and downlink (DOWNDEMO). To see how the optimum modulation indices are selected for the uplink, load the UPDEMO subprogram. The steps are:

1-Turn the system on.
2-Change the directory to MCAD.
3-Load the MCAD program by typing MCAD/M.
4-Load the MT program by typing the **load** key, [F5].
5-Insert the MT program in disk drive A and press [Enter] key.
6-Use the **arrow** key to move the cursor to UPDEMO and press [Enter].
7-The demonstrator program for the uplink is loaded. Use the **arrow** key to move the cursor and read the instruction in the program carefully. A hard copy of this demonstrator subprogram, UPDEMO, is shown in Appendix B.

After you have viewed the uplink demonstrator program for the selection of modulation indices, you can clear this by typing:

[Esc] clear [Enter]

This command will clear the UPDEMO program and start over with a blank screen. To load the DOWNDEMO (a demonstrator subprogram for the selection of modulation indices for the downlink) press the **load** key ([F5]) and repeat Steps 6 and 7 above. Notice that this program requires some input data (Ranging_Signal_to_noise_ratio, DELTA_S, Pint) from the uplink and PINT(BIPH or SQSU) subprograms. The input values for the Ranging_Signal_to_noise_ratio, DELTA_S and Pint used in this demonstrator program (DOWNDEMO) have been taken from the UPDEMO and PINTDEMO subprograms, respectively. To see where the value of DELTA_S comes from, move the cursor to the middle of the screen and then press the **split** key, [F7]. MathCAD splits the screen into two windows by creating a second message line at the current cursor position. The top window is the current subprogram, DOWNDEMO. The cursor now moves to the second window, where there is an empty screen. You can load the subprogram UPDEMO in this window by repeating Steps 4, 6, and 7 above. Since the computation for the parameter DELTA_S is on line 168 in this subprogram, you can move to this line by typing:

[Esc] goto 168 [Enter].

Now, you are on line 168 of the UPDEMO subprogram. To calculate the parameter DELTA_S, press **calculate** key, [F9], or type:

[Esc] automatic [Enter].

You can compare the value of DELTA_S in this subprogram (UPDEMO) with the one in the DOWNDEMO subprogram shown on the top window. They should be the same. You can check out the value for Ranging_Signal_to_noise_ratio. To check this value out, you can use the **switch** key, [F8], to move the cursor from one window to the other.

You can check the value for the parameter Pint in the DOWNDEMO subprogram by clearing the UPDEMO in the bottom window and loading the PINTDEMO subprogram. To do this, type:

[Esc] clear [Enter] [F5] [Enter].

You can load PINTDEMO by moving the cursor to this subprogram and pressing [Enter]. Again, you can repeat the above steps to check the values between the DOWNDEMO and PINTDEMO subprograms. They should be the same. After checking all these values, you can unsplit the screen to return to the DOWNDEMO subprogram. To do this, press the **unsplit** key, [Ctrl][F7]. The screen resumes to the DOWNDEMO; you can view this program by using the arrow keys and following the instructions described in the program. The hard copies of the DOWNDEMO and PINTDEMO are shown in Appendices C and D, respectively.

**NOTE**

The MT sofware program can be obtained from:

Mr. Martin L. Warren
CCSDS, Subpanel 1E Chairman
MS 303-402
Telephone (818) 354-5635

or

Tien Manh Nguyen
Jet Propulsion Laboratory
4800 Oak Grove Drive
MS-161-228
Pasadena, California 91109
Telephone (818) 354-1723/1826

The MathCAD software program can be obtained from

MathSoft, Inc.
One Kendall Square
Cambridge, MA 02139

or by telephoning 1-800-MathCAD (In MA: 617-577-1017).

## REFERENCES


[1] Nguyen, Tien Manh,"Technique to Select the Optimum Modulation Indices for Suppression of Undesired Signals for Simultaneous Range and Data Operations," Proceedings of IEEE-EMC, August 1988, Seattle, Washington. (Also published in NASA Tech Brief NPO 17535)

[2] Consultative Committee for Space Data Systems, Recommendations for Space Data System Standards, Radio Frequency and Modulation Systems, Part 1: Earth Stations and Spacecraft, CCSDS 401.0-B-1, January 1987, CCSDS Secretariat, Communications and Data Systems Division (Code TS), NASA, Washington, DC 20546, USA.

# APPENDIX A

## HARD COPY OF MT PROGRAM

## APPENDIX A.1

## MT SUBPROGRAM 1

UPSICMDN: This Subprogram Provides the Selection of Modulation Indices for the Uplink with Sine-Wave Command Subcarrier, NASA/JPL Ranging System (Square-Wave Ranging).

######## SELECTION OF MODULATION INDICES FOR OPTIMUM POWER DIVISION ##########
################ FOR SIMULTANEOUS RANGE/COMMAND OPERATIONS ###################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THIS PROGRAM HAS ASSUMED THAT (1) SQUARE-WAVE RANGING UPLINK, (2) SINE-WAVE SUBCARRIER FOR THE TELECOMMAND.

REFRENCE: TIEN MANH NGUYEN, "TECHNIQUE TO SELECT THE OPTIMUM MODULATION INDICES FOR SUPPRESSION OF UNDESIRED SIGNALS FOR SIMULTANEOUS RANGE AND DATA OPERATIONS," PROCEEDINGS OF IEEE-EMC, AUGUST 1988, SEATTLE, WASHINGTON. (ALSO PUBLISHED IN NASA TECH BRIEF NPO 17535.)

********************************INPUT DATA***********************************

```
ENTER PLL NOISE BANDWIDTH, TWO-BLO, EXPRESSED IN Hz:
TWO_BLO := 0

ENTER THE REQUIRED OPERATING THRESHOLD IN 2BLO, EXPRESSED IN dB:
REQUIRED_SNR_IN_TWO_BLO_dB := 0

ENTER THE REQUIRED BER:
BER := 0


ENTER THE REQUIRED COMMAND BIT RATE, EXPRESSED IN BPS:
BIT_RATE := 0

ENTER THE SIGNAL DEGRADATION DUE TO RECEIVER HARDWARE, EXPRESSED IN dB:
SNR_DEGRAD_DUE_TO_HARDWARE := 0

ENTER THE RANGING TRANSPONDER BANDWIDTH, EXPRESSED IN Hz:
BW := 0


ENTER THE REQUIRED SNR IN THE SPECIFIED RANGING TRANSPONDER BANDWIDTH, IN dB:
REQUIRED_SNR_IN_BW := 0

ENTER THE SIGNAL DEGRADATION DUE TO RANGING RECEIVER HARDWARE, IN dB:
LOSS_IN_RANG_CHANNEL := 0

ENTER THE DESIRED DEGRADATION IN THE DATA CHANNEL DUE TO THE
INTERFERENCE FROM THE RANGING CHANNEL, EXPRESSED IN dB:
DELTA_D_dB := 0

ENTER THE COMPONENT NUMBER OF CLOCK FREQUENCY, N:
N := 0

ENTER THE COMPONENT NUMBER BEING CHOPPED, M:
(NOTE THAT THIS NUMBER DEPENDS ON THE COMMAND SUBCARRIER FREQUENCY USED)
M := 0
```

ENTER THE SIDEBAND NUMBER OF COMPONENT BEING CHOPPED, K1:
K1 := 0

*******************************************************************************
*****************************END OF USER INPUTS*******************************

*********************PRESS ESCAPE AND THEN TYPE AUTOMATIC********************

**********************PRESS ESCAPE AND THEN TYPE GOTO 179********************

*************CALCULATE THE THRESHOLD REQUIREMENT FOR THE CARRIER*************

CALCULATE 2BLO IN dB:
TWO_BLO_dB_Hz := 10·log(TWO_BLO)
TWO_BLO_dB_Hz =

THE THRESHOLD REQUIRED FOR THE CARRIER IS:
SNRC_dB := TWO_BLO_dB_Hz + REQUIRED_SNR_IN_TWO_BLO_dB
SNRC_dB =

**************CALCULATE THE THRESHOLD REQUIREMENT FOR THE DATA**************

CALCULATE THE REQUIRED BIT SNR(dB) FOR A DESIRED BER:

$$\mathrm{BIT\_SNR} := \ln\left[(2\cdot\pi\cdot\mathrm{BER})^{1}\right]$$

BIT_SNR_dB := 10·log(BIT_SNR) - 0.24

THUS, THE REQUIRED BIT SNR, EXPRESSED IN dB IS:
BIT_SNR_dB =

CALCULATE THE REQUIRED BIT RATE, IN dB:
REQUIRED_BIT_RATE_dB_Hz := 10·log(BIT_RATE)
REQUIRED_BIT_RATE_dB_Hz =

THE THRESHOLD REQUIRED FOR THE COMMAND DATA CHANNEL IS:
SNRD_dB := BIT_SNR_dB + REQUIRED_BIT_RATE_dB_Hz + SNR_DEGRAD_DUE_TO_HARDWARE
SNRD_dB =

*********CALCULATE THE THRESHOLD REQUIREMENT FOR THE RANGING CHANNEL*********

CALCULATE THE RANGING TRANSPONDER BANDWIDTH IN dB:
RANGE_TRANSPONDER_BW_dB := 10·log(BW)
RANGE_TRANSPONDER_BW_dB =

THE THRESHOLD REQUIRED FOR THE RANGING CHANNEL IS:
SNRR_dB := RANGE_TRANSPONDER_BW_dB + REQUIRED_SNR_IN_BW + LOSS_IN_RANG_CHANNEL
SNRR_dB =

*****************CALCULATE THE CONSTANTS A1, A2, A3, A4, A5******************

CALCULATE A1, IN dB:
A1_dB := SNRD_dB - SNRC_dB
A1_dB =

CALCULATE A2, IN dB:
A2_dB := SNRD_dB - SNRR_dB
A2_dB =

CALCULATE A3, IN dB:
A3 := SNRR_dB - SNRD_dB
A3 =

CALCULATE A4, IN dB:
A4 := SNRD_dB
A4 =

CALCULATE A5, IN dB:

$$A5 := 10 \cdot \log\left[10^{\frac{DELTA\_D\_dB}{10}} - 1\right]$$

A5 =

***********CALCULATE THE MAXIMUM RANGING POWER LEVEL WHICH FALLS*************
***************************INTO THE DATA CHANNEL******************************

FOR THE NASA/DSN RANGING SYSTEM, THE MAXIMUM POWER LEVEL THAT CAN INTERFERE WITH THE COMMAND DATA CHANNEL IS GIVEN BY:

$$PI\_dB := 10 \cdot \log\left[8 \cdot \left[\frac{\tan\left[K1 \cdot \frac{\pi}{M+1}\right]}{K1 \cdot \pi}\right]^2\right]$$

PI_dB = (EXPRESSED IN dB)

******CALCULATE THE RANGING SUPPRESSION RELATIVE TO THE DATA POWER LEVEL******

DELTA_S_dB := A5 - (BIT_SNR_dB + PI_dB)
DELTA_S_dB =

*************************CALCULATE THE DESIGN FACTOR K************************

CALCULATE THE DESIGN FACTOR K:
DESIGN_FACT_K := SNRR_dB - SNRD_dB - DELTA_S_dB
DESIGN_FACT_K =

*************************CHECKING THE DESIGN FACTOR K************************

CHECK THE CONDITION: A3 < K < A4.
*-IF THIS CONDITION IS SATISFIED THEN PROCEED FURTHER.
*-IF NOT, GO BACK TO LINE 52 AND ASSIGN A NEW VALUE FOR DELTA_D_dB.
**TO GO BACK TO LINE 52 PRESS ESCAPE AND THEN TYPE GOTO 52.

DESIGN_FACT_K =

A3 = (IF K < A3, TOO MUCH POWER ALLOCATED TO THE RANGING)

A4 = (IF K > A4, TOO MUCH POWER ALLOCATED TO THE DATA)

######### NOTICE THAT BY LOOKING AT K, A3, A4 WE CAN SHIFT THE VALUE OF DELTA_D_dB TO A PROPER VALUE SO THAT THIS CONDITION CAN BE SATISFIED ########

*************PRESS [CTRL][PAGE DOWN] TO MOVE DOWN 80 % OF THE PAGE************

**********************CALCULATE THE MODULATION INDICES**********************

ENTER THE UPPER AND LOWER VALUES FOR THE RANGE OF MODULATION INDICES:
UPPER := 100 (MAXIMUM NUMBER OF POINTS ALLOWED IS 20, i.e UPPER-LOWER = 20)
LOWER := 120

m := UPPER ..LOWER (m DENOTES THE RANGE VARIABLE INDEX)

$$mc_m := \frac{m}{100}$$ (mc IS THE COMMAND MODULATION INDEX)

SET (PD/PR) = K.A2, AND CALCULATE THE SET OF MODULATION INDICES THAT SATISFY THIS RELATIONSHIP.

####### NOTE THAT PD IS THE RECOVERABLE POWER OF THE COMMAND CHANNEL, AND PR IS THE RECOVERABLE IN THE FIRST ORDER SIDEBAND OF THE RANGING CHANNEL #######

$$A6 := DESIGN\_FACT\_K + A2\_dB - 10 \cdot \log\left[\frac{\pi^2}{4}\right]$$

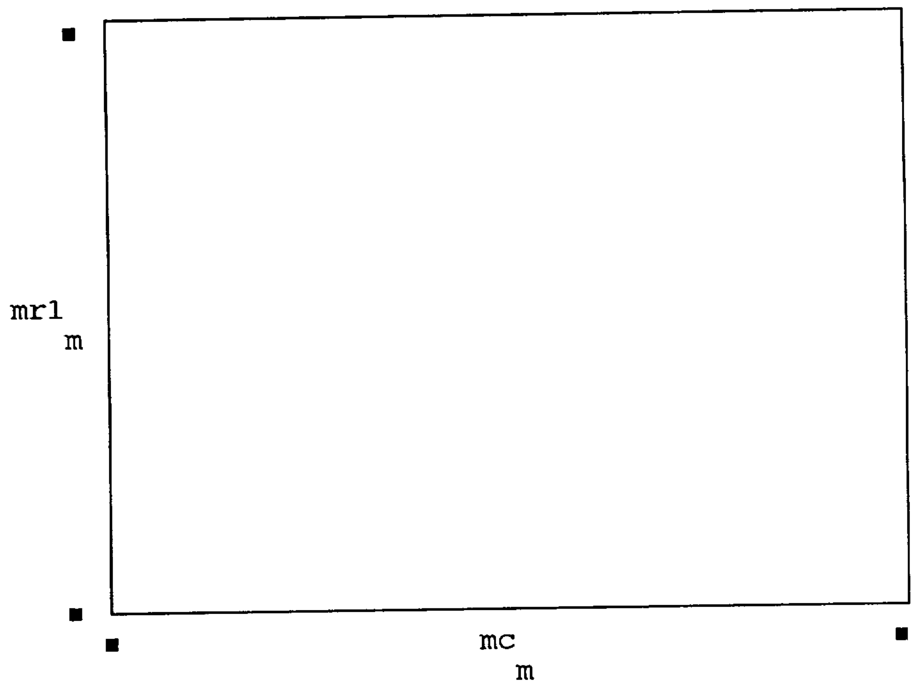
A6 =

$$A7_m := 20 \cdot \log\left[\frac{J1\left[mc_m\right]}{J0\left[mc_m\right]}\right] - A6$$

$$mr1_m := \operatorname{atan}\left[10^{\frac{A7_m}{20}}\right]$$ (mr1 IS THE UPLINK RANGING MODULATION INDEX)

PLOT OF THE SET OF MODULATION INDICES THAT SATISFIED (PD/PR) = K.A2

$mc_m =$ $\quad mr1_m =$




**************************CALCULATE THE POWER RATIOS************************

CALCULATE (PC/PT), (PD/PT), (PR/PT), (PLOSS/PT) FOR THE VALUES OF MODULATION INDICES FOUND IN THE PREVIOUS STEP.

THE POWER REMAINING IN THE CARRIER AFTER THE PHASE MODULATION IS:

$$PC\_OVER\_PT_m := \left[\cos\left[mr1_m\right] \cdot J0\left[mc_m\right]\right]^2$$

$$PC_m := 10 \cdot \log\left[PC\_OVER\_PT_m\right] \qquad \text{(EXPRESSED IN dB)}$$

THE RECOVERABLE POWER OF THE SINE-WAVE SUBCARRIER TELECOMMAND IS:

$$PCD\_OVER\_PT_m := 2 \cdot \left[\cos\left[mr1_m\right] \cdot J1\left[mc_m\right]\right]^2$$

$$PCD_m := 10 \cdot \log\left[PCD\_OVER\_PT_m\right] \qquad \text{(EXPRESSED IN dB)}$$

THE RECOVERABLE POWER IN THE FIRST ORDER SIDEBAND OF THE SQUARE-WAVE RANGING IS:

$$PR\_OVER\_PT_m := \frac{8}{\pi^2} \cdot \left[\sin\left[mr1_m\right] \cdot J0\left[mc_m\right]\right]^2$$

$$PR_m := 10 \cdot \log\left[PR\_OVER\_PT_m\right] \qquad \text{(EXPRESSED IN dB)}$$

THE POWER LOSS AFTER THE PHASE MODULATION IS:

$$PLOSS\_OVER\_PT_m := 1 - \left[PC\_OVER\_PT_m + PCD\_OVER\_PT_m + PR\_OVER\_PT_m\right]$$

$$PLOSS_m := 10 \cdot \log\left[PLOSS\_OVER\_PT_m\right] \qquad \text{(EXPRESSED IN dB)}$$

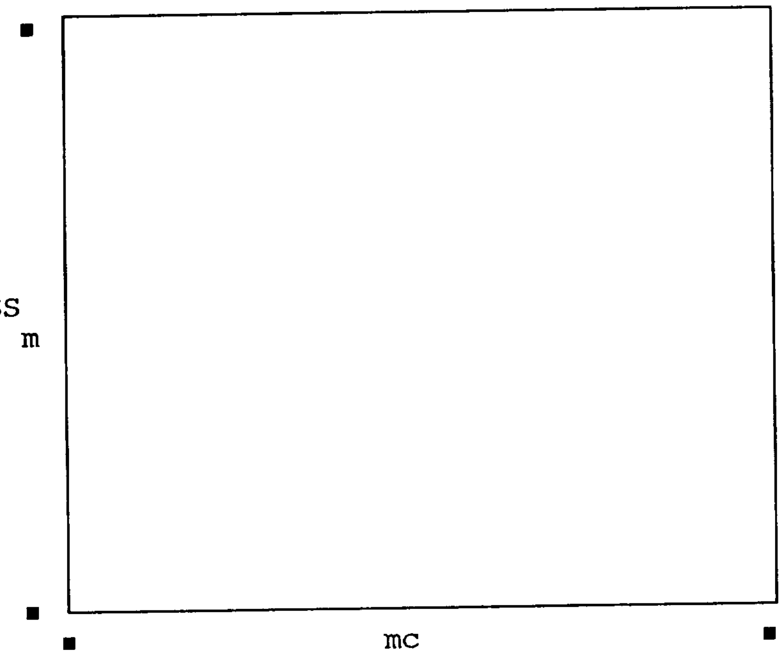
POWER RATIOS AS THE FUNCTION OF THE MODULATION INDICES FOUND IN PREVIOUS STEP:

$mc_m =$ $\quad mr1_m =$ $\quad PC_m =$ $\quad PCD_m =$ $\quad PR_m =$ $\quad PLOSS_m =$

**********************IT IS IMPORTANT TO READ THIS NOTE*******************
FROM THE ABOVE TABLE, THE SET OF MODULATION INDICES THAT MAXIMIZES THE POWER CURVES PCD, PR CAN BE FOUND. LET'S DENOTE THESE MODULATION INDICES AS mc(max) mr1(max). IF THE MAXIMUM POINT CAN NOT BE FOUND FOR THE GIVEN RANGE OF mc THEN GO BACK TO LINES 201, 202 AND CHANGE THE UPPER AND LOWER VALUES, RESPECTIVELY. TO DO THIS, PRESS ESCAPE KEY AND TYPE GOTO 201.
*************************************************************************

PLOT OF (PD/PT), (PR/PT), (PC/PT), (PLOSS/PT) VERSUS THE COMMAND MODULATION INDEX, mc, IN RADIAN

$PCD_m, PR_m, PC_m, PLOSS_m$

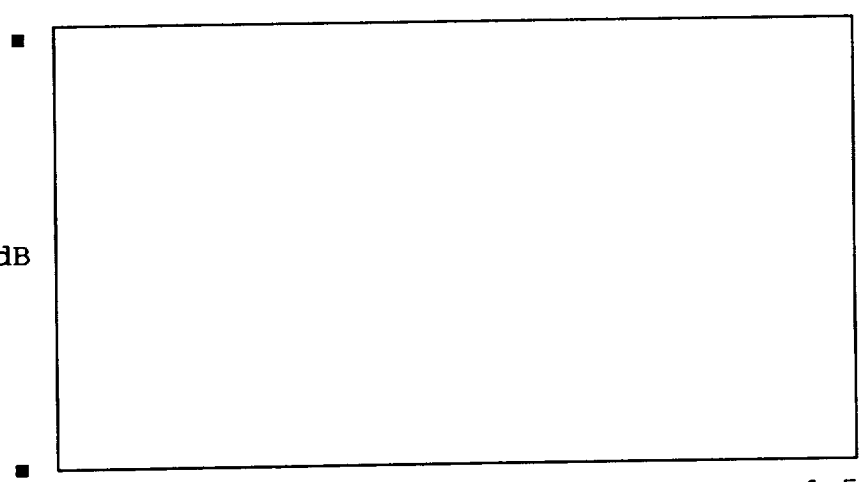



**************************CALCULATE THE UPPER BOUNDS***********************

CALCULATE THE UPPER BOUND FOR THE COMMAND MODULATION INDEX:

MC := 0.1,0.11 ..1.5

$$10 \cdot \log\left[2 \cdot \left[\frac{J1(MC)}{J0(MC)}\right]^2\right] - A1\_dB$$



FROM THE ABOVE PLOT, GUESS THE VALUE OF MC THAT GIVES THE ZERO VALUE ON THE Y-AXIS. THE GUESS VALUE IS:

$MC := .5$

$$mc\_BOUND := root\left[10 \cdot \log\left[2 \cdot \left[\frac{J1(MC)}{J0(MC)}\right]^2\right] - A1\_dB, MC\right]$$

UPPER BOUND FOR THE COMMAND MODULATION INDEX, IN RADIAN, IS:

mc_BOUND =

CALCULATE THE UPPER BOUND FOR THE RANGING MODULATION INDEX:

$$A7 := 20 \cdot \log\left[\frac{J1(mc\_BOUND)}{J0(mc\_BOUND)}\right] - A6$$

$$mr1\_BOUND := atan\left[10^{\frac{A7}{20}}\right]$$

UPPER BOUND FOR THE RANGING MODULATION INDEX, IN RADIAN:

mr1_BOUND =

**************************************************************************
**********************PRESS ESCAPE AND THEN TYPE MANUAL*********************

************************SELECTION OF MODULATION INDICES**********************

LET'S COMPARE THE MODULATION INDICES mc(max), mr1(max) WITH mc_BOUND AND mr1_BOUND.

**-IF mc_BOUND > mc(max), AND mr1_BOUND > mr1(max) THEN THE MODULATION INDICES THAT SHOULD BE SELECTED ARE:

mc(max), mr1(max).

**-IF mc_BOUND < mc(max), AND mr1_BOUND < mr1(max) THEN THE MODULATION INDICES THAT SHOULD BE SELECTED ARE:

mc_BOUND, mr1_BOUND.

***THE MODULATION INDICES SELECTED HERE WILL BE USED IN THE CALCULATION OF THE LINK PERFORMANCE MARGINS. IF THESE SELECTED MODULATION INDICES PROVIDE THE REQUIRED PERFORMANCE MARGINS THEN THIS SET OF MODULATION INDICES IS OPTIMUM UNDER THIS CONDITION. IF NOT, WE THEN COMPARE THE CALCULATED PERFORMANCE MARGINS WITH THE REQUIRED MARGINS AND DETERMINE WHETHER OR NOT WE CAN MAKE SOME ADJUSTMENTS IN THE POWER ALLOCATION TO THE COMMAND DATA, RANGE AND CARRIER. AS AN EXAMPLE, THE POWER ADJUSTMENT IS POSSIBLE IF THE CALCULATED COMMAND PERFORMANCE MARGIN IS MUCH LARGER THAN THE REQUIRED COMMAND MARGIN, AND THE CALCULATED RANGING MARGIN IS MUCH SMALLER THAN THE REQUIRED MARGIN. FOR THIS CASE MORE POWER SHOULD BE ALLOCATED TO THE RANGING THAN THE COMMAND DATA CHANNEL. THIS CAN BE DONE BY GOING BACK TO THE LINE 52 AND INCREASING THE VALUE OF DELTA_D_dB. AFTER MAKING THIS CHANGE, IT IS NECESSARY TO CHECK THE CONDITION IN LINE 181.

***IF THERE IS NO REQUIREMENT ON THE LINK PERFORMANCE MARGINS THEN THE MOULATION INDICES SELECTED HERE WILL BE OPTIMUM FOR: (1) THE GIVEN VALUE OF DELTA_D_dB, THE DEGRADATION IN THE COMMAND DUE TO INTERFERENCE FROM THE RANGING, (2) THE REQUIRED THRESHOLDS ON THE TELECOMMUNICATIONS LINK (WHICH ARE SPECIFIED IN THE INPUT DATA SECTION.)

********FINAL NOTE: THE CONDITION EXPRESSED IN LINE 181 IS VERY IMPORTANT.**** IT DICTATES HOW THE VALUE DELTA_D_dB CAN BE CHANGED WITHOUT GUESSING.
*******************************************************************************

*******************************************************************************

******************CALCULATION OF THE LINK PERFORMANCE MARGINS*****************

**********************************INPUT DATA**********************************

ENTER TOTAL TRANSMITTED POWER AT ANTENNA TERMINAL, Pt, EXPRESSED IN WATTS:

Pt := 0

ENTER TRANSMITTING CIRCUIT LOSS DUE TO CABLING, Lt, EXPRESSED IN dB:
Lt := 0

ENTER TRANSMITTING ANTENNA GAIN, Gt, EXPRESSED IN dBi:
Gt := 0

ENTER POINTING LOSS OF THE TRANSMITTING ANTENNA, Ltp, EXPRESSED IN dB:
Ltp := 0

ENTER THE TRANSMITTING FREQUENCY, Ft, EXPRESSED IN Hz:

Ft := 0

ENTER THE DISTANCE BETWEEN SPACECRAFT AND GROUND ANTENNA, R, EXPRESSED IN METER:

R := 0

ENTER ATMOSPHERIC ATTENUATION, La, EXPRESSED IN dB:
La := 0

ENTER POLARIZATION LOSS BETWEEN TRANSMITTING AND RECEIVING ANTENNAS, Lp, EXPRESSED IN dB:
Lp := 0

ENTER THE POINTING LOSS OF THE RECEIVING ANTENNA, Lrp, EXPRESSED IN dB:
Lrp := 0

ENTER RECEIVING ANTENNA GAIN, Gr, EXPRESSED IN dBI:
Gr := 0

ENTER RECEIVING CIRCUIT LOSS BETWEEN RECEIVING ANTENNA AND RECEIVER DUE TO CABLING, Lr, EXPRESSED IN dB:
Lr := 0

ENTER THE COMMAND MODULATION INDEX (FOUND IN THE PREVIOUS STEP), mc, EXPRESSED IN RADIANS:
mc := 0

ENTER THE RANGING MODULATION INDEX (FOUND IN THE PREVIOUS STEP), mr1, EXPRESSED IN RADIANS:
mr1 := 0

ENTER THE SYSTEM EQUIVALENT NOISE TEMPERATURE IN DEGREE OF KELVIN:
Teq := 0

ENTER OTHER LOSS IN THE CARRIER, Lc, EXPRESSED IN dB:
Lc := 0

ENTER OTHER LOSS IN THE DATA CHANNEL + DEGRADATION DUE TO RANGING CHANNEL, EXPRESSED IN dB:
Ld := 0

*******************************************************************************
********************************END OF USER INPUTS****************************

************************PRESS ESCAPE AND THEN TYPE AUTOMATIC*****************

**********************CALCULATE THE CARRIER PERFORMANCE MARGIN****************

THE NOISE SPECTRAL DENSITY, EXPRESSED IN dB, IS:

$No := -228.6 + 10 \cdot \log(Teq)$
No =

THE SPACE LOSS, Ls, EXPRESSED IN dB, IS:

$$Ls := 20 \cdot \log\left[3 \cdot \frac{10^{8}}{4 \cdot \pi \cdot R \cdot Ft}\right]$$

Ls =

THE TOTAL RECEIVED POWER, PR, EXPRESSED IN dB, IS:

$PR := 10 \cdot \log(Pt) + Lt + Gt + Ltp + Ls + La + Lp + Lrp + Gr + Lr$
PR =

THE MODULATION LOSS IN THE CARRIER, Lm, IS, EXPRESSED IN dB:

$PC\_OVER\_PT := (\cos(mr1) \cdot J0(mc))^{2}$

$Lm := 10 \cdot \log(PC\_OVER\_PT)$
Lm =

THE RECEIVED CARRIER POWER IS, EXPRESSED IN dB:

$Pc := PR + Lm$

THE CARRIER MARGIN IS, EXPRESSED IN dB:

$CM := Pc - TWO\_BLO\_dB\_Hz - REQUIRED\_SNR\_IN\_TWO\_BLO\_dB - No + Lc$

CM =

*****************************************************************************
COMPARE THE CALCULATED CARRIER MARGIN, CM, WITH THE REQUIRED CARRIER MARGIN, CMreq.

**IF CM >= CMreq THEN PROCEED FURTHER.

**IF CM < CMreq THEN GO BACK TO LINE 25 AND ENTER A NEW VALUE FOR DELTA_D.

**TO GO BACK TO LINE 52: PRESS ESCAPE AND THEN TYPE GOTO 52.
*****************************************************************************

*********************CALCULATE THE DATA PERFORMANCE MARGIN*******************

MODULATION LOSS IN THE DATA CHANNEL, Lmd, EXPRESSED IN dB, IS:

$$PCD\_OVER\_PT := 2 \cdot (\cos(mr1) \cdot J1(mc))^{2}$$

Lmd := 10· log(PCD_OVER_PT)
Lmd =

THE RECEIVED DATA POWER, Pd, EXPRESSED IN dB, IS:

Pd := PR + Lmd
Pd =

THE DATA PERFORMANCE MARGIN, DM, EXPRESSED IN dB, IS:

DM := Pd + Ld - BIT_SNR_dB - REQUIRED_BIT_RATE_dB_Hz - No

DM =

*****************************************************************************
COMPARE THE CALCULATED DATA MARGIN, DM, WITH THE REQUIRED DATA MARGIN, DMreq.

**IF DM >= DMreq THEN PROCEED FURTHER.

**IF DM < DMreq THEN GO BACK TO LINE 52 AND ENTER A NEW VALUE FOR DELTA_D.

**TO GO BACK TO LINE 52: PRESS ESCAPE AND THEN TYPE GOTO 52.
*****************************************************************************

*********************CALCULATE THE RANGING PERFORMANCE MARGIN****************

THE MODULATION LOSS IN THE RANGING CHANNEL, Lmr, EXPRESSED IN dB, IS:

$$PR\_OVER\_PT := (\sin(mr1) \cdot J0(mc))^{2}$$

Lmr := 10· log(PR_OVER_PT)
Lmr =

THE RECEIVED RANGING SIGNAL, Prg, EXPRESSED IN dB, IS:

Prg := PR + Lmr
Prg =

THE RANGING PERFORMANCE MARGIN, RM, EXPRESSED IN dB, IS:

RM := Prg - No - LOSS_IN_RANG_CHANNEL - 10· log(BW) - REQUIRED_SNR_IN_BW

RM =

*****************************************************************************
COMPARE THE CALCULATED RANGING MARGIN, RM, WITH THE REQUIRED RANGING MARGIN, RMreq.

**IF RM >= RMreq THEN THE SET OF MODULATION INDICES SELECTED BY THE PREVIOUS STEPS IS INDEED THE OPTIMUM SET UNDER THESE REQUIREMENTS.

**IF CM < MCreq THEN GO BACK TO LINE 52 AND ENTER A NEW VALUE FOR DELTA_D.

**TO GO BACK TO LINE 52: PRESS ESCAPE AND THEN TYPE GOTO 52.
*****************************************************************************

*****************************************************************************
END OF PROGRAM
*****************************************************************************

## APPENDIX A.2

### MT SUBPROGRAM 2

DSICDONB: This Subprogram Provides the Selection of Modulation Indices for the Downlink with Sine-Wave Command Subcarrier Activated on the Uplink, NASA/JPL Ranging System; Category B Missions.

######## SELECTION OF MODULATION INDICES FOR OPTIMUM POWER DIVISION ##########
############### FOR SIMULTANEOUS RANGE/TELEMETRY OPERATIONS ##################

################## TELECOMMAND IS ACTIVATED ON THE UPLINK ####################

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THIS PROGRAM HAS ASSUMED THAT (1) THE SQUARE WAVE RANGING UP-SINE WAVE RANGING DOWN, (2) SINE WAVE TELECOMMAND SUBCARRIER, (3) BI-PHASE TELEMETRY DATA MODULATED DIRECTLY ON THE CARRIER OR SQUARE-WAVE TELEMETRY SUBCARRIER PM MODULATED ON THE CARRIER, (4) POWER-CONTROL AGC IN THE RANGING TRANSPONDER.

********************************INPUT DATA************************************

ENTER THE RANGING SNR AT THE OUTPUT OF THE RANGING TRANSPONDER, NOT IN dB:
(IF THE UPLINK RANGING PERFORMANCE MARGIN IS GREATER THAN 0 dB, A VALUE OF 1 IS RECOMMENDED. THIS GIVES A ZERO dB RANGING SNR AT THE OUTPUT OF THE RANGING TRANSPONDER. IF IT IS LESS THAN O dB THEN ENTER THE REAL VALUE FOR THE RANGING PERFORMANCE MARGIN, RM. THIS VALUE CAN BE FOUND FROM THE UPLINK PROGRAM, CALCULATION OF THE UPLINK PERFORMANCE MARGINS, LINE 716.)
Ranging_Signal_to_noise_ratio := 0 (NOT EXPRESSED IN dB)

ENTER THE RANGING SUPPRESSION IN RELATION TO THE COMMAND DATA CHANNEL:
(THIS VALUE CAN BE FOUND FROM THE UPLINK PROGRAM, LINE 168)
DELTA_S := 0 (EXPRESSED IN dB)

ENTER THE PLL NOISE BANDWIDTH, TWO-BLO, EXPRESSED IN Hz:
TWO_BLO := 0

ENTER THE REQUIRED THRESHOLD IN 2BLO, EXPRESSED IN dB:
THRESHOLD_IN_TWO_BLO := 0

ENTER THE REQUIRED BER:
BER := 0

ENTER THE CODING GAIN, IF THERE IS ANY, EXPRESSED IN dB:
CODING_GAIN := 0

ENTER THE REQUIRED BIT RATE, EXPRESSED IN BPS:
BIT_RATE := 0

ENTER THE SIGNAL DEGRADATION DUE TO RECEIVER HARDWARE, EXPRESSED IN dB:
LOSS_DUE_HARDWARE := 0

ENTER THE DESIRED RECEIVED RANGING SNR IN THE REQUIRED EFFECTIVE BANDWIDTH, EXPRESSED IN dB:
RANGING_SNR_IN_BW := 0

ENTER THE LOSS DUE TO RANGING RECEIVER, EXPRESSED IN dB:
LOSS_RANGE := 0

ENTER THE REQUIRED INTEGRATION TIME FOR A GIVEN RANGING ACCURACY AT THE DESIRED RECEIVED RANGING SNR, EXPRESSED IN SEC:
Ti := 0

ENTER -1 IF THE DATA IS BI-PHASE MODULATED, AND 1 IF THE DATA IS SQUARE-WAVE MODULATED:
U := 0

ENTER THE DESIRED DEGRADATION IN THE TELEMETRY DATA CHANNEL DUE TO THE INTERFERENCE FROM THE RANGING CHANNEL, EXPRESSED IN dB:
$\delta D := 0$

ENTER THE MAXIMUM RANGING POWER LEVEL WHICH FALLS INTO THE TELEMETRY DATA CHANNEL, EXPRESSED IN dB:
(THIS VALUE CAN BE FOUND FROM THE PROGRAM PINTBIPH.MCD OR PINTSQSU.MCD)
Pint := 0

*******************************************************************************
***************************** END OF USER INPUTS *****************************

*********************PRESS ESCAPE AND THEN TYPE AUTOMATIC********************

**********************PRESS ESCAPE AND THEN TYPE GOTO 281********************

****CALCULATE THE TOTAL RANGING SNR AT THE INPUT TO THE RANGING TRANSPONDER***

THE TOTAL RANGING SNR AT THE INPUT OF THE RANGING TRANSPONDER IS:

$$\text{alphaR} := \frac{\pi^2}{8} \cdot (\text{Ranging\_Signal\_to\_noise\_ratio})$$

alphaR = (NOT EXPRESSED IN dB)

***************CALCULATE THE TOTAL COMMAND POWER-TO-NOISE RATIO**************

THE TOTAL COMMAND POWER-TO-NOISE RATIO, NOT EXPRESSED IN dB, IS:

$$\text{alphaC} := 0.5 \cdot 10^{\frac{-\text{DELTA\_S}}{10}} \cdot (\text{Ranging\_Signal\_to\_noise\_ratio})$$

*********CALCULATE THE CONSTANT BETA, THE GAIN COEFFICIENT DUE TO AGC*********

$$\text{beta} := 2 \cdot \text{alphaC} + \frac{8 \cdot \text{alphaR}}{\pi^2} + 1$$

beta =

*****CALCULATE THE "AMPLITUDES" OF THE COMMAND, RANGING SIGNALS AND NOISE*****
*******************COMPONENTS AT THE OUTPUT OF THE AGC**********************

$$alpha1p := 2 \cdot \sqrt{\frac{alphaC}{beta}}$$

alpha1p =

$$alpha2p := \frac{4}{\pi} \cdot \sqrt{\frac{alphaR}{beta}}$$

alpha2p =

$$alpha3p := \frac{1}{\sqrt{beta}}$$

alpha3p =

*****CALCULATE THE EFFECTIVE MODULATION INDICES FOR THE RANGING SIGNAL,******
*********THE COMMAND AND THE NOISE COMPONENTS IN THE RANGING CHANNEL*********

ENTER THE UPPER AND LOWER VALUES:
UPPER := 25 (MAXIMUM 20 POINTS, i.e. UPPER VALUE - LOWER VALUE = 20)
LOWER := 45

m := UPPER ..LOWER

$$mr2_m := \frac{m}{100}$$ (mr2 IS THE DOWNLINK RANGING MODULATION INDEX)

$$alpha1_m := alpha1p \cdot mr2_m$$

$$alpha2_m := alpha2p \cdot mr2_m$$

$$alpha3_m := alpha3p \cdot mr2_m$$

alpha1p =

alpha2p =

alpha3p =

*************CALCULATE THE THRESHOLD REQUIREMENT FOR THE CARRIER************

CALCULATE THE PLL NOISE BANDWIDTH, IN dB:
TWO_BLO_dB := 10· log(TWO_BLO)
TWO_BLO_dB =

THE THRESHOLD REQUIRED FOR CARRIER, IN dB, IS:
SNR_C := TWO_BLO_dB + THRESHOLD_IN_TWO_BLO
SNR_C =

**************CALCULATE THE THRESHOLD REQUIREMENT FOR THE DATA**************

CALCULATE THE REQUIRED BIT SNR(dB) FOR A DESIRED BER:

$$\mathrm{BIT\_SNR} := \ln\left[(2\cdot\pi\cdot \mathrm{BER})^{-1}\right]$$

BIT_SNR_dB := 10· log(BIT_SNR) - 0.24

THUS, THE REQUIRED BIT SNR, EXPRESSED IN dB IS:
BIT_SNR_dB =

CALCULATE THE BIT RATE, IN dB:
BIT_RATE_DB := 10· log(BIT_RATE)
BIT_RATE_DB =

THE THRESHOLD REQUIRED FOR THE TELEMETRY CHANNEL, EXPRESSED IN dB, IS:
SNR_TLM := BIT_RATE_DB + BIT_SNR + LOSS_DUE_HARDWARE - CODING_GAIN
SNR_TLM =

*********CALCULATE THE THRESHOLD REQUIREMENT FOR THE RANGING CHANNEL*********

CALCULATE THE EFFECTIVE RANGING BANDWIDTH, Hz:

$$\mathrm{EFFECTIVE\_BW} := \frac{1}{\mathrm{Ti}}$$

EFFECTIVE_BW =

CALCULATE THE EFFECTIVE BANDWIDTH, IN dB:
BW := 10· log(EFFECTIVE_BW)

THE THRESHOLD REQUIRED FOR THE RANGING CHANNEL, EXPRESSED IN dB, IS:
SNR_RANGE := RANGING_SNR_IN_BW + BW + LOSS_RANGE
SNR_RANGE =

******************CALCULATE THE CONSTANTS A1, A2, A3, A4******************

CALCULATE A1, IN dB:
A1 := SNR_TLM - SNR_C
A1 =

CALCULATE A2, IN dB:
A2 := SNR_TLM - SNR_RANGE
A2 =

CALCULATE A3, IN dB:
A3 := SNR_RANGE - SNR_TLM
A3 =

CALCULATE A4, IN dB:
A4 := SNR_RANGE
A4 =

******CALCULATE THE RANGING SUPPRESSION RELATIVE TO THE DATA POWER LEVEL******

$$\delta s := 10 \cdot \log\left[10^{\frac{\delta D}{10}} - 1\right] - (\mathrm{BIT\_SNR} - \mathrm{CODING\_GAIN} + \mathrm{Pint})$$

$\delta s$ =

************************CALCULATE THE DESIGN FACTOR K2**********************

K2 := SNR_RANGE - SNR_TLM - $\delta s$

K2 =

************************CHECKING THE DESIGN FACTOR K2***********************

CHECK THE CONDITION: A3 < K2 < A4.
*-IF THIS CONDITION IS SATISFIED THEN PROCEED FURTHER.
*-IF NOT, GO BACK TO LINE 70 AND ASSIGN A NEW VALUE FOR $\delta D$.
**-TO GO BACK TO LINE 70: PRESS ESCAPE AND THEN TYPE GOTO 70.

K2 =

A3 = (IF K2 < A3, TOO MUCH POWER ALLOCATED TO THE RANGING)

A4 = (IF K2 > A4, TOO MUCH POWER ALLOCATED TO THE DATA)

######### NOTICE THAT BY LOOKING AT K2, A3, A4 WE CAN SHIFT THE VALUE OF DELTA_D dB TO A PROPER VALUE SO THAT THIS CONDITION CAN BE SATISFIED ########

************PRESS [CTRL][PAGE DOWN] TO MOVE DOWN 80 % OF THE PAGE************

**********************CALCULATE THE MODULATION INDICES***********************

SET (Ptlm/Pr) = K2.A2, AND CALCULATE THE SET OF MODULATION INDICES THAT SATISFY THIS RELATIONSHIP.

################ NOTE THAT Ptlm IS THE RECOVERABLE POWER OF THE TELEMETRY CHANNEL, AND Pr IS THE RECOVERABLE POWER OF THE RANGING CHANNEL ############

$$C := K2 + A2 - 10 \cdot \log(0.5)$$

$$C =$$

$$D_m := 20 \cdot \log\left[\frac{J0\left[alpha1_m\right]}{J1\left[alpha1_m\right]}\right]$$

$$A_m := \frac{C - D_m}{20}$$

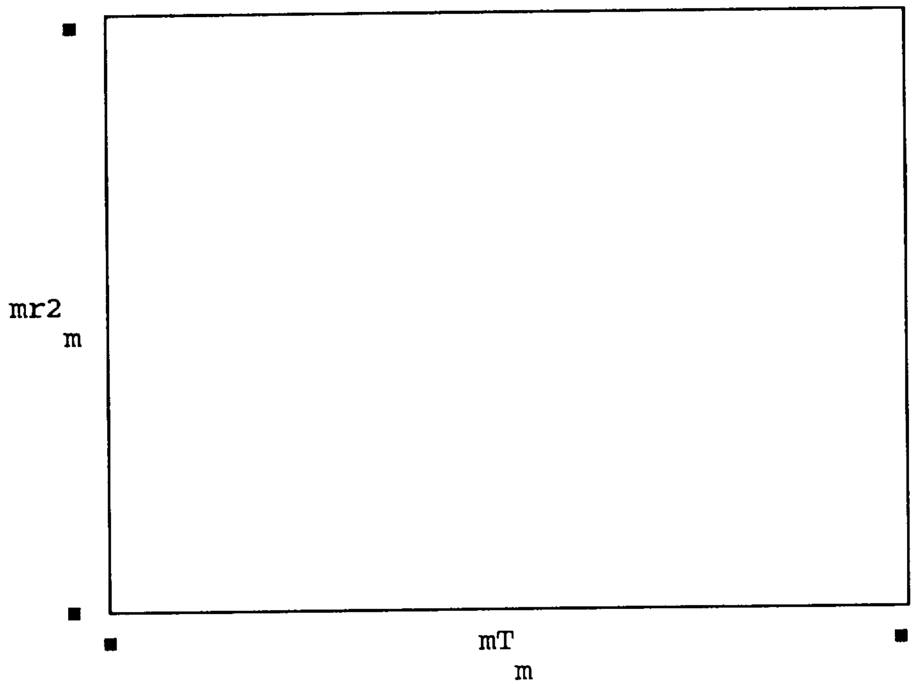
$$mT_m := \operatorname{atan}\left[10^{A_m}\right]$$ (mT IS THE TELEMETRY MODULATION INDEX)

******************************************************************************

*******************PRESS [CTRL][Page Down] TO SEE THE PLOT OF*****************
*******************RANGING MODULATION INDEX, mr2, VERSUS WITH*****************
**********************THE TELEMETRY MODULATION INDEX, mT********************

PLOT OF RANGING MODULATION INDEX, mr2, VERSUS THE TELEMETRY MODULATION INDEX, mT

$mr2_m =$ $mT_m =$




***************************CALCULATE THE POWER RATIOS*************************

CALCULATE THE POWER RATIOS (Pcd/Pt), (Ptlm/Pt), (Prange/Pt), (Pc/Pt), (Ploss/Pt) USING THE VALUES OF MODULATION INDICES FOUND IN PREVIOUS STEP.

$$E_m := \exp\left[-alpha3_m^{\,2}\right]$$

THE POWER REMAINING IN THE CARRIER AFTER THE PHASE MODULATION IS:

$$Pc\_over\_Pt_m := \left[J0\left[alpha1_m\right] \cdot J0\left[alpha2_m\right] \cdot \cos\left[mT_m\right]\right]^2 \cdot E_m$$

$$Pc_m := 10 \cdot \log\left[Pc\_over\_Pt_m\right]$$ (EXPRESSED IN dB)

THE RECOVERABLE POWER OF THE COMMAND IN THE DOWNLINK SIGNAL IS:

$$Pcd\_over\_Pt_m := 2 \cdot \left[J1\left[alpha1_m\right] \cdot J0\left[alpha2_m\right] \cdot \cos\left[mT_m\right]\right]^2 \cdot E_m$$

$$Pcd_m := 10 \cdot \log\left[Pcd\_over\_Pt_m\right]$$ (EXPRESSED IN dB)

THE RECOVERABLE POWER OF THE TELEMETRY SIGNAL IN THE DOWNLINK SIGNAL IS:

$$Ptlm\_over\_Pt_m := \left[J0\left[alpha1_m\right] \cdot J0\left[alpha2_m\right] \cdot \sin\left[mT_m\right]\right]^2 \cdot E_m$$

$$Ptlm_m := 10 \cdot \log\left[Ptlm\_over\_Pt_m\right]$$ (EXPRESSED IN dB)

THE RECOVERABLE POWER IN THE FIRST ORDER SIDEBAND OF THE SQUARE-WAVE RANGING IN THE DOWNLINK IS:

$$Prange\_over\_Pt_m := 2 \cdot \left[J0\left[alpha1_m\right] \cdot J1\left[alpha2_m\right] \cdot \cos\left[mT_m\right]\right]^2 \cdot E_m$$

$$Prange_m := 10 \cdot \log\left[Prange\_over\_Pt_m\right]$$ (EXPRESSED IN dB)

THE POWER LOSS AFTER THE PHASE MODULATION IS:

$$Ploss\_N_m := 1 - \left[Pc\_over\_Pt_m + Pcd\_over\_Pt_m + Ptlm\_over\_Pt_m + Prange\_over\_Pt_m\right]$$

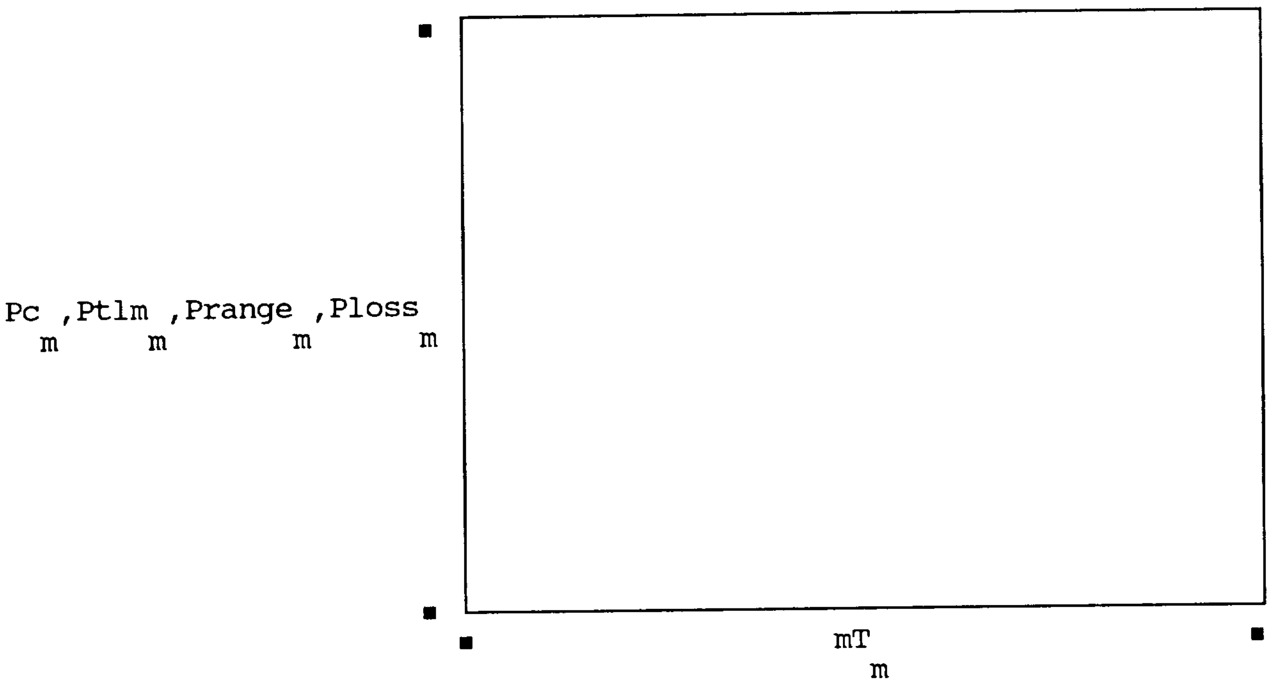
$$Ploss_m := 10 \cdot \log\left[Ploss\_N_m\right]$$ (EXPRESSED IN dB)

POWER RATIOS AS THE FUNCTION OF THE MODULATION INDICES FOUND IN PREVIOUS STEP:

$mr2_m =$ $mT_m =$ $Pc_m =$ $Ptlm_m =$ $Prange_m =$ $Ploss_m =$

***********************IT IS IMPORTANT TO READ THIS NOTE********************
FROM THE ABOVE TABLE, THE SET OF MODULATION INDICES THAT MAXIMIZES THE POWER CURVES Ptlm, Prange CAN BE FOUND. LET'S DENOTE THESE MODULATION INDICES AS mT(max), mr2(max). IF THE MAXIMUM POINT CAN NOT BE FOUND FOR THE GIVEN RANGE OF mr2 THEN GO BACK TO LINES 152, 153 AND CHANGE THE UPPER AND LOWER VALUES, RESPECTIVELY. TO DO THIS, PRESS ESCAPE KEY AND TYPE: GOTO 152.
*****************************************************************************

PLOT OF (Pc/Pt), (Ptlm/Pt), (Prange/Pt), (Ploss/Pt) VERSUS THE TELEMETRY MODULATION INDEX, mT, IN RADIAN




**************************CALCULATE THE UPPER BOUNDS************************

THE UPPER BOUND FOR THE TELEMETRY MODULATION INDEX, mT-bound, IS:

$$\text{mT\_bound} := \operatorname{atan}\left[10^{\frac{A1}{20}}\right]$$

mT_bound = (EXPRESSED IN RADIAN)

CALCULATE THE UPPER BOUND FOR THE RANGING MODULATION INDEX, mr2-bound.

CALCULATE THE ROOT OF EQUATION (Ptlm/Pr) = K2*A2:

ENTER THE GUESS VALUE FOR THE RANGING MODULATION INDEX, mr2-g, IN RADIAN:
mr2_g := .1

$$\text{mr2\_bound} := \operatorname{root}\left[20\cdot\log\left[\frac{J0(\text{alpha1p}\cdot\text{mr2\_g})}{J1(\text{alpha1p}\cdot\text{mr2\_g})}\right] - C + 20\cdot\log(\tan(\text{mT\_bound})),\text{mr2\_g}\right]$$

mr2_bound =

**************************************************************************************
**********************PRESS ESCAPE AND THEN TYPE MANUAL*********************

***********************SELECTION OF MODULATION INDICES**********************

LET'S COMPARE THE MODULATION INDICES mT(max), mr2(max) WITH mT_bound AND mr2_bound.

**-IF mT_bound > mT(max), AND mr2_bound > mr2(max) THEN THE MODULATION INDICES THAT SHOULD BE SELECTED ARE:

mT(max), mr2(max).

**-IF mT_bound < mT(max), AND mr2_bound < mr2(max) THEN THE MODULATION INDICES THAT SHOULD BE SELECTED ARE:

mT_bound, mr2_bound.

***THE MODULATION INDICES SELECTED HERE WILL BE USED IN THE CALCULATION OF THE LINK PERFORMANCE MARGINS. IF THESE SELECTED MODULATION INDICES PROVIDE THE REQUIRED PERFORMANCE MARGINS THEN THIS SET OF MODULATION INDICES IS OPTIMUM UNDER THIS CONDITION. IF NOT, WE THEN COMPARE THE CALCULATED PERFORMANCE MARGINS WITH THE REQUIRED MARGINS AND DETERMINE WHETHER OR NOT WE CAN MAKE SOME ADJUSTMENTS IN THE POWER ALLOCATION TO THE TELEMETRY DATA, RANGE AND CARRIER. AS AN EXAMPLE, THE POWER ADJUSTMENT IS POSSIBLE IF THE CALCULATED TELEMETRY PERFORMANCE MARGIN IS MUCH HIGHER THAN THE REQUIRED TELEMETRY MARGIN, AND THE CALCULATED RANGING MARGIN IS MUCH LOWER THAN THE REQUIRED MARGIN. FOR THIS CASE MORE POWER SHOULD BE ALLOCATED TO THE RANGING THAN THE TELEMETRY DATA CHANNEL. THIS CAN BE DONE BY GOING BACK TO THE LINE 70 AND INCREASING THE VALUE OF DELTA_D_dB. AFTER MAKING THIS CHANGE, IT IS NECESSARY TO CHECK THE CONDITION IN LINE 283.

***IF THERE IS NO REQUIREMENT ON THE LINK PERFORMANCE MARGINS THEN THE MOULATION INDICES SELECTED HERE WILL BE OPTIMUM FOR: (1) THE GIVEN VALUE OF DELTA_D_dB, THE DEGRADATION IN THE COMMAND DUE TO INTERFERENCE FROM THE RANGING, (2) THE REQUIRED THRESHOLDS ON THE TELECOMMUNICATIONS LINK (WHICH WERE SPECIFIED IN THE INPUT DATA SECTION.)

********FINAL NOTE: THE CONDITION EXPRESSED IN LINE 283 IS VERY IMPORTANT. IT DICTATES HOW THE VALUE DELTA_D_dB CAN BE CHANGED WITHOUT GUESSING.************

**************************************************************************************
****************TELECOMMUNICATIONS LINK DESIGN CONTROL TABLE****************

***********************************INPUT DATA***********************************

ENTER TOTAL TRANSMITTED POWER AT ANTENNA TERMINAL, Pt, EXPRESSED IN WATTS:
Pt := 0

ENTER TRANSMITTING CIRCUIT LOSS DUE TO CABLING, Lt, EXPRESSED IN dB:
Lt := 0

ENTER TRANSMITTING ANTENNA GAIN, Gt, EXPRESSED IN dBi:
Gt := 0

ENTER POINTING LOSS OF THE TRANSMITTING ANTENNA, Ltp, EXPRESSED IN dB:
Ltp := 0

ENTER THE TRANSMITTING FREQUENCY, Ft, EXPRESSED IN Hz:

Ft := 0

ENTER THE DISTANCE BETWEEN SPACECRAFT AND GROUND ANTENNA, R, EXPRESSED IN METER:

R := 0

ENTER ATMOSPHERIC ATTENUATION, La, EXPRESSED IN dB:
La := 0

ENTER POLARIZATION LOSS BETWEEN TRANSMITTING AND RECEIVING ANTENNAS, Lp, EXPRESSED IN dB:
Lp := 0

ENTER THE POINTING LOSS OF THE RECEIVING ANTENNA, Lrp, EXPRESSED IN dB:
Lrp := 0

ENTER RECEIVING ANTENNA GAIN, Gr, EXPRESSED IN dBI:
Gr := 0

ENTER RECEIVING CIRCUIT LOSS BETWEEN RECEIVING ANTENNA AND RECEIVER DUE TO CABLING, Lr, EXPRESSED IN dB:
Lr := 0

ENTER THE TELEMETRY MODULATION INDEX (FOUND IN THE PREVIOUS STEP), mT, EXPRESSED IN RADIANS:
mT := 0

ENTER THE RANGING MODULATION INDEX (FOUND IN THE PREVIOUS STEP), mr2, EXPRESSED IN RADIANS:
mr2 := 0

ENTER THE SYSTEM EQUIVALENT NOISE TEMPERATURE IN DEGREE OF KELVIN:
Teq := 0

ENTER OTHER LOSS IN THE CARRIER, Lc, EXPRESSED IN dB:
Lc := 0

ENTER OTHER LOSS IN THE DATA CHANNEL + DEGRADATION DUE TO RANGING CHANNEL, EXPRESSED IN dB:
Ld := 0

************************************************************************
********************************END OF USER INPUTS***************************

************************PRESS ESCAPE AND THEN TYPE AUTOMATIC*****************

*********************CALCULATE THE CARRIER PERFORMANCE MARGIN****************

THE NOISE SPECTRAL DENSITY, EXPRESSED IN dB, IS:

$$No := -228.6 + 10\cdot \log(Teq)$$
No =

THE SPACE LOSS, Ls, EXPRESSED IN dB, IS:

$$Ls := 20\cdot \log\left[3\cdot \frac{10^{8}}{4\cdot \pi\cdot R\cdot Ft}\right]$$

Ls =

THE TOTAL RECEIVED POWER, PR, EXPRESSED IN dB, IS:

$$PR := 10\cdot \log(Pt) + Lt + Gt + Ltp + Ls + La + Lp + Lrp + Gr + Lr$$
PR =

THE MODULATION LOSS IN THE CARRIER, Lm, IS, EXPRESSED IN dB:

$$Pc\_over\_Pt := (J0(alpha1p\cdot mr2)\cdot J0(alpha2p\cdot mr2)\cdot \cos(mT))^{2}\cdot \exp\left[-(alpha3p\cdot mr2)^{2}\right]$$

$$Lm := 10\cdot \log(Pc\_over\_Pt)$$
Lm =

THE RECEIVED CARRIER POWER IS, EXPRESSED IN dB:

$$Pc := PR + Lm$$
Pc =

THE CARRIER MARGIN IS, EXPRESSED IN dB:

$$CM := Pc - TWO\_BLO\_dB - THRESHOLD\_IN\_TWO\_BLO - No + Lc$$

CM =

******************************************************************************
COMPARE THE CALCULATED CARRIER MARGIN, CM, WITH THE REQUIRED CARRIER MARGIN, CMreq.

**IF CM >= CMreq THEN PROCEED FURTHER.

**IF CM < CMreq THEN GO BACK TO LINE 70 AND ENTER A NEW VALUE FOR $\delta$D
TO GO BACK TO LINE 70: PRESS ESCAPE AND THEN TYPE GOTO 70.
******************************************************************************

*********************CALCULATE THE DATA PERFORMANCE MARGIN*****************

MODULATION LOSS IN THE TELEMETRY CHANNEL, Lmd, EXPRESSED IN dB, IS:

$$\mathrm{Ptlm\_over\_Pt} := (\mathrm{J0}(\mathrm{alpha1p}\cdot \mathrm{mr2})\cdot \mathrm{J0}(\mathrm{alpha2p}\cdot \mathrm{mr2})\cdot \sin(\mathrm{mT}))^{2}\cdot \exp\left[-(\mathrm{alpha3p}\cdot \mathrm{mr2})^{2}\right]$$

$$\mathrm{Lmd} := 10\cdot \log(\mathrm{Ptlm\_over\_Pt})$$

Lmd =

THE RECEIVED DATA POWER, Pd, EXPRESSED IN dB, IS:

$$\mathrm{Pd} := \mathrm{PR} + \mathrm{Lmd}$$

Pd =

THE DATA PERFORMANCE MARGIN, DM, EXPRESSED IN dB, IS:

$$\mathrm{DM} := \mathrm{Pd} + \mathrm{Ld} + \mathrm{CODING\_GAIN} - \mathrm{BIT\_SNR\_dB} - \mathrm{BIT\_RATE\_DB} - \mathrm{No}$$

DM =

********************************************************************************

COMPARE THE CALCULATED TELEMETRY MARGIN, DM, WITH THE REQUIRED TELEMETRY MARGIN, DMreq.

**IF DM >= DMreq THEN PROCEED FURTHER.

**IF DM < DMreq THEN GO BACK TO LINE 70 AND ENTER A NEW VALUE FOR $\delta$D.

**TO GO BACK TO LINE 70: PRESS ESCAPE THEN TYPE GOTO 70.

********************************************************************************

*********************CALCULATE THE RANGING PERFORMANCE MARGIN***************

THE MODULATION LOSS IN THE RANGING CHANNEL, Lmr, EXPRESSED IN dB, IS:

$$\mathrm{Prange} := 2\cdot (\mathrm{J0}(\mathrm{alpha1p}\cdot \mathrm{mr2})\cdot \mathrm{J1}(\mathrm{alpha2p}\cdot \mathrm{mr2})\cdot \cos(\mathrm{mT}))^{2}\cdot \exp\left[-(\mathrm{alpha3p}\cdot \mathrm{mr2})^{2}\right]$$

$$\mathrm{Lmr} := 10\cdot \log(\mathrm{Prange})$$

Lmr =

THE RECEIVED RANGING SIGNAL, Prg, EXPRESSED IN dB, IS:

$$\mathrm{Prg} := \mathrm{PR} + \mathrm{Lmr}$$

Prg =

THE RANGING PERFORMANCE MARGIN, RM, EXPRESSED IN dB, IS:

$$\mathrm{RM} := \mathrm{Prg} - \mathrm{No} - \mathrm{RANGING\_SNR\_IN\_BW} - \mathrm{LOSS\_RANGE} - 10\cdot \log\left[\frac{2}{\mathrm{Ti}}\right]$$

RM =

*******************************************************************************
COMPARE THE CALCULATED RANGING MARGIN, RM, WITH THE REQUIRED RANGING MARGIN, RMreq.

**IF RM >= RMreq THEN THE SET OF MODULATION INDICES SELECTED BY THE PREVIOUS STEPS IS INDEED THE OPTIMUM SET UNDER THESE REQUIREMENTS.

**IF CM < MCreq THEN GO BACK TO LINE 70 AND ENTER A NEW VALUE FOR $\delta$D.

**TO GO BACK TO LINE 70: PRESS ESCAPE AND THEN TYPE GOTO 70.

*******************************************************************************
END OF PROGRAM
*******************************************************************************

# APPENDIX B

## A DEMONSTRATOR PROGRAM FOR THE SELECTION OF MODULATION INDICES FOR THE UPLINK

######## SELECTION OF MODULATION INDICES FOR OPTIMUM POWER DIVISION ##########
################ FOR SIMULTANEOUS RANGE/COMMAND OPERATIONS ###################

TIEN MANH NGUYEN
JET PROPULSION LABORATORY
4800 OAK GROVE DRIVE
PASADENA, CALIFORNIA 91109
MAIL STOP 161-228
PHONE:(818) 354-1826/1723

THIS PROGRAM HAS ASSUMED THAT (1) SQUARE-WAVE RANGING UPLINK, (2) SINE-WAVE SUBCARRIER FOR THE TELECOMMAND.

REFRENCE: TIEN MANH NGUYEN, "TECHNIQUE TO SELECT THE OPTIMUM MODULATION INDICES FOR SUPPRESSION OF UNDESIRED SIGNALS FOR SIMULTANEOUS RANGE AND DATA OPERATIONS," PROCEEDINGS OF IEEE-EMC, AUGUST 1988, SEATTLE, WASHINGTON. (ALSO PUBLISHED IN NASA TECH BRIEF NPO 17535.)

********************************INPUT DATA***********************************

ENTER PLL NOISE BANDWIDTH, TWO-BLO, EXPRESSED IN Hz:
TWO_BLO := 800

ENTER THE REQUIRED OPERATING THRESHOLD IN 2BLO, EXPRESSED IN dB:
REQUIRED_SNR_IN_TWO_BLO_dB := 16

ENTER THE REQUIRED BER:
BER := $10^{-8}$

ENTER THE REQUIRED COMMAND BIT RATE, EXPRESSED IN BPS:
BIT_RATE := 2000

ENTER THE SIGNAL DEGRADATION DUE TO RECEIVER HARDWARE, EXPRESSED IN dB:
SNR_DEGRAD_DUE_TO_HARDWARE := 2.6

ENTER THE RANGING TRANSPONDER BANDWIDTH, EXPRESSED IN Hz:
BW := $3 \cdot 10^{6}$

ENTER THE REQUIRED SNR IN THE SPECIFIED RANGING TRANSPONDER BANDWIDTH, IN dB:
REQUIRED_SNR_IN_BW := 0

ENTER THE SIGNAL DEGRADATION DUE TO RANGING RECEIVER HARDWARE, IN dB:
LOSS_IN_RANG_CHANNEL := 1.46

ENTER THE DESIRED DEGRADATION IN THE DATA CHANNEL DUE TO THE INTERFERENCE FROM THE RANGING CHANNEL, EXPRESSED IN dB:
DELTA_D_dB := 0.03

ENTER THE COMPONENT NUMBER OF CLOCK FREQUENCY, N:
N := 0

ENTER THE COMPONENT NUMBER BEING CHOPPED, M:
(NOTE THAT THIS NUMBER DEPENDS ON THE COMMAND SUBCARRIER FREQUENCY USED)
M := 6

ENTER THE SIDEBAND NUMBER OF COMPONENT BEING CHOPPED, K1:
K1 := 1

****************************************************************************
*****************************END OF USER INPUTS******************************

*********************PRESS ESCAPE AND THEN TYPE AUTOMATIC*******************

**********************PRESS ESCAPE AND THEN TYPE GOTO 179*******************

*************CALCULATE THE THRESHOLD REQUIREMENT FOR THE CARRIER*************

CALCULATE 2BLO IN dB:
TWO_BLO_dB_Hz := 10·log(TWO_BLO)
TWO_BLO_dB_Hz = 29.031

THE THRESHOLD REQUIRED FOR THE CARRIER IS:
SNRC_dB := TWO_BLO_dB_Hz + REQUIRED_SNR_IN_TWO_BLO_dB
SNRC_dB = 45.031

**************CALCULATE THE THRESHOLD REQUIREMENT FOR THE DATA**************

CALCULATE THE REQUIRED BIT SNR(dB) FOR A DESIRED BER:

$$\mathrm{BIT\_SNR} := \ln\left[(2\cdot\pi\cdot \mathrm{BER})^{1}\right]$$

BIT_SNR_dB := 10·log(BIT_SNR) - 0.24

THUS, THE REQUIRED BIT SNR, EXPRESSED IN dB IS:
BIT_SNR_dB = 11.957

CALCULATE THE REQUIRED BIT RATE, IN dB:
REQUIRED_BIT_RATE_dB_Hz := 10·log(BIT_RATE)
REQUIRED_BIT_RATE_dB_Hz = 33.01

THE THRESHOLD REQUIRED FOR THE COMMAND DATA CHANNEL IS:
SNRD_dB := BIT_SNR_dB + REQUIRED_BIT_RATE_dB_Hz + SNR_DEGRAD_DUE_TO_HARDWARE
SNRD_dB = 47.567

*********CALCULATE THE THRESHOLD REQUIREMENT FOR THE RANGING CHANNEL*********

CALCULATE THE RANGING TRANSPONDER BANDWIDTH IN dB:
RANGE_TRANSPONDER_BW_dB := 10·log(BW)
RANGE_TRANSPONDER_BW_dB = 64.771

THE THRESHOLD REQUIRED FOR THE RANGING CHANNEL IS:
SNRR_dB := RANGE_TRANSPONDER_BW_dB + REQUIRED_SNR_IN_BW + LOSS_IN_RANG_CHANNEL
SNRR_dB = 66.231

*****************CALCULATE THE CONSTANTS A1, A2, A3, A4, A5******************

CALCULATE A1, IN dB:
A1_dB := SNRD_dB - SNRC_dB
A1_dB = 2.536

CALCULATE A2, IN dB:
A2_dB := SNRD_dB - SNRR_dB
A2_dB = -18.664

CALCULATE A3, IN dB:
A3 := SNRR_dB - SNRD_dB
A3 = 18.664

CALCULATE A4, IN dB:
A4 := SNRD_dB
A4 = 47.567

CALCULATE A5, IN dB:

$$A5 := 10 \cdot \log\left[10^{\frac{DELTA\_D\_dB}{10}} - 1\right]$$

A5 = -21.592

***********CALCULATE THE MAXIMUM RANGING POWER LEVEL WHICH FALLS*************
***************************INTO THE DATA CHANNEL*****************************

FOR NASA/DSN RANGING SYSTEM, THE MAXIMUM POWER LEVEL THAT CAN INTERFERE WITH THE COMMAND DATA CHANNEL IS GIVEN BY:

$$PI\_dB := 10 \cdot \log\left[8 \cdot \left[\frac{\tan\left[K1 \cdot \frac{\pi}{2^{M+1}}\right]}{K1 \cdot \pi}\right]^2\right]$$

PI_dB = -33.112 (EXPRESSED IN dB)

******CALCULATE THE RANGING SUPPRESSION RELATIVE TO THE DATA POWER LEVEL******

DELTA_S_dB := A5 - (BIT_SNR_dB + PI_dB)
DELTA_S_dB = -0.437

*************************CALCULATE THE DESIGN FACTOR K************************

CALCULATE THE DESIGN FACTOR K:
DESIGN_FACT_K := SNRR_dB - SNRD_dB - DELTA_S_dB
DESIGN_FACT_K = 19.101

*************************CHECKING THE DESIGN FACTOR K*************************

CHECK THE CONDITION: A3 < K < A4.
*-IF THIS CONDITION IS SATISFIED THEN PROCEED FURTHER.
*-IF NOT, GO BACK TO LINE 52 AND ASSIGN A NEW VALUE FOR DELTA_D_dB.
**TO GO BACK TO LINE 52 PRESS ESCAPE AND THEN TYPE GOTO 52.

DESIGN_FACT_K = 19.101

A3 = 18.664 (IF K < A3, TOO MUCH POWER ALLOCATED TO THE RANGING)

A4 = 47.567 (IF K > A4, TOO MUCH POWER ALLOCATED TO THE DATA)

######### NOTICE THAT BY LOOKING AT K, A3, A4 WE CAN SHIFT THE VALUE OF DELTA_D_dB TO A PROPER VALUE SO THAT THIS CONDITION CAN BE SATISFIED ########

*************PRESS [CTRL][PAGE DOWN] TO MOVE DOWN 80 % OF THE PAGE************

*********************CALCULATE THE MODULATION INDICES**********************

ENTER THE UPPER AND LOWER VALUES FOR THE RANGE OF MODULATION INDICES:
UPPER := 100 (MAXIMUM NUMBER OF POINTS ALLOWED IS 20, i.e UPPER-LOWER = 20)
LOWER := 120

m := UPPER ..LOWER (m DENOTES THE RANGE VARIABLE INDEX)

$$mc_m := \frac{m}{100}$$ (mc IS THE COMMAND MODULATION INDEX)

SET (PD/PR) = K.A2, AND CALCULATE THE SET OF MODULATION INDICES THAT SATISFY THIS RELATIONSHIP.

####### NOTE THAT PD IS THE RECOVERABLE POWER OF THE COMMAND CHANNEL, AND PR IS THE RECOVERABLE IN THE FIRST ORDER SIDEBAND OF THE RANGING CHANNEL #######

$$A6 := DESIGN\_FACT\_K + A2\_dB - 10 \cdot \log\left[\frac{\pi^2}{4}\right]$$

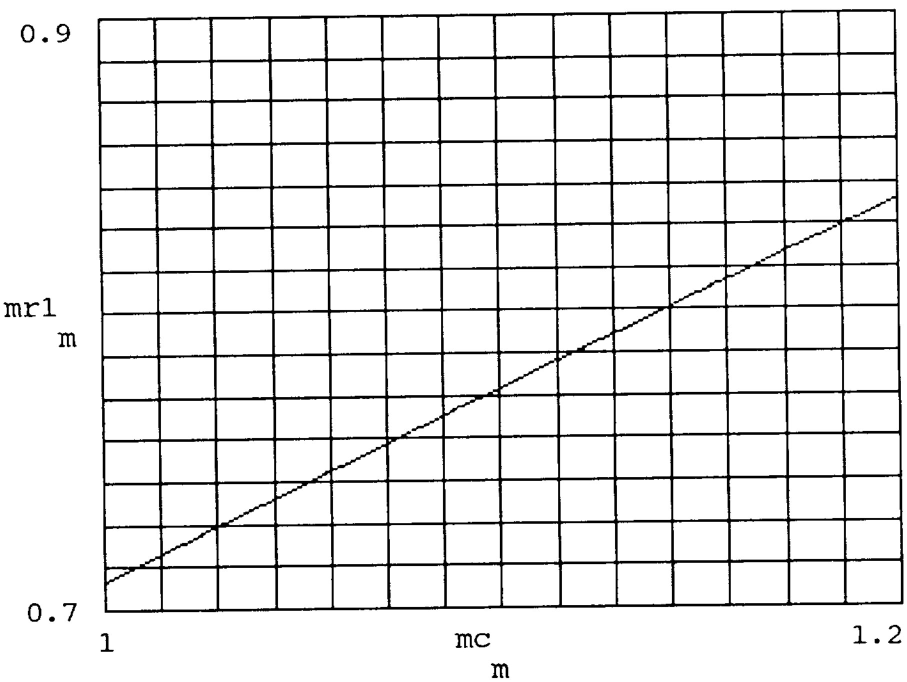
A6 = -3.486

$$A7_m := 20 \cdot \log\left[\frac{J1\left[mc_m\right]}{J0\left[mc_m\right]}\right] - A6$$

$$mr1_m := \operatorname{atan}\left[10^{\frac{A7_m}{20}}\right]$$ (mr1 IS THE UPLINK RANGING MODULATION INDEX)

PLOT OF THE SET OF MODULATION INDICES THAT SATISFIED (PD/PR) = K.A2

| $mc_m$ | $mr1_m$ |
|---|---|
| 1 | 0.71 |
| 1.01 | 0.716 |
| 1.02 | 0.723 |
| 1.03 | 0.729 |
| 1.04 | 0.736 |
| 1.05 | 0.742 |
| 1.06 | 0.748 |
| 1.07 | 0.755 |
| 1.08 | 0.761 |
| 1.09 | 0.768 |
| 1.1 | 0.774 |
| 1.11 | 0.78 |
| 1.12 | 0.787 |
| 1.13 | 0.793 |
| 1.14 | 0.799 |
| 1.15 | 0.806 |
| 1.16 | 0.812 |
| 1.17 | 0.818 |
| 1.18 | 0.825 |
| 1.19 | 0.831 |
| 1.2 | 0.837 |




***************************CALCULATE THE POWER RATIOS*************************

CALCULATE (PC/PT), (PD/PT), (PR/PT), (PLOSS/PT) FOR THE VALUES OF MODULATION INDICES FOUND IN THE PREVIOUS STEP.

THE POWER REMAINING IN THE CARRIER AFTER THE PHASE MODULATION IS:

$$PC\_OVER\_PT_m := \left[\cos\left[mr1_m\right] \cdot J0\left[mc_m\right]\right]^2$$

$$PC_m := 10 \cdot \log\left[PC\_OVER\_PT_m\right] \qquad \text{(EXPRESSED IN dB)}$$

THE RECOVERABLE POWER OF THE SINE-WAVE SUBCARRIER TELECOMMAND IS:

$$PCD\_OVER\_PT_m := 2 \cdot \left[\cos\left[mr1_m\right] \cdot J1\left[mc_m\right]\right]^2$$

$$PCD_m := 10 \cdot \log\left[PCD\_OVER\_PT_m\right] \qquad \text{(EXPRESSED IN dB)}$$

THE RECOVERABLE POWER IN THE FIRST ORDER SIDEBAND OF THE SQUARE-WAVE RANGING IS:

$$PR\_OVER\_PT_m := \frac{8}{\pi^2} \cdot \left[\sin\left[mr1_m\right] \cdot J0\left[mc_m\right]\right]^2$$

$$PR_m := 10 \cdot \log\left[PR\_OVER\_PT_m\right] \qquad \text{(EXPRESSED IN dB)}$$

THE POWER LOSS AFTER THE PHASE MODULATION IS:

$$PLOSS\_OVER\_PT_m := 1 - \left[PC\_OVER\_PT_m + PCD\_OVER\_PT_m + PR\_OVER\_PT_m\right]$$

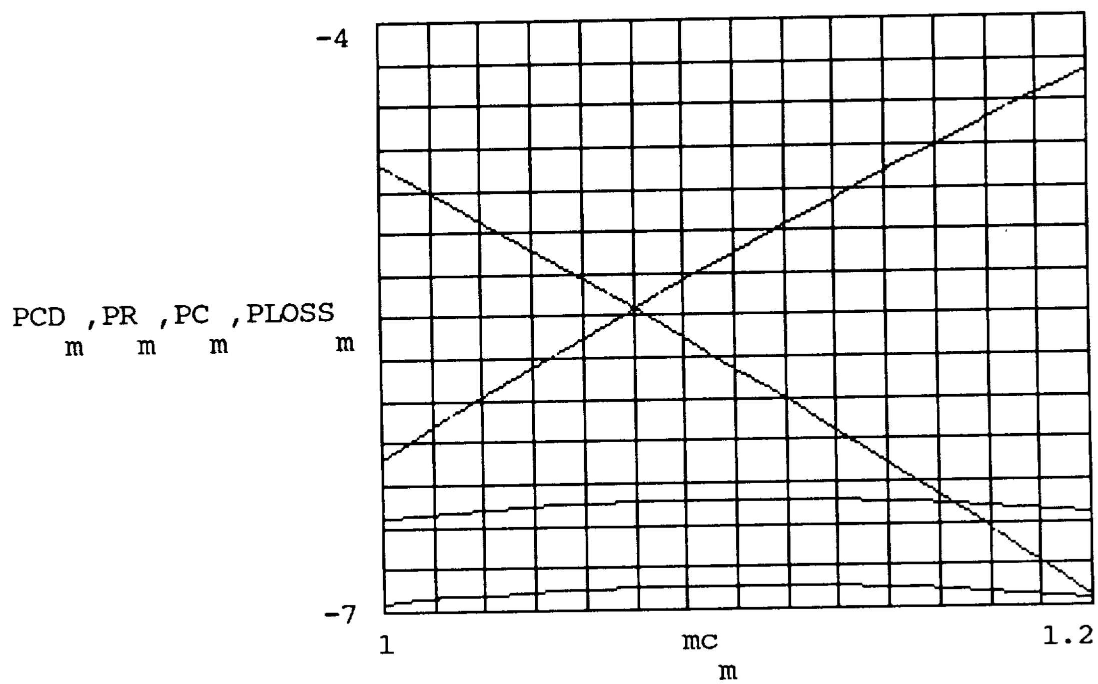
$$PLOSS_m := 10 \cdot \log\left[PLOSS\_OVER\_PT_m\right] \qquad \text{(EXPRESSED IN dB)}$$

POWER RATIOS AS THE FUNCTION OF THE MODULATION INDICES FOUND IN PREVIOUS STEP:

| $mc_m$ | $mr1_m$ | $PC_m$ | $PCD_m$ | $PR_m$ | $PLOSS_m$ |
|---|---|---|---|---|---|
| 1 | 0.71 | -4.725 | -6.52 | -6.957 | -6.221 |
| 1.01 | 0.716 | -4.824 | -6.505 | -6.942 | -6.111 |
| 1.02 | 0.723 | -4.924 | -6.492 | -6.929 | -6.002 |
| 1.03 | 0.729 | -5.026 | -6.48 | -6.917 | -5.895 |
| 1.04 | 0.736 | -5.128 | -6.47 | -6.907 | -5.789 |
| 1.05 | 0.742 | -5.232 | -6.462 | -6.899 | -5.684 |
| 1.06 | 0.748 | -5.337 | -6.455 | -6.892 | -5.581 |
| 1.07 | 0.755 | -5.444 | -6.45 | -6.887 | -5.479 |
| 1.08 | 0.761 | -5.551 | -6.446 | -6.883 | -5.379 |
| 1.09 | 0.768 | -5.66 | -6.444 | -6.881 | -5.279 |
| 1.1 | 0.774 | -5.77 | -6.444 | -6.88 | -5.182 |
| 1.11 | 0.78 | -5.882 | -6.445 | -6.881 | -5.085 |
| 1.12 | 0.787 | -5.995 | -6.447 | -6.884 | -4.99 |
| 1.13 | 0.793 | -6.109 | -6.451 | -6.888 | -4.896 |
| 1.14 | 0.799 | -6.225 | -6.457 | -6.894 | -4.803 |
| 1.15 | 0.806 | -6.342 | -6.464 | -6.901 | -4.711 |
| 1.16 | 0.812 | -6.46 | -6.473 | -6.91 | -4.621 |
| 1.17 | 0.818 | -6.579 | -6.483 | -6.92 | -4.532 |
| 1.18 | 0.825 | -6.701 | -6.495 | -6.932 | -4.444 |
| 1.19 | 0.831 | -6.823 | -6.508 | -6.945 | -4.357 |
| 1.2 | 0.837 | -6.947 | -6.523 | -6.96 | -4.272 |

***********************IT IS IMPORTANT TO READ THIS NOTE*******************
FROM THE ABOVE TABLE, THE SET OF MODULATION INDICES THAT MAXIMIZES THE POWER CURVES PCD, PR CAN BE FOUND. LET'S DENOTE THESE MODULATION INDICES AS mc(max) mr1(max). IF THE MAXIMUM POINT CAN NOT BE FOUND FOR THE GIVEN RANGE OF mc THEN GO BACK TO LINES 201, 202 AND CHANGE THE UPPER AND LOWER VALUES, RESPECTIVELY. TO DO THIS, PRESS ESCAPE KEY AND TYPE GOTO 201.
*************************************************************************

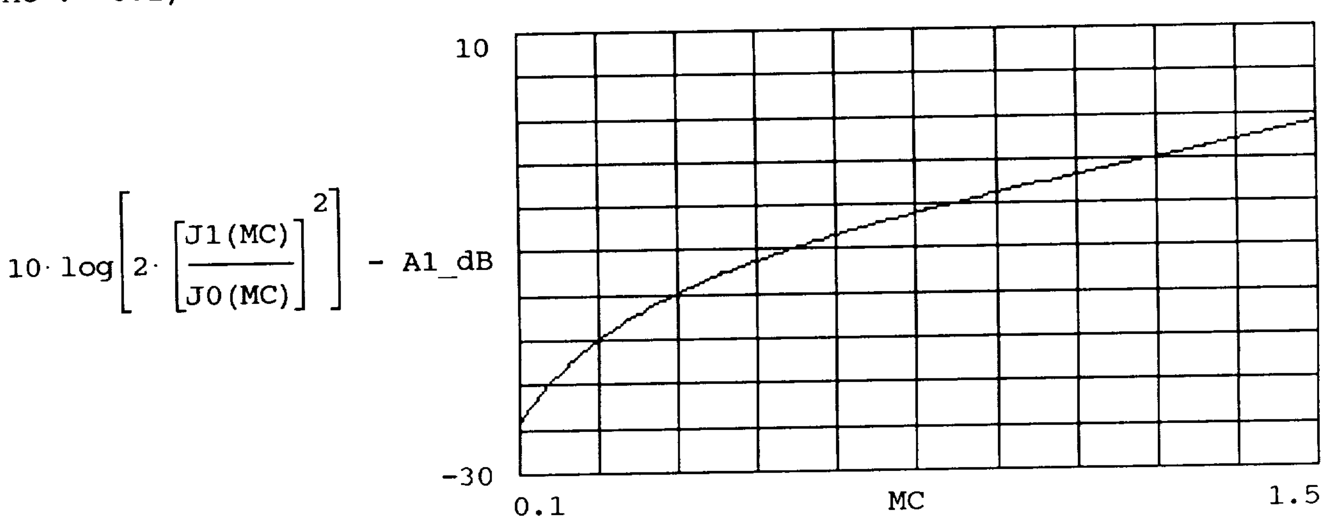
PLOT OF (PD/PT), (PR/PT), (PC/PT), (PLOSS/PT) VERSUS THE COMMAND MODULATION INDEX, mc, IN RADIAN




***************************CALCULATE THE UPPER BOUNDS***********************

CALCULATE THE UPPER BOUND FOR THE COMMAND MODULATION INDEX:

MC := 0.1,0.11 ..1.5



FROM THE ABOVE PLOT, GUESS THE VALUE OF MC THAT GIVES THE ZERO VALUE ON THE Y-AXIS. THE GUESS VALUE IS:

$$MC := .5$$

$$mc\_BOUND := root\left[10 \cdot \log\left[2 \cdot \left[\frac{J1(MC)}{J0(MC)}\right]^2\right] - A1\_dB, MC\right]$$

UPPER BOUND FOR THE COMMAND MODULATION INDEX, IN RADIAN, IS:

$$mc\_BOUND = 1.392$$

CALCULATE THE UPPER BOUND FOR THE RANGING MODULATION INDEX:

$$A7 := 20 \cdot \log\left[\frac{J1(mc\_BOUND)}{J0(mc\_BOUND)}\right] - A6$$

$$mr1\_BOUND := atan\left[10^{\frac{A7}{20}}\right]$$

UPPER BOUND FOR THE RANGING MODULATION INDEX, IN RADIAN:

$$mr1\_BOUND = 0.955$$

******************************************************************************
**********************PRESS ESCAPE AND THEN TYPE MANUAL*********************

***********************SELECTION OF MODULATION INDICES**********************

LET'S COMPARE THE MODULATION INDICES mc(max), mr1(max) WITH mc_BOUND AND mr1_BOUND.

**-IF mc_BOUND > mc(max), AND mr1_BOUND > mr1(max) THEN THE MODULATION INDICES THAT SHOULD BE SELECTED ARE:

mc(max), mr1(max).

**-IF mc_BOUND < mc(max), AND mr1_BOUND < mr1(max) THEN THE MODULATION INDICES THAT SHOULD BE SELECTED ARE:

mc_BOUND, mr1_BOUND.

**FOR THIS PARTICULAR EXAMPLE, THE MODULATION INDICES SELECTED ARE:
mc = 1.1 radians, mr1 = 0.774 radians

***THE MODULATION INDICES SELECTED HERE WILL BE USED IN THE CALCULATION OF THE LINK PERFORMANCE MARGINS. IF THESE SELECTED MODULATION INDICES PROVIDE THE REQUIRED PERFORMANCE MARGINS THEN THIS SET OF MODULATION INDICES IS OPTIMUM UNDER THIS CONDITION. IF NOT, WE THEN COMPARE THE CALCULATED PERFORMANCE MARGINS WITH THE REQUIRED MARGINS AND DETERMINE WHETHER OR NOT WE CAN MAKE SOME ADJUSTMENTS IN THE POWER ALLOCATION TO THE COMMAND DATA, RANGE AND CARRIER. AS AN EXAMPLE, THE POWER ADJUSTMENT IS POSSIBLE IF THE CALCULATED COMMAND PERFORMANCE MARGIN IS MUCH LARGER THAN THE REQUIRED COMMAND MARGIN, AND THE CALCULATED RANGING MARGIN IS MUCH SMALLER THAN THE REQUIRED MARGIN. FOR THIS CASE MORE POWER SHOULD BE ALLOCATED TO THE RANGING THAN THE COMMAND DATA CHANNEL. THIS CAN BE DONE BY GOING BACK TO THE LINE 52 AND INCREASING THE VALUE OF DELTA_D dB. AFTER MAKING THIS CHANGE, IT IS NECESSARY TO CHECK THE CONDITION IN LINE 181.

***IF THERE IS NO REQUIREMENT ON THE LINK PERFORMANCE MARGINS THEN THE MODULATION INDICES SELECTED HERE WILL BE OPTIMUM FOR: (1) THE GIVEN VALUE OF DELTA_D dB, THE DEGRADATION IN THE COMMAND DUE TO INTERFERENCE FROM THE RANGING, (2) THE REQUIRED THRESHOLDS ON THE TELECOMMUNICATIONS LINK (WHICH ARE SPECIFIED IN THE INPUT DATA SECTION.)

********FINAL NOTE: THE CONDITION EXPRESSED IN LINE 181 IS VERY IMPORTANT.****
IT DICTATES HOW THE VALUE DELTA_D dB CAN BE CHANGED WITHOUT GUESSING.
******************************************************************************

******************************************************************************

******************CALCULATION OF THE LINK PERFORMANCE MARGINS*****************

*********************************INPUT DATA**********************************

ENTER TOTAL TRANSMITTED POWER AT ANTENNA TERMINAL, Pt, EXPRESSED IN WATTS:

$Pt := 1 \cdot 10^{4}$

ENTER TRANSMITTING CIRCUIT LOSS DUE TO CABLING, Lt, EXPRESSED IN dB:
$Lt := 0$

ENTER TRANSMITTING ANTENNA GAIN, Gt, EXPRESSED IN dBi:
$Gt := 51.5$

ENTER POINTING LOSS OF THE TRANSMITTING ANTENNA, Ltp, EXPRESSED IN dB:
$Ltp := -0.1$

ENTER THE TRANSMITTING FREQUENCY, Ft, EXPRESSED IN Hz:

ENTER THE DISTANCE BETWEEN SPACECRAFT AND GROUND ANTENNA, R, EXPRESSED IN METER:

$R := 1.7 \cdot 10^{9}$

ENTER ATMOSPHERIC ATTENUATION, La, EXPRESSED IN dB:
La := -0.2

ENTER POLARIZATION LOSS BETWEEN TRANSMITTING AND RECEIVING ANTENNAS, Lp, EXPRESSED IN dB:
Lp := -0.1

ENTER THE POINTING LOSS OF THE RECEIVING ANTENNA, Lrp, EXPRESSED IN dB:
Lrp := -0.2

ENTER RECEIVING ANTENNA GAIN, Gr, EXPRESSED IN dBI:
Gr := 18.08

ENTER RECEIVING CIRCUIT LOSS BETWEEN RECEIVING ANTENNA AND RECEIVER DUE TO CABLING, Lr, EXPRESSED IN dB:
Lr := -2.02

ENTER THE COMMAND MODULATION INDEX (FOUND IN THE PREVIOUS STEP), mc, EXPRESSED IN RADIANS:
mc := 1.1

ENTER THE RANGING MODULATION INDEX (FOUND IN THE PREVIOUS STEP), mr1, EXPRESSED IN RADIANS:
mr1 := 0.774

ENTER THE SYSTEM EQUIVALENT NOISE TEMPERATURE IN DEGREE OF KELVIN:
Teq := 1191.242

ENTER OTHER LOSS IN THE CARRIER, Lc, EXPRESSED IN dB:
Lc := -1.1

ENTER OTHER LOSS IN THE DATA CHANNEL + DEGRADATION DUE TO RANGING CHANNEL, EXPRESSED IN dB:
Ld := -2.63

******************************************************************************
********************************END OF USER INPUTS****************************

************************PRESS ESCAPE AND THEN TYPE AUTOMATIC*****************

**********************CALCULATE THE CARRIER PERFORMANCE MARGIN****************

THE NOISE SPECTRAL DENSITY, EXPRESSED IN dB, IS:

$No := -228.6 + 10 \cdot \log(Teq)$
$No = -197.84$

THE SPACE LOSS, Ls, EXPRESSED IN dB, IS:

$$Ls := 20 \cdot \log\left[3 \cdot \frac{10^{8}}{4 \cdot \pi \cdot R \cdot Ft}\right]$$

$Ls = -223.37$

THE TOTAL RECEIVED POWER, PR, EXPRESSED IN dB, IS:

$PR := 10 \cdot \log(Pt) + Lt + Gt + Ltp + Ls + La + Lp + Lrp + Gr + Lr$
$PR = -116.41$

THE MODULATION LOSS IN THE CARRIER, Lm, IS, EXPRESSED IN dB:

$PC\_OVER\_PT := (\cos(mr1) \cdot J0(mc))^{2}$

$Lm := 10 \cdot \log(PC\_OVER\_PT)$
$Lm = -5.77$

THE RECEIVED CARRIER POWER IS, EXPRESSED IN dB:

$Pc := PR + Lm$

THE CARRIER MARGIN IS, EXPRESSED IN dB:

$CM := Pc - TWO\_BLO\_dB\_Hz - REQUIRED\_SNR\_IN\_TWO\_BLO\_dB - No + Lc$

$CM = 29.529$

******************************************************************************
COMPARE THE CALCULATED CARRIER MARGIN, CM, WITH THE REQUIRED CARRIER MARGIN, CMreq.

**IF CM >= CMreq THEN PROCEED FURTHER.

**IF CM < CMreq THEN GO BACK TO LINE 52 AND ENTER A NEW VALUE FOR DELTA_D

**TO GO BACK TO LINE 25: PRESS ESCAPE AND THEN TYPE GOTO 52.

** SUPPOSE THAT CMreq = 10 dB. THUS, CM > CMreq.
******************************************************************************

**********************CALCULATE THE DATA PERFORMANCE MARGIN*******************

MODULATION LOSS IN THE DATA CHANNEL, Lmd, EXPRESSED IN dB, IS:

$$PCD\_OVER\_PT := 2 \cdot (\cos(mr1) \cdot J1(mc))^2$$

$Lmd := 10 \cdot \log(PCD\_OVER\_PT)$
$Lmd = -6.443$

THE RECEIVED DATA POWER, Pd, EXPRESSED IN dB, IS:

$Pd := PR + Lmd$
$Pd = -122.854$

THE DATA PERFORMANCE MARGIN, DM, EXPRESSED IN dB, IS:

$DM := Pd + Ld - BIT\_SNR\_dB - REQUIRED\_BIT\_RATE\_dB\_Hz - No$

$DM = 27.389$

*******************************************************************************
COMPARE THE CALCULATED DATA MARGIN, DM, WITH THE REQUIRED DATA MARGIN, DMreq.

**IF DM >= DMreq THEN PROCEED FURTHER.

**IF DM < DMreq THEN GO BACK TO LINE 52 AND ENTER A NEW VALUE FOR DELTA_D.

**TO GO BACK TO LINE 52: PRESS ESCAPE AND THEN TYPE GOTO 52.

**SUPPOSE THAT DMreq = 4 dB. THUS, DM > DM req.
*******************************************************************************

**********************CALCULATE THE RANGING PERFORMANCE MARGIN****************

THE MODULATION LOSS IN THE RANGING CHANNEL, Lmr, EXPRESSED IN dB, IS:

$$PR\_OVER\_PT := (\sin(mr1) \cdot J0(mc))^2$$

$Lmr := 10 \cdot \log(PR\_OVER\_PT)$
$Lmr = -5.968$

THE RECEIVED RANGING SIGNAL, Prg, EXPRESSED IN dB, IS:

$Prg := PR + Lmr$
$Prg = -122.379$

THE RANGING PERFORMANCE MARGIN, RM, EXPRESSED IN dB, IS:

$RM := Prg - No - LOSS\_IN\_RANG\_CHANNEL - 10 \cdot \log(BW) - REQUIRED\_SNR\_IN\_BW$

$RM = 9.23$

********************************************************************************
COMPARE THE CALCULATED RANGING MARGIN, RM, WITH THE REQUIRED RANGING MARGIN, RMreq.

**IF RM >= RMreq THEN THE SET OF MODULATION INDICES SELECTED BY THE PREVIOUS STEPS IS INDEED THE OPTIMUM SET UNDER THESE REQUIREMENTS.

**IF CM < MCreq THEN GO BACK TO LINE 52 AND ENTER A NEW VALUE FOR DELTA_D.

**TO GO BACK TO LINE 52: PRESS ESCAPE AND THEN TYPE GOTO 52.

**SUPPOSE THAT RMreq = 5 dB. THUS, RM > RMreq.

**THE OPTIMUM SET OF MODULATION INDICES IS: mc = 1.1 rads, mr1 = 0.774 rads.
********************************************************************************

********************************************************************************
END OF PROGRAM
********************************************************************************

# APPENDIX C

## A DEMONSTRATOR PROGRAM FOR THE SELECTION OF MODULATION INDICES FOR THE DOWNLINK

######## SELECTION OF MODULATION INDICES FOR OPTIMUM POWER DIVISION ##########
############### FOR SIMULTANEOUS RANGE/TELEMETRY OPERATIONS ##################

################## TELECOMMAND IS ACTIVATED ON THE UPLINK ####################

TIEN MANH NGUYEN
JET PROPULSION LABORATORY
4800 OAK GROVE DRIVE
PASADENA, CALIFORNIA 91109
MAIL STOP 161-228
PHONE:(818) 354-1826/1723

THIS PROGRAM HAS ASSUMED THAT (1) THE SQUARE WAVE RANGING UP-SINE WAVE RANGING DOWN, (2) SINE WAVE TELECOMMAND SUBCARRIER, (3) BI-PHASE TELEMETRY DATA MODULATED DIRECTLY ON THE CARRIER OR SQUARE-WAVE TELEMETRY SUBCARRIER PM MODULATED ON THE CARRIER, (4) POWER-CONTROL AGC IN THE RANGING TRANSPONDER.

********************************INPUT DATA************************************

ENTER THE RANGING SNR AT THE OUTPUT OF THE RANGING TRANSPONDER, NOT IN dB:
(IF THE UPLINK RANGING PERFORMANCE MARGIN IS GREATER THAN 0 dB, A VALUE OF 1 IS RECOMMENDED. THIS GIVES A ZERO dB RANGING SNR AT THE OUTPUT OF THE RANGING TRANSPONDER. IF IT IS LESS THAN 0 dB THEN ENTER THE REAL VALUE FOR THE RANGING PERFORMANCE MARGIN, RM. THIS VALUE CAN BE FOUND FROM THE UPLINK PROGRAM, CALCULATION OF THE UPLINK PERFORMANCE MARGINS, LINE 716.)
Ranging_Signal_to_noise_ratio := 1 (NOT EXPRESSED IN dB)

ENTER THE RANGING SUPPRESSION RELATIVE TO THE COMMAND DATA CHANNEL:
(THIS VALUE CAN BE FOUND FROM THE UPLINK PROGRAM, LINE 168)
DELTA_S := -0.437 (EXPRESSED IN dB)

ENTER THE PLL NOISE BANDWIDTH, TWO-BLO, EXPRESSED IN Hz:
TWO_BLO := 600

ENTER THE REQUIRED THRESHOLD IN 2BLO, EXPRESSED IN dB:
THRESHOLD_IN_TWO_BLO := 10

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ENTER THE REQUIRED BER:
BER := $10^{-5}$

ENTER THE CODING GAIN, IF THERE IS ANY, EXPRESSED IN dB:
CODING_GAIN := 7.3

ENTER THE REQUIRED BIT RATE, EXPRESSED IN BPS:
BIT_RATE := 220000

ENTER THE SIGNAL DEGRADATION DUE TO RECEIVER HARDWARE, EXPRESSED IN dB:
LOSS_DUE_HARDWARE := 1.5

ENTER THE DESIRED RECEIVED RANGING SNR IN THE REQUIRED EFFECTIVE BANDWIDTH, EXPRESSED IN dB:
RANGING_SNR_IN_BW := 0

ENTER THE LOSS DUE TO RANGING RECEIVER, EXPRESSED IN dB:
LOSS_RANGE := 0.5


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ENTER THE REQUIRED INTEGRATION TIME FOR A GIVEN RANGING ACCURACY AT THE DESIRED RECEIVED RANGING SNR, EXPRESSED IN SEC:
Ti := 1.5

ENTER -1 IF THE DATA IS BI-PHASE MODULATED, AND 1 IF THE DATA IS SQUARE-WAVE MODULATED:
U := -1

ENTER THE DESIRED DEGRADATION IN THE TELEMETRY DATA CHANNEL DUE TO THE INTERFERENCE FROM THE RANGING CHANNEL, EXPRESSED IN dB:
$\delta$D := 0.008

ENTER THE MAXIMUM RANGING POWER LEVEL WHICH FALLS INTO THE TELEMETRY DATA CHANNEL, EXPRESSED IN dB:
(THIS VALUE CAN BE FOUND FROM THE PROGRAM PINTBIPH.MCD OR PINTSQSU.MCD)
Pint := -4.485

*****************************************************************************
****************************** END OF USER INPUTS ******************************

*********************PRESS ESCAPE AND THEN TYPE AUTOMATIC*********************

**********************PRESS ESCAPE AND THEN TYPE GOTO 281*********************

****CALCULATE THE TOTAL RANGING SNR AT THE INPUT TO THE RANGING TRANSPONDER***

THE TOTAL RANGING SNR AT THE INPUT OF THE RANGING TRANSPONDER IS:

$$\text{alphaR} := \frac{\pi^2}{8} \cdot (\text{Ranging\_Signal\_to\_noise\_ratio})$$

alphaR = 1.234 (NOT EXPRESSED IN dB)

****************CALCULATE THE TOTAL COMMAND POWER-TO-NOISE RATIO**************

THE TOTAL COMMAND POWER-TO-NOISE RATIO, NOT EXPRESSED IN dB, IS:

$$\text{alphaC} := 0.5 \cdot 10^{\frac{-\text{DELTA\_S}}{10}} \cdot (\text{Ranging\_Signal\_to\_noise\_ratio})$$

*********CALCULATE THE CONSTANT BETA, THE GAIN COEFFICIENT DUE TO AGC*********

$$\text{beta} := 2 \cdot \text{alphaC} + \frac{8 \cdot \text{alphaR}}{\pi^2} + 1$$

beta = 3.106

****CALCULATE THE "AMPLITUDES" OF THE COMMAND, RANGING SIGNALS AND NOISE*****
*******************COMPONENTS AT THE OUTPUT OF THE AGC**********************

$$alpha1p := 2 \cdot \sqrt{\frac{alphaC}{beta}}$$

alpha1p = 0.844

$$alpha2p := \frac{4}{\pi} \cdot \sqrt{\frac{alphaR}{beta}}$$

alpha2p = 0.802

$$alpha3p := \frac{1}{\sqrt{beta}}$$

alpha3p = 0.567

*****CALCULATE THE EFFECTIVE MODULATION INDICES FOR THE RANGING SIGNAL,*****
********THE COMMAND AND THE NOISE COMPONENTS IN THE RANGING CHANNEL*********

ENTER THE UPPER AND LOWER VALUES:
UPPER := 20 (MAXIMUM 20 POINTS, i.e. UPPER VALUE - LOWER VALUE = 20)
LOWER := 40

m := UPPER ..LOWER

$$mr2_m := \frac{m}{100}$$ (mr2 IS THE DOWNLINK RANGING MODULATION INDEX)

$$alpha1_m := alpha1p \cdot mr2_m$$

$$alpha2_m := alpha2p \cdot mr2_m$$

$$alpha3_m := alpha3p \cdot mr2_m$$

alpha1p = 0.844

alpha2p = 0.802

alpha3p = 0.567

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**************CALCULATE THE THRESHOLD REQUIREMENT FOR THE CARRIER************

CALCULATE THE PLL NOISE BANDWIDTH, IN dB:
TWO_BLO_dB := 10·log(TWO_BLO)
TWO_BLO_dB = 27.782

THE THRESHOLD REQUIRED FOR CARRIER, IN dB, IS:
SNR_C := TWO_BLO_dB + THRESHOLD_IN_TWO_BLO
SNR_C = 37.782

***************CALCULATE THE THRESHOLD REQUIREMENT FOR THE DATA***************

CALCULATE THE REQUIRED BIT SNR(dB) FOR A DESIRED BER:

$$\mathrm{BIT\_SNR} := \ln\left[(2\cdot\pi\cdot \mathrm{BER})^{-1}\right]$$

BIT_SNR_dB := 10·log(BIT_SNR) - 0.24

THUS, THE REQUIRED BIT SNR, EXPRESSED IN dB IS:
BIT_SNR_dB = 9.617

CALCULATE THE BIT RATE, IN dB:
BIT_RATE_DB := 10·log(BIT_RATE)
BIT_RATE_DB = 53.424

THE THRESHOLD REQUIRED FOR THE TELEMETRY CHANNEL, EXPRESSED IN dB, IS:
SNR_TLM := BIT_RATE_DB + BIT_SNR_dB + LOSS_DUE_HARDWARE - CODING_GAIN
SNR_TLM = 57.241

*********CALCULATE THE THRESHOLD REQUIREMENT FOR THE RANGING CHANNEL*********

CALCULATE THE EFFECTIVE RANGING BANDWIDTH, Hz:

$$\mathrm{EFFECTIVE\_BW} := \frac{1}{\mathrm{Ti}}$$

EFFECTIVE_BW = 0.667

CALCULATE THE EFFECTIVE BANDWIDTH, IN dB:
BW := 10·log(EFFECTIVE_BW)

THE THRESHOLD REQUIRED FOR THE RANGING CHANNEL, EXPRESSED IN dB, IS:
SNR_RANGE := RANGING_SNR_IN_BW + BW + LOSS_RANGE
SNR_RANGE = -1.261

*******************CALCULATE THE CONSTANTS A1, A2, A3, A4*******************

CALCULATE A1, IN dB:
A1 := SNR_TLM - SNR_C
A1 = 19.459

CALCULATE A2, IN dB:
A2 := SNR_TLM - SNR_RANGE
A2 = 58.502

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CALCULATE A3, IN dB:
A3 := SNR_RANGE - SNR_TLM
A3 = -58.502

CALCULATE A4, IN dB:
A4 := SNR_RANGE
A4 = -1.261

******CALCULATE THE RANGING SUPPRESSION RELATIVE TO THE DATA POWER LEVEL******

$$s := 10 \cdot \log\left[10^{\frac{\delta D}{10}} - 1\right] - (BIT\_SNR - CODING\_GAIN + Pint)$$

s = -25.233

************************CALCULATE THE DESIGN FACTOR K2**********************

K2 := SNR_RANGE - SNR_TLM - δs

K2 = -33.269

************************CHECKING THE DESIGN FACTOR K2***********************

CHECK THE CONDITION:  A3 < K2 < A4.
*-IF THIS CONDITION IS SATISFIED THEN PROCEED FURTHER.
*-IF NOT, GO BACK TO LINE 70 AND ASSIGN A NEW VALUE FOR δD.
*-TO GO BACK TO LINE 70: PRESS ESCAPE AND THEN TYPE GOTO 70.

K2 = -33.269

A3 = -58.502        (IF  K2 < A3, TOO MUCH POWER ALLOCATED TO THE RANGING)

A4 = -1.261        (IF K2 > A4, TOO MUCH POWER ALLOCATED TO THE DATA)

######## NOTICE THAT BY LOOKING AT K2, A3, A4 WE CAN SHIFT THE VALUE OF
ELTA_D_dB TO A PROPER VALUE SO THAT THIS CONDITION CAN BE SATISFIED ########

************PRESS [CTRL][PAGE DOWN] TO MOVE DOWN 80 % OF THE PAGE************

**********************CALCULATE THE MODULATION INDICES**********************

SET (Ptlm/Pr) = K2.A2, AND CALCULATE THE SET OF MODULATION INDICES THAT SATISFY THIS RELATIONSHIP.

################ NOTE THAT Ptlm IS THE RECOVERABLE POWER OF THE TELEMETRY CHANNEL, AND Pr IS THE RECOVERABLE POWER OF THE RANGING CHANNEL ############

$C := K2 + A2 - 10 \cdot \log(0.5)$
$C = 28.243$

$$G_m := 20 \cdot \log\left[\frac{J0\left[alpha1_m\right]}{J1\left[alpha1_m\right]}\right]$$

$$H_m := 20 \cdot \log\left[\frac{J0\left[alpha2_m\right]}{J1\left[alpha2_m\right]}\right]$$

$$D_m := \mathrm{if}\left[U \le 0, G_m, H_m\right]$$

$$A_m := \frac{C - D_m}{20}$$

$$mT_m := \mathrm{atan}\left[10^{A_m}\right]$$ (mT IS THE TELEMETRY MODULATION INDEX)

*******************************************************************************

******************PRESS [CTRL][Page Down] TO SEE THE PLOT OF*****************
*********************RANGING MODULATION INDEX, mr2, VERSUS*******************
**********************THE TELEMETRY MODULATION INDEX, mT********************

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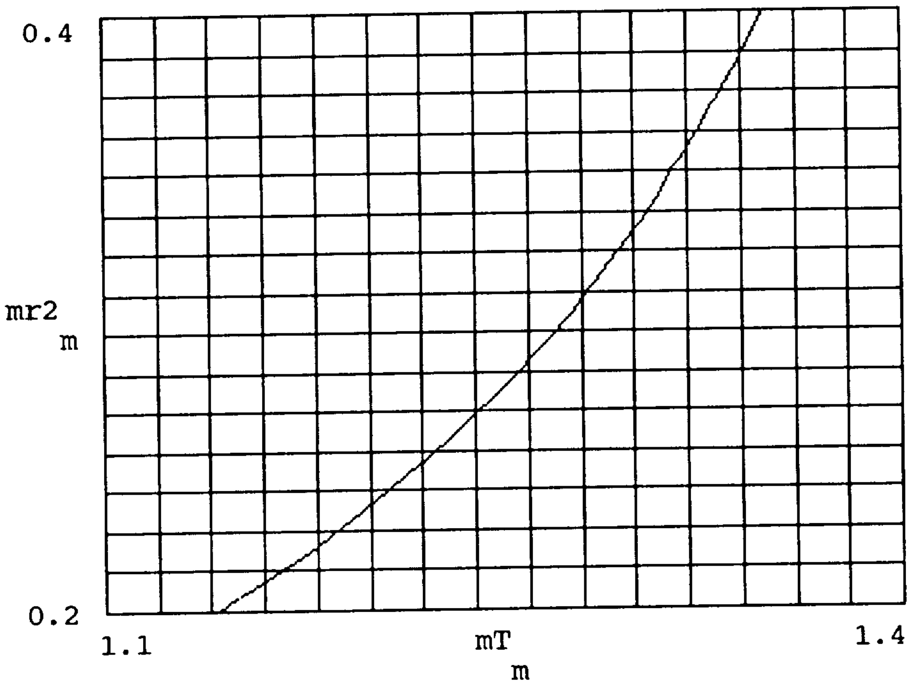
PLOT OF RANGING MODULATION INDEX, mr2, VERSUS THE TELEMETRY MODULATION INDEX, mT

| $mr2_m$ | $mT_m$ |
|---|---|
| 0.2 | 1.142 |
| 0.21 | 1.16 |
| 0.22 | 1.177 |
| 0.23 | 1.193 |
| 0.24 | 1.207 |
| 0.25 | 1.221 |
| 0.26 | 1.233 |
| 0.27 | 1.245 |
| 0.28 | 1.256 |
| 0.29 | 1.267 |
| 0.3 | 1.276 |
| 0.31 | 1.285 |
| 0.32 | 1.294 |
| 0.33 | 1.302 |
| 0.34 | 1.31 |
| 0.35 | 1.317 |
| 0.36 | 1.324 |
| 0.37 | 1.331 |
| 0.38 | 1.337 |
| 0.39 | 1.343 |
| 0.4 | 1.348 |




***************************CALCULATE THE POWER RATIOS*************************

CALCULATE THE POWER RATIOS (Pcd/Pt), (Ptlm/Pt), (Prange/Pt), (Pc/Pt), (Ploss/Pt) USING THE VALUES OF MODULATION INDICES FOUND IN PREVIOUS STEP.

$$E_m := \exp\left[-alpha3_m^{\,2}\right]$$

THE POWER REMAINING IN THE CARRIER AFTER THE PHASE MODULATION IS:

$$Pc\_over\_Pt_m := \left[J0\left[alpha1_m\right]\cdot J0\left[alpha2_m\right]\cdot \cos\left[mT_m\right]\right]^2 \cdot E_m$$

$$Pc_m := 10\cdot \log\left[Pc\_over\_Pt_m\right]$$ (EXPRESSED IN dB)

THE RECOVERABLE POWER OF THE COMMAND IN THE DOWNLINK SIGNAL IS:

$$Pcd\_over\_Pt_m := 2\cdot \left[J1\left[alpha1_m\right]\cdot J0\left[alpha2_m\right]\cdot \cos\left[mT_m\right]\right]^2 \cdot E_m$$

$$Pcd_m := 10 \cdot \log\left[Pcd\_over\_Pt_m\right]$$ (EXPRESSED IN dB)

THE RECOVERABLE POWER OF THE TELEMETRY SIGNAL IN THE DOWNLINK SIGNAL IS:

$$Ptlm\_over\_Pt_m := \left[J0\left[alpha1_m\right] \cdot J0\left[alpha2_m\right] \cdot \sin\left[mT_m\right]\right]^2 \cdot E_m$$

$$Ptlm_m := 10 \cdot \log\left[Ptlm\_over\_Pt_m\right]$$ (EXPRESSED IN dB)

THE RECOVERABLE POWER IN THE FIRST ORDER SIDEBAND OF THE SQUARE-WAVE RANGING IN THE DOWNLINK IS:

$$Prange\_over\_Pt_m := 2 \cdot \left[J0\left[alpha1_m\right] \cdot J1\left[alpha2_m\right] \cdot \cos\left[mT_m\right]\right]^2 \cdot E_m$$

$$Prange_m := 10 \cdot \log\left[Prange\_over\_Pt_m\right]$$ (EXPRESSED IN dB)

THE POWER LOSS AFTER THE PHASE MODULATION IS:

$$Ploss\_N_m := 1 - \left[Pc\_over\_Pt_m + Pcd\_over\_Pt_m + Ptlm\_over\_Pt_m + Prange\_over\_Pt_m\right]$$

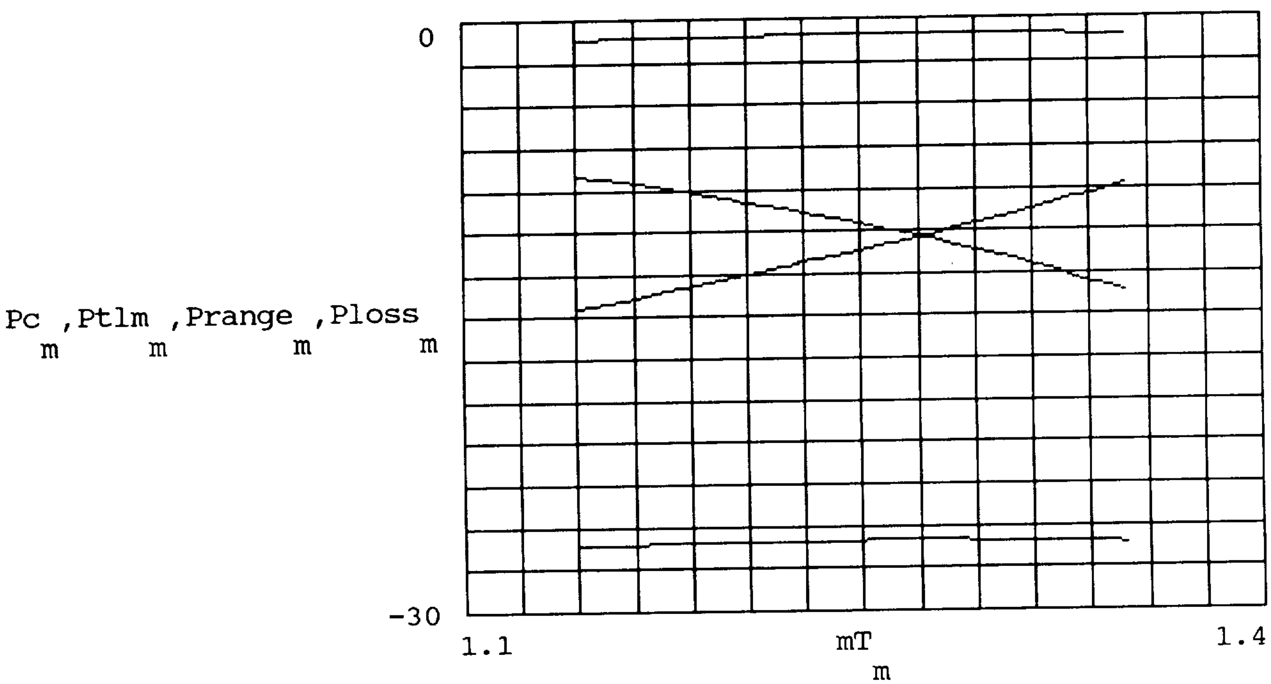
$$Ploss_m := 10 \cdot \log\left[Ploss\_N_m\right]$$ (EXPRESSED IN dB)

POWER RATIOS AS THE FUNCTION OF THE MODULATION INDICES FOUND IN PREVIOUS STEP:

| $mr2_m$ | $mT_m$ | $Pc_m$ | $Ptlm_m$ | $Prange_m$ | $Ploss_m$ |
|---|---|---|---|---|---|
| 0.2 | 1.142 | -7.798 | -0.998 | -26.671 | -14.594 |
| 0.21 | 1.16 | -8.172 | -0.945 | -26.618 | -14.133 |
| 0.22 | 1.177 | -8.535 | -0.901 | -26.575 | -13.698 |
| 0.23 | 1.193 | -8.89 | -0.866 | -26.54 | -13.286 |
| 0.24 | 1.207 | -9.234 | -0.837 | -26.512 | -12.894 |
| 0.25 | 1.221 | -9.57 | -0.815 | -26.49 | -12.521 |
| 0.26 | 1.233 | -9.898 | -0.798 | -26.473 | -12.165 |
| 0.27 | 1.245 | -10.218 | -0.786 | -26.461 | -11.825 |
| 0.28 | 1.256 | -10.531 | -0.778 | -26.454 | -11.5 |
| 0.29 | 1.267 | -10.836 | -0.774 | -26.451 | -11.187 |
| 0.3 | 1.276 | -11.135 | -0.774 | -26.451 | -10.888 |
| 0.31 | 1.285 | -11.427 | -0.777 | -26.454 | -10.6 |
| 0.32 | 1.294 | -11.714 | -0.783 | -26.461 | -10.322 |
| 0.33 | 1.302 | -11.995 | -0.792 | -26.47 | -10.055 |
| 0.34 | 1.31 | -12.271 | -0.803 | -26.482 | -9.797 |
| 0.35 | 1.317 | -12.542 | -0.816 | -26.496 | -9.549 |
| 0.36 | 1.324 | -12.808 | -0.832 | -26.512 | -9.308 |
| 0.37 | 1.331 | -13.069 | -0.85 | -26.53 | -9.075 |
| 0.38 | 1.337 | -13.326 | -0.87 | -26.551 | -8.85 |
| 0.39 | 1.343 | -13.58 | -0.891 | -26.573 | -8.632 |

***********************IT IS IMPORTANT TO READ THIS NOTE*******************
FROM THE ABOVE TABLE, THE SET OF MODULATION INDICES THAT MAXIMIZES THE POWER CURVES Ptlm, Prange CAN BE FOUND. LET'S DENOTE THESE MODULATION INDICES AS mT(max), mr2(max). IF THE MAXIMUM POINT CAN NOT BE FOUND FOR THE GIVEN RANGE OF mr2 THEN GO BACK TO LINES 152, 153 AND CHANGE THE UPPER AND LOWER VALUES, RESPECTIVELY. TO DO THIS, PRESS ESCAPE KEY AND TYPE: GOTO 152.
****************************************************************************

PLOT OF (Pc/Pt), (Ptlm/Pt), (Prange/Pt), (Ploss/Pt) VERSUS THE TELEMETRY MODULATION INDEX, mT, IN RADIAN




**************************CALCULATE THE UPPER BOUNDS************************

THE UPPER BOUND FOR THE TELEMETRY MODULATION INDEX, mT-bound, IS:

$$mT\_bound := \operatorname{atan}\left[10^{\frac{A1}{20}}\right]$$

$mT\_bound = 1.465$ (EXPRESSED IN RADIAN)

CALCULATE THE UPPER BOUND FOR THE RANGING MODULATION INDEX, mr2-bound.

CALCULATE THE ROOT OF EQUATION (Ptlm/Pr) = K2*A2:

ENTER THE GUESS VALUE FOR THE RANGING MODULATION INDEX, mr2-g, IN RADIAN:
$mr2\_g := .1$

$$mr2\_bound := \operatorname{root}\left[20\cdot\log\left[\frac{J0(alpha1p\cdot mr2\_g)}{J1(alpha1p\cdot mr2\_g)}\right] - C + 20\cdot\log(\tan(mT\_bound)), mr2\_g\right]$$

$mr2\_bound = 0.811$

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*******************************************************************************
*********************PRESS ESCAPE AND THEN TYPE MANUAL********************

**********************SELECTION OF MODULATION INDICES*********************

LET'S COMPARE THE MODULATION INDICES mT(max), mr2(max) WITH mT_bound AND mr2_bound.

**-IF mT_bound > mT(max), AND mr2_bound > mr2(max) THEN THE MODULATION INDICES THAT SHOULD BE SELECTED ARE:

mT(max), mr2(max).

**-IF mT_bound < mT(max), AND mr2_bound < mr2(max) THEN THE MODULATION INDICES THAT SHOULD BE SELECTED ARE:

mT_bound, mr2_bound.

**FOR THIS PSRTICULAR EXAMPLE, THE MODULATION INDICES SELECTED ARE:
mT = 1.276 radians, mr2 = 0.3 radians.

***THE MODULATION INDICES SELECTED HERE WILL BE USED IN THE CALCULATION OF THE LINK PERFORMANCE MARGINS. IF THESE SELECTED MODULATION INDICES PROVIDE THE REQUIRED PERFORMANCE MARGINS THEN THIS SET OF MODULATION INDICES IS OPTIMUM UNDER THIS CONDITION. IF NOT, WE THEN COMPARE THE CALCULATED PERFORMANCE MARGINS WITH THE REQUIRED MARGINS AND DETERMINE WHETHER OR NOT WE CAN MAKE SOME ADJUSTMENTS IN THE POWER ALLOCATION TO THE TELEMETRY DATA, RANGE AND CARRIER. AS AN EXAMPLE, THE POWER ADJUSTMENT IS POSSIBLE IF THE CALCULATED TELEMETRY PERFORMANCE MARGIN IS MUCH HIGHER THAN THE REQUIRED TELEMETRY MARGIN, AND THE CALCULATED RANGING MARGIN IS MUCH LOWER THAN THE REQUIRED MARGIN. FOR THIS CASE MORE POWER SHOULD BE ALLOCATED TO THE RANGING THAN THE TELEMETRY DATA CHANNEL. THIS CAN BE DONE BY GOING BACK TO THE LINE 70 AND INCREASING THE VALUE OF DELTA_D_dB. AFTER MAKING THIS CHANGE, IT IS NECESSARY TO CHECK THE CONDITION IN LINE 283.

***IF THERE IS NO REQUIREMENT ON THE LINK PERFORMANCE MARGINS THEN THE MODULATION INDICES SELECTED HERE WILL BE OPTIMUM FOR: (1) THE GIVEN VALUE OF DELTA_D_dB, THE DEGRADATION IN THE COMMAND DUE TO INTERFERENCE FROM THE RANGING, (2) THE REQUIRED THRESHOLDS ON THE TELECOMMUNICATIONS LINK (WHICH WERE SPECIFIED IN THE INPUT DATA SECTION.)

*******FINAL NOTE: THE CONDITION EXPRESSED IN LINE 283 IS VERY IMPORTANT. IT DICTATES HOW THE VALUE DELTA_D_dB CAN BE CHANGED WITHOUT GUESSING.***********

*******************************************************************************
***************TELECOMMUNICATIONS LINK DESIGN CONTROL TABLE***************

********************************INPUT DATA**********************************

ENTER TOTAL TRANSMITTED POWER AT ANTENNA TERMINAL, Pt, EXPRESSED IN WATTS:
Pt := 10

ENTER TRANSMITTING CIRCUIT LOSS DUE TO CABLING, Lt, EXPRESSED IN dB:
Lt := -2.02

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ENTER TRANSMITTING ANTENNA GAIN, Gt, EXPRESSED IN dBi:
Gt := 19.08

ENTER POINTING LOSS OF THE TRANSMITTING ANTENNA, Ltp, EXPRESSED IN dB:
Ltp := -0.2

ENTER THE TRANSMITTING FREQUENCY, Ft, EXPRESSED IN Hz:

$Ft := 2248 \cdot 10^{6}$

ENTER THE DISTANCE BETWEEN SPACECRAFT AND GROUND ANTENNA, R, EXPRESSED IN METER:

$R := 1.7 \cdot 10^{9}$

ENTER ATMOSPHERIC ATTENUATION, La, EXPRESSED IN dB:
La := -0.2

ENTER POLARIZATION LOSS BETWEEN TRANSMITTING AND RECEIVING ANTENNAS, Lp, EXPRESSED IN dB:
Lp := -0.1

ENTER THE POINTING LOSS OF THE RECEIVING ANTENNA, Lrp, EXPRESSED IN dB:
Lrp := -0.15

ENTER RECEIVING ANTENNA GAIN, Gr, EXPRESSED IN dBI:
Gr := 52.2

ENTER RECEIVING CIRCUIT LOSS BETWEEN RECEIVING ANTENNA AND RECEIVER DUE TO CABLING, Lr, EXPRESSED IN dB:
Lr := 0

ENTER THE TELEMETRY MODULATION INDEX (FOUND IN THE PREVIOUS STEP), mT, EXPRESSED IN RADIANS:
mT := 1.276

ENTER THE RANGING MODULATION INDEX (FOUND IN THE PREVIOUS STEP), mr2, EXPRESSED IN RADIANS:
mr2 := 0.30

ENTER THE SYSTEM EQUIVALENT NOISE TEMPERATURE IN DEGREE OF KELVIN:
Teq := 124.45

ENTER OTHER LOSS IN THE CARRIER, Lc, EXPRESSED IN dB:
Lc := 0

ENTER OTHER LOSS IN THE DATA CHANNEL + DEGRADATION DUE TO RANGING CHANNEL, EXPRESSED IN dB:
Ld := -1.508

*****************************************************************************
********************************END OF USER INPUTS***************************

**********************PRESS ESCAPE AND THEN TYPE AUTOMATIC*****************

**********************CALCULATE THE CARRIER PERFORMANCE MARGIN****************

THE NOISE SPECTRAL DENSITY, EXPRESSED IN dB, IS:

$$No := -228.6 + 10 \cdot \log(Teq)$$
$$No = -207.65$$

THE SPACE LOSS, Ls, EXPRESSED IN dB, IS:

$$Ls := 20 \cdot \log\left[3 \cdot \frac{10^{8}}{4 \cdot \pi \cdot R \cdot Ft}\right]$$

$$Ls = -224.087$$

THE TOTAL RECEIVED POWER, PR, EXPRESSED IN dB, IS:

$$PR := 10 \cdot \log(Pt) + Lt + Gt + Ltp + Ls + La + Lp + Lrp + Gr + Lr$$
$$PR = -145.477$$

THE MODULATION LOSS IN THE CARRIER, Lm, IS, EXPRESSED IN dB:

$$Pc\_over\_Pt := (J0(alpha1p \cdot mr2) \cdot J0(alpha2p \cdot mr2) \cdot \cos(mT))^{2} \cdot \exp\left[-(alpha3p \cdot mr2)^{2}\right]$$

$$Lm := 10 \cdot \log(Pc\_over\_Pt)$$
$$Lm = -11.128$$

THE RECEIVED CARRIER POWER IS, EXPRESSED IN dB:

$$Pc := PR + Lm$$
$$Pc = -156.604$$

THE CARRIER MARGIN IS, EXPRESSED IN dB:

$$CM := Pc - TWO\_BLO\_dB - THRESHOLD\_IN\_TWO\_BLO - No + Lc$$

$$CM = 13.264$$

****************************************************************************
COMPARE THE CALCULATED CARRIER MARGIN, CM, WITH THE REQUIRED CARRIER MARGIN, CMreq.

**IF CM >= CMreq THEN PROCEED FURTHER.

**IF CM < CMreq THEN GO BACK TO LINE 70 AND ENTER A NEW VALUE FOR $\delta$D
TO GO BACK TO LINE 70: PRESS ESCAPE AND THEN TYPE GOTO 70.

**SUPPOSE THAT CMreq = 10 dB. THUS, CM > CMreq.
****************************************************************************

*********************CALCULATE THE DATA PERFORMANCE MARGIN******************

ODULATION LOSS IN THE TELEMETRY CHANNEL, Lmd, EXPRESSED IN dB, IS:

$$tlm\_over\_Pt := (J0(alpha1p \cdot mr2) \cdot J0(alpha2p \cdot mr2) \cdot \sin(mT))^2 \cdot \exp\left[-(alpha3p \cdot mr2)^2\right]$$

md := 10· log(Ptlm_over_Pt)
md = -0.775

HE RECEIVED DATA POWER, Pd, EXPRESSED IN dB, IS:

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d := PR + Lmd
d = -146.252

HE DATA PERFORMANCE MARGIN, DM, EXPRESSED IN dB, IS:

M := Pd + Ld + CODING_GAIN - BIT_SNR_dB - BIT_RATE_DB - No

M = 4.15

***************************************************************************
OMPARE THE CALCULATED TELEMETRY MARGIN, DM, WITH THE REQUIRED TELEMETRY ARGIN, DMreq.

*IF DM >= DMreq THEN PROCEED FURTHER.

*IF DM < DMreq THEN GO BACK TO LINE 70 AND ENTER A NEW VALUE FOR δD.

*TO GO BACK TO LINE 70: PRESS ESCAPE THEN TYPE GOTO 70.

*SUPPOSE THAT DMreq = 3 dB. THUS, DM > DMreq.
***************************************************************************

********************CALCULATE THE RANGING PERFORMANCE MARGIN****************

HE MODULATION LOSS IN THE RANGING CHANNEL, Lmr, EXPRESSED IN dB, IS:

$$range := 2 \cdot (J0(alpha1p \cdot mr2) \cdot J1(alpha2p \cdot mr2) \cdot \cos(mT))^2 \cdot \exp\left[-(alpha3p \cdot mr2)^2\right]$$

nr := 10· log(Prange)
nr = -26.444

HE RECEIVED RANGING SIGNAL, Prg, EXPRESSED IN dB, IS:

rg := PR + Lmr
rg = -171.92

HE RANGING PERFORMANCE MARGIN, RM, EXPRESSED IN dB, IS:

$$I := Prg - No - RANGING\_SNR\_IN\_BW - LOSS\_RANGE - 10 \cdot \log\left[\frac{2}{Ti}\right]$$

I = 33.98

*******************************************************************************
COMPARE THE CALCULATED RANGING MARGIN, RM, WITH THE REQUIRED RANGING MARGIN, RMreq.

**IF RM >= RMreq THEN THE SET OF MODULATION INDICES SELECTED BY THE PREVIOUS STEPS IS INDEED THE OPTIMUM SET UNDER THESE REQUIREMENTS.

**IF CM < MCreq THEN GO BACK TO LINE 70 AND ENTER A NEW VALUE FOR $\delta$D.

**TO GO BACK TO LINE 70: PRESS ESCAPE AND THEN TYPE GOTO 70.

**SUPPOSE THAT RMreq = 20 dB. THUS, RM > RMreq.

**THEREFORE, THE OPIMUM MODULATION INDICES FOR THIS PARTICULAR EXAMPLE ARE:

mT = 1.276 rads, mr2 = 0.30 rads.

*******************************************************************************

END OF PROGRAM

*******************************************************************************

# APPENDIX D

## A DEMONSTRATOR PROGRAM FOR THE COMPUTATION OF THE MAXIMUM RANGING POWER LEVEL WHICH FALLS INTO THE DATA CHANNEL, Pint

################ COMPUTATION OF THE MAXIMUM RANGING POWER LEVEL ##############
################## WHICH FALLS INTO THE TELEMETRY DATA CHANNEL ###############

##################### TELECOMMAND IS ACTIVATED ON THE UPLINK #################

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HIS PROGRAM HAS ASSUMED THAT (1) THE SQUARE WAVE RANGING UP-SINE WAVE RANGING OWN, (2) SINE WAVE TELECOMMAND SUBCARRIER, (3) BI-PHASE TELEMETRY DATA IODULATED DIRECTLY ON THE CARRIER, AND (4) POWER-CONTROL AGC IN THE RANGING RANSPONDER.

*******************************INPUT DATA*************************************

NTER THE RANGING SNR AT THE OUTPUT OF THE RANGING TRANSPONDER, NOT IN dB:
IF THE UPLINK RANGING PERFORMANCE MARGIN IS GREATER THAN 0 dB, A VALUE OF 1 S RECOMMENDED. THIS GIVES A ZERO dB RANGING SNR AT THE OUTPUT OF THE RANGING RANSPONDER. IF IT IS LESS THAN 0 dB THEN ENTER THE REAL VALUE FOR THE ANGING PERFORMANCE MARGIN HERE. THIS VALUE CAN BE FOUND FROM THE UPLINK NALYSIS.)

anging_Signal_to_noise_ratio := 1 (NOT EXPRESSED IN dB)

NTER THE RANGING SUPPRESSION IN RELATION TO THE COMMAND DATA CHANNEL:
THIS VALUE CAN BE FOUND FROM THE UPLINK PROGRAM, LINE 168)

ELTA_S := -0.437

****************************************************************************
**************************** END OF USER INPUTS ******************************

*********************PRESS ESCAPE AND THEN TYPE AUTOMATIC*******************

**********************PRESS ESCAPE AND THEN TYPE GOTO 94********************

***CALCULATE THE TOTAL RANGING SNR AT THE INPUT TO THE RANGING TRANSPONDER***

IE TOTAL RANGING SNR AT THE INPUT OF THE RANGING TRANSPONDER IS:

$$\text{lphaR} := \frac{\pi^2}{8} \cdot (\text{Ranging\_Signal\_to\_noise\_ratio})$$

phaR = 1.234 (NOT EXPRESSED IN dB)

****************CALCULATE THE TOTAL COMMAND POWER-TO-NOISE RATIO**************

THE TOTAL COMMAND POWER-TO-NOISE RATIO, NOT EXPRESSED IN dB, IS:

$$\text{alphaC} := 0.5 \cdot 10^{\frac{-\text{DELTA\_S}}{10}} \cdot (\text{Ranging\_Signal\_to\_noise\_ratio})$$

alphaC = 0.553

*********CALCULATE THE CONSTANT BETA, THE GAIN COEFFICIENT DUE TO AGC*********

$$\text{beta} := 2 \cdot \text{alphaC} + \frac{8 \cdot \text{alphaR}}{\pi^2} + 1$$

beta = 3.106

****************CALCULATE THE MAXIMUM RANGING POWER LEVEL WHICH***************
*******************FALLS INTO THE TELEMETRY DATA CHANNEL********************

WHEN THE TELEMETRY DATA IS BI-PHASE MODULATED DIRECTLY ON THE DATA, THE MAXIMUM RANGING POWER THAT CAUSED INTERFERENCE TO THE TELEMETRY DATA CHANNEL, EXPRESSED IN dB, IS:

$$\text{Pint} := 10 \cdot \log\left[2 \cdot \left[\frac{\text{alphaC}}{\text{beta}}\right]\right]$$

Pint = -4.485

*********************************END OF PROGRAM*********************************

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16. Abstract

MT's algorithm has been developed as an aid in the design of space telecommunications systems when utilized with simultaneous range/command/telemetry operations. This algorithm provides selection of modulation indices for: (1) suppression of undesired signals to achieve desired link performance margins and/or to allow for a specified performance degradation in the data channel (command/telemetry) due to the presence of undesired signals (interferers); and (2) optimum power division between the carrier, the range, and the data channel.

A software program using this algorithm has been developed for use with MathCAD software. This software program, called the MT program, provides the computation of optimum modulation indices for all possible cases that are recommended by the Consultative Committee on Space Data Systems (CCSDS) (with emphasis on the square-wave, NASA/JPL ranging system).

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