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Meteor Burst Communications Model

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METEOR BURST COMMUNICATIONS MODEL

Eldon J. Haakinson*

The meteor burst communications model is a user-interactive computer model that predicts the reliability of a communications system that uses meteor bursts as the communications channel. The model predicts the waiting times required to complete the transfer of messages from a master station to a remote station as a function of frequency, transmitter and receiver characteristics, system protocol, distance separation, time of year, and time of day. The model also allows the user to specify a network of stations including the master, remote, and relay stations. Waiting time estimates are computed for the entire network. The model is implemented on a mini-computer operated by the Institute for Telecommunication Sciences. Model users remotely access the computer from their own terminals over telephone lines.

Key words: communications; meteor burst; radio propagation model; VHF

1. OVERVIEW

1.1 Purpose

The purpose of this report is to describe the implementation of a user-interactive computer program which predicts the performance of a meteor burst communications system using the analytical and statistical techniques described in the listed references. Since system performance is a function of many system parameters, the program allows the user to assess the effects of various combinations of the parameters on the resulting performance.

1.2 Existing Methods and Procedures

The listed references contain the formulas and graphs for calculating the performance of meteor burst communications systems. The outputs in each case are waiting times required to deliver a message from one station to another. Although the references provide examples and families of curves for various parameter values, the user of the references would have to complete many intermediate calculations to obtain a measure of a system's performance. Any changes in the parameter values would require recalculation of the intermediate values.

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1.3 Improved Methods and Procedures

The present development provides an interactive computer model that first allows the user to specify various system parameters and then computes the system performance based on the analysis techniques as referenced. The user can easily redefine input values and obtain a system performance prediction based on the new values. This allows the user to determine the sensitivity of system performance to changes in the parameter values.

2. APPLICATION

2.1 Functions

Input-output control

The user remains under program control for all input and output. The program guides the user through the menu of options, the data input section, and the calculations output section. On data input, the user has various options (e.g., whether to select single burst message transfer or message piecing message transfer) which affect following input. The program controls the logical flow of the user input based upon previous parameter and option selections. The program traps user input errors and reissues the questions or options. The program provides a means that allows the user to break out of a menu selection and lets the user proceed on to another selection or terminate the program. The menu allows the user to select from a list of program options. The options and their meanings are:

HELP	- gives user guidance on program operation and control
DESCRIPTION	- describes the program's purpose
VERBOSE	- asks the user for input parameter values with explanatory dialog
CONCISE	- asks for input values with minimum dialog
EDIT	- allows the user to edit or alter the current data set
SUMMARY	- lists the options and parameters along with their default or user-selected values
PROCESS	- commands the program to calculate system performance with the current data set
QUIT	- terminates the program

Verbose, concise, and edit

The function of these three options is to carry on a dialog with the user about wanted options and parameter values. In these sections, the user chooses characteristics about the meteor burst communications system, the desired probability of communications, the mode of message transfer, etc. Each option or parameter has a range of acceptable values which can be displayed to the user and each response is checked to ensure that it is within the allowed range.

Process

The function of this program section is to calculate and display the predicted waiting times for the chosen options and parameters. Calculations of external noise level, antenna power gain patterns, diurnal and seasonal effects on meteor statistics, etc., also are made in this section. Details of the analysis methods used are contained in the Model Development section of this report.

2.2 Inputs-Outputs

Figure 1 shows a complete run of program BURST. Program parameters are described in Section 3.1. The first three pages of Figure 1 show the dialog with the user in the verbose mode. The values that are contained in parentheses are default values or values previously selected by the user. If the user wishes to retain the value in parentheses, the user merely types a carriage return in response to the question. If the user wants to change the value, he/she types in the new value and terminates it with a carriage return. The concise mode differs from the verbose mode by not printing out a detailed explanation of the question. The concise mode format is the question number, a short question identifier, the current value in parentheses, and a question mark.

Page 7 shows a sample output with a summary of the user-selected options and parameter values. Below the summary on pages 8 through 10 is a table of calculated values including meteor arrival rates, burst duration times, and associated waiting times for the given system parameters.

The data that was entered as an example in Figure 1 came from the report by Meteor Communications Consultants, Inc. (1980). Figure 4.2 of their report gives an example of the performance prediction procedure that utilizes roughly six tables and figures to obtain the waiting time predictions. Figure 1 gives waiting times that are comparable to those given in the report.

```
Enter command (first four characters is enough): BURST
```

User requests program BURST

```
          INSTITUTE FOR TELECOMMUNICATION SCIENCES

             METEOR BURST COMMUNICATIONS MODEL
                        VERSION 1.0

                 WED 22 SEP 1982  10:46:04

CHOOSE FROM THE MENU:
     H=HELP
     D=PROGRAM DESCRIPTION
     C=CONCISE DIALOG
     V=VERBOSE DIALOG
     E=EDIT DATA
     S=SUMMARY OF DATA
     P=PROCESS LAST DATA SET ENTERED
     Q=QUIT

MENU(VERBOSE)=?
```

default values are in parentheses; by typing only a carriage return, the default value is selected.

```
ENTER INPUT DATA

NO. OF SITES ( 2 TO  4)
 1) NO. OF SITES( 4)? 2
```

user responds to all questions; type desired selection <u>and</u> carriage return.

```
MONTH THAT SYSTEM IS TO BE OPERATED
   1 = JANUARY, 2 = FEBRUARY, ETC. ( 1 TO 12)
 2) MONTH OF OPERATION( 2)? 5

DESIRED COMMUNICATIONS RELIABILITY (   .10 TO 99.99 %)
 3) RELIABLITY(95.00 %)? 99

TIME TO COMPLETE AN UNINTERRUPTED MESSAGE (    0.0 TO 10000.0 MILLISECONDS)
MODEL ALREADY USES MESSAGE TIMES OF 50, 100, 200, 400, 800, AND 1600 MS
 4) MESSAGE TIME(  120.0 MS)? 75

MESSAGE TRANSMISSION OPTION
   P = MESSAGE PIECING ON MULTIPLE BURSTS
   S = COMPLETE MESSAGE TRANSFER BY A SINGLE BURST
 5) MESSAGE OPT(MESS PIECING)?
```

while entering data in the verbose dialog, a short description is given along with acceptable alphabetic responses or range of acceptable numeric values (within parentheses).

Figure 1. Sample dialog between a user and program BURST for single link computations.

```
ENTER DATA FOR SITE  1

TYPE SITE LAT (FOLLOWED BY CARRIAGE RETURN) AND SITE LON (RETURN)
FOR EACH OF THE SITES.
ENTER THE REFERENCE SITE'S LOCATION FIRST.
   LIMITS ARE-    -90 <= LAT <=    90 DEG N
                 -180 <= LON <=   180 DEG E
   INPUTS OF THE FORM X,Y,Z IMPLY DEGREES, MINUTES AND SECONDS
   INPUTS OF THE FORM X.Y IMPLY DECIMAL DEGREES
10) SITE  1 LAT( 26.9880 DEG N OR  26,59,17 DMS N)? 40.5
10) SITE  1 LON( 110.3423 DEG E OR  110,20,32 DMS E)? -105.75  <---  negative value
                                                                     indicates that
NO. OF OBSTACLES ( 0 TO  4)                                          longitude is
11) NO. OF OBSTACLES( 0)?                                            actually 105.75
                                                                     degrees W
MAN-MADE NOISE ENVIRONMENT
   BU = BUSINESS
   RE = RESIDENTIAL
   RU = RURAL
   QU = QUIET RURAL
14) NOISE(   RURAL    )? QU

NO. OF DIFFERENT CARRIER FREQUENCIES ( 1 TO  4)
15) NO. OF FREQUENCIES( 1)?


ENTER DATA FOR SITE  1  FREQUENCY  1

SYSTEM FREQUENCY ( 30.0 TO   120.0 MHZ)
20) FREQ(   40.0 MHZ)? 30

ANTENNA SELECTION OPTION
   G = MAINBEAM GAINS FOR BOTH XMTR AND RCVR ARE GIVEN
   P = AN ANTENNA PATTERN IS SELECTED AND THE MAIN
       BEAM POINTING ANGLES ARE GIVEN
21) ANT OPTION(GAIN ONLY )?

XMTR POWER OUT OF THE FINAL AMPLIFIER(    -10.0 TO      80.0 DBW)
25) XMTR PW(     10.0 DBW)? 30

XMTR TRANSMISSION LINE LOSSES FROM FINAL AMPLIFIER TO ANTENNA
TERMINALS (   0.0 TO  100.0 DB)
26) XMTR LINE LOSS(   1.0 DB)? 2

XMTR ANTENNA POWER GAIN RELATIVE TO AN ISOTROPIC RADIATOR IN THE
DIRECTION OF THE RCVR ( -50.0 TO   50.0 DBI).   IF GAIN IS KNOWN
RELATIVE TO A DIPOLE, THEN DBI = DBD + 2.15
27) XMTR GN(  21.0 DBI)? 15

RCVR ANTENNA POWER GAIN RELATIVE TO AN ISOTROPIC RADIATOR IN THE
DIRECTION OF THE XMTR ( -50.0 TO   50.0 DBI).   IF GAIN IS KNOWN
RELATIVE TO A DIPOLE, THEN DBI = DBD + 2.15
30) RCVR GN(  21.0 DBI)? 15
```

Figure 1. (Cont.)

```
ANTENNA CIRCUIT LOSS FACTOR--POWER AVAILABLE FROM LOSSLESS ANTENNA/POWER
AVAILABLE FROM ACTUAL ANTENNA (   0.0 TO  100.0 DB)
31) ANT CKT LOSS(   0.0 DB)?

RCVR TRANSMISSION LINE LOSSES FROM ANTENNA TERMINALS TO THE RCVR
INPUT (   0.0 TO  100.0 DB)
32) RCVR LINE LOSS(   1.0 DB)? 2

RCVR NOISE FIGURE AT RCVR INPUT (  0.0 TO 100.0 DB)
33) RCVR NOISE FIG(  3.0)? 10

RCVR IF NOISE BANDWIDTH (   .001 TO 1000.00 KHZ)
APPROXIMATELY EQUAL TO 3-DB BANDWIDTH
34) RCVR IF BW(   .500 KHZ)? 2

REQUIRED PREDETECTION SIGNAL-TO-NOISE RATIO (  -30.0 TO    30.0 DB)
35) REQ'D S/N(    6.0 DB)? 3

SYSTEM OVERHEAD PER BURST, INCLUDES SYCHRONIZATION,
PROTOCOL, ETC (    0.0 TO 10000.0 MILLISECONDS)
36) SYS OVERHEAD(   76.0 MS)? 83


ENTER DATA FOR SITE  2
10) SITE  2 LAT( 36.7899 DEG N OR  36,47,24 DMS N)? 49.5788
10) SITE  2 LON( 125.3450 DEG E OR  125,20,42 DMS E)? -115.9818
11) NO. OF OBSTACLES( 0)?
14) NOISE(   RURAL    )? QU
15) NO. OF FREQUENCIES( 1)?


ENTER DATA FOR SITE  2  FREQUENCY  1
20) FREQ(   30.0 MHZ)?
21) ANT OPTION(GAIN ONLY )?
25) XMTR PW(      25.0 DBW)? 30
26) XMTR LINE LOSS(   1.0 DB)? 2
27) XMTR GN(  18.0 DBI)? 7
30) RCVR GN(  14.0 DBI)? 7
31) ANT CKT LOSS(   0.0 DB)?
32) RCVR LINE LOSS(   1.3 DB)? 2
33) RCVR NOISE FIG(  4.5)? 10
34) RCVR IF BW(  1.000 KHZ)? 2
35) REQ'D S/N(    7.0 DB)? 3
36) SYS OVERHEAD(   76.0 MS)? 83

INPUT OF DATA IS COMPLETE

DO YOU WANT A SUMMARY OF THE INPUT DATA? (Y OR N) Y
```

Figure 1. (Cont.)

METEOR BURST INPUT SUMMARY

1) NUMBER OF SITES	2	note that each parameter has a question number associated with it; the user can change the parameter in the EDIT mode by selecting the question number of the parameter to be altered.
2) MONTH OF OPERATION	MAY	
3) RELIABILITY	99.0 %	
4) MESSAGE TIME	75. MS	
5) MESSAGE OPTION	MESSAGE PIECING	

10) LOCATION

SITE	LATITUDE (DEG)	LATITUDE (D M S)	LONGITUDE (DEG)	LONGITUDE (D M S)
1	40.5000 N	40 30 0 N	105.7500 W	105 45 0 W
2	49.5788 N	49 34 44 N	115.9818 W	115 58 54 W

OBSTACLE DATA

SITE	11) NUMBER	12) BEARING (DEG E OF N)	13) ELEVATION (DEG ABOVE HORIZON)	14) NOISE ENVIRONMENT	15) NO. OF FREQUENCIES
1	0			QUIET RURAL	1
2	0			QUIET RURAL	1

				ANTENNA PATTERN DATA			TRANSMITTER DATA		
SITE	FREQ NO.	20) FREQ	21) ANT OPTION	22) NO.	23) BEARING (DEG E OF N)	24) ELEVATION (DEG ABOVE HORIZON)	25) POWER (DBW)	26) LINE LOSSES (DB)	27) ANT GAIN (DBI)
1	1	30.00	GAIN				30.00	2.0	15.00
2	1	30.00	GAIN				30.00	2.0	7.00

RECEIVER DATA

SITE	FREQ NO.	30) ANT GAIN (DBI)	31) ANT CKT LOSS (DB)	32) LINE LOSSES (DB)	33) NOISE FIGURE (DB)	34) IF BANDWIDTH (KHZ)	35) REQ'D SIG-TO-NOISE (DB)	36) SYS OVERHEAD (MS)
1	1	15.0	0.0	2.0	10.0	2.000	3.0	83.
2	1	7.0	0.0	2.0	10.0	2.000	3.0	83.

DO YOU WANT TO PROCESS THIS DATA? (Y OR N) Y

Figure 1. (Cont.)

To stop the listing, type the BREAK key. The computer will print

```
    S=XX  COMMAND ?
```

Then you type

```
     BR  <carriage return>
```

The listing should stop after a few lines.

```
               METEOR BURST CALCULATIONS

CALCULATIONS OF ESTIMATED WAITING TIME OPTION
  S = SINGLE LINK
  N = NETWORK, ALL POSSIBLE LINKS
CALCULATIONS OPTION (SINGLE LINK)?

SITE NUMBER FOR THE MASTER STATION (1 TO  2)
MASTER STATION SITE NO. ( 1)?

SITE NUMBER FOR THE REMOTE STATION (1 TO  2)
REMOTE STATION SITE NO. ( 2)?

MASTER-TO-REMOTE LINK CARRIER FREQUENCY. MHZ
MASTER STATION TRANSMIT FREQ (30.0 MHZ)?

REMOTE-TO-MASTER LINK CARRIER FREQUENCY. MHZ
REMOTE STATION TRANSMIT FREQ (30.0 MHZ)?
```

Figure 1. (Cont.)

METEOR BURST COMMUNICATIONS

INPUT PARAMETERS

	MASTER	REMOTE	
FREQUENCY	30.0	30.0	MHZ
TRANSMIT POWER	30.0	30.0	DBW
TRANSMIT LINE LOSSES	2.0	2.0	DB
TRANSMIT ANTENNA OPTION	GAIN	GAIN	
TRANSMIT ANTENNA GAIN	15.0	7.0	DBI
RECEIVE ANTENNA OPTION	GAIN	GAIN	
RECEIVE ANTENNA GAIN	15.0	7.0	DBI
ANTENNA CIRCUIT LOSSES	0.0	0.0	DB
RECEIVE LINE LOSSES	2.0	2.0	DB
RECEIVE NOISE FIGURE	10.0	10.0	DB
IF BANDWIDTH	2.0	2.0	KHZ
REQ'D PRE-DETECTION S/N RATIO	3.0	3.0	DB
LOCATION DESCRIPTION	QUIET RURAL	QUIET RURAL	
MESSAGE TRANSFER	MULTIPLE BURST MODE		
SYSTEM OVERHEAD PER BURST	83.0	83.0	MS
USER-DEFINED MESSAGE LENGTH		75.0	MS

DISTANCE BETWEEN MASTER AND REMOTE		1287.5	KM
		800.2	S MI
COMPUTED SYSTEM NOISE POWER	-120.8	-120.8	DBM
MONTH OF OPERATION		MAY	

OUTPUT PARAMETERS

POWER FACTOR = TRANSMIT POWER - TRANSMIT LINE LOSSES
+ ANTENNA GAINS - (SYSTEM NOISE POWER
+ REQD SIGNAL-TO-NOISE RATIO)

THE MASTER-TO-REMOTE LINK POWER FACTOR = 197.8 DB
THE REMOTE-TO-MASTER LINK POWER FACTOR = 197.8 DB
THE WAITING TIME CALCULATIONS ARE BASED
ON THE SMALLER POWER FACTOR.

THE AVERAGE METEOR BURST DURATION = 1.0 SEC

COMPLETE MESSAGE TRANSFER BY MESSAGE PIECING
ON MULTIPLE BURSTS

Figure 1. (Cont.)

LOCAL TIME MIDPOINT BETWEEN MASTER AND REMOTE	AVERAGE INTERVAL BETWEEN BURSTS	USER-DEFINED 75 MS	WAITING TIMES NOT EXCEEDED FOR 99.00% OF THE TIME FOR THE GIVEN MESSAGE TIME 50 MS	100 MS	200 MS	400 MS	800 MS	1600 MS
--------	--------	----------	----------	----------	----------	----------	----------	----------
	(SEC)	(SEC)	(SEC)	(SEC)	(SEC)	(SEC)	(SEC)	(SEC)
0	3.1	17	16	17	18	20	24	30
200	2.7	15	14	15	16	18	20	25
400	2.6	14	14	14	15	17	20	25
600	3.0	16	15	16	17	19	23	28
800	3.6	19	18	19	21	23	27	34
1000	4.2	22	22	23	24	26	32	40
1200	5.0	26	26	27	29	32	39	47
1400	6.6	35	34	35	39	42	51	63
1600	8.1	42	42	44	46	53	62	77
1800	8.1	42	42	44	46	53	62	77
2000	6.5	35	33	35	37	42	49	63
2200	4.0	21	21	22	23	26	31	39

MENU(CONCISE)=? QUIT

END BURST COMMUNICATIONS MODEL

Figure 1. (Cont.)

3. MODEL DEVELOPMENT

A complete discussion of meteor burst communications is contained in references such as Sugar (1964), Oetting (1980), and Meteor Communications Consultants, Inc. (1980). Since these papers describe the complete process including meteor trail physics, meteor burst statistics, and system dependencies, we will not repeat that information here. Instead, we will concentrate on options and parameters that are available to the user of this meteor burst communications model. In this section we describe how analysis techniques, which were developed in the references, are incorporated into the model. The following discussions give the user guidance on selection of values for the input parameters and provide the equations used to calculate waiting times based on those values.

3.1 General Options

The following options and parameters require selections or values by the user. These are listed in the order that a user would encounter them while running the program (see Figure 1 for example).

Number of sites

The model allows the user to enter data for two to four sites. Each site location is specified by providing its latitude and longitude. Each site can have up to four frequencies for which the user supplies transmit and/or receive parameter values. Figure 2 depicts possible site and frequency options. The simplest meteor burst system is composed of two sites with the transmit and receive frequencies separated by less than 1 MHz (as shown at the top of Figure 2). For this case, the user would supply data for two sites with one frequency at each site. The middle of Figure 2 shows a more complex system. There are two sites, and the carrier frequencies between the sites are separated by more than 1 MHz. For this case, the user would enter data at site 1 for two frequencies; the first frequency would have those values associated with the transmit characteristics at site one; the second frequency would have those values associated with the receive characteristics at site one. The corresponding characteristics would be given for the two frequencies at site two.

As will be shown in Section 3.4, Burst Statistics, the number of meteors per hour that are available as part of a communications path between the master

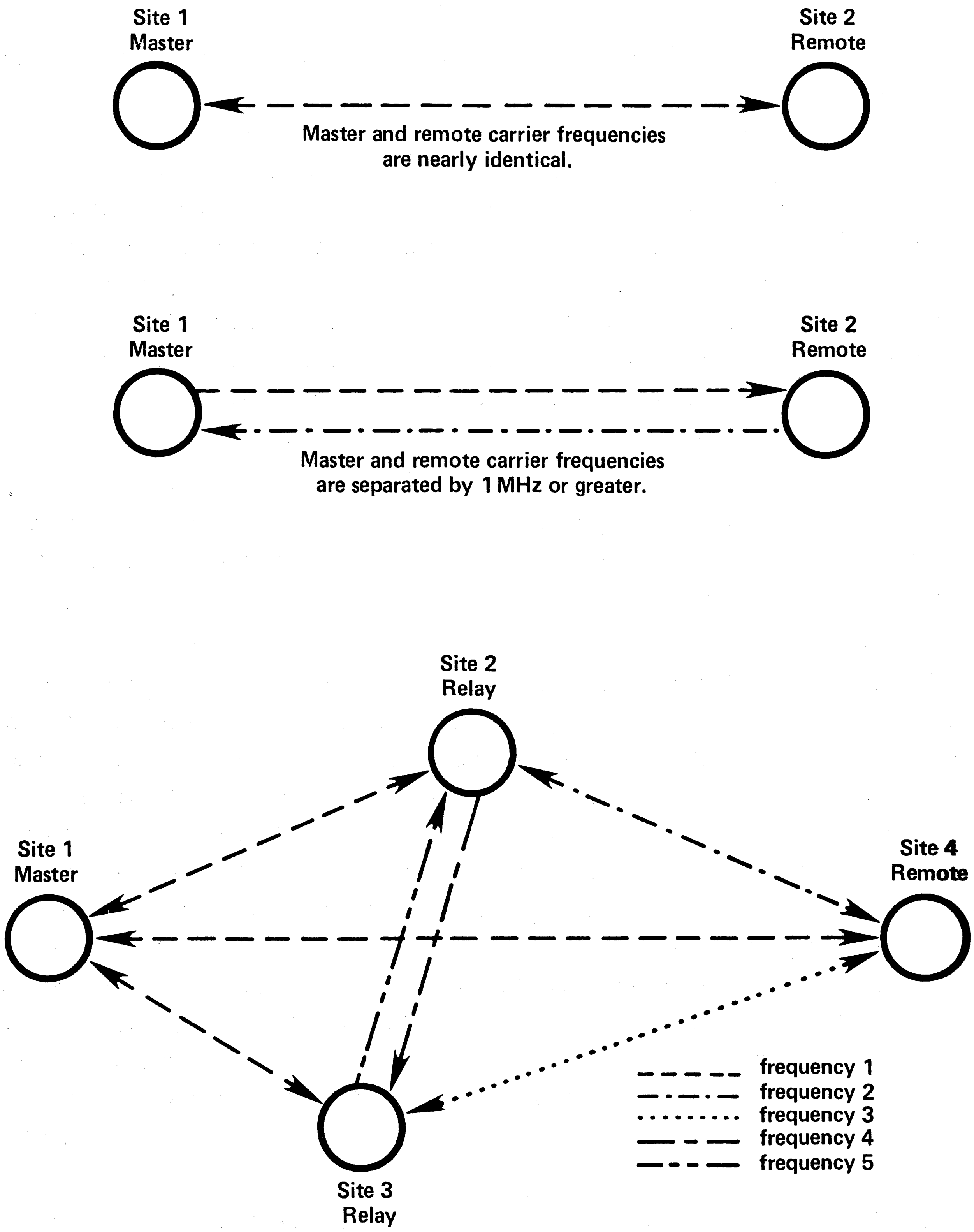


Figure 2. Three examples of possible site and frequency selections.

and remote stations is inversely proportional to their carrier frequencies. We suggest that if the master-to-remote and the remote-to-master carrier frequencies differ by more than 1 MHz (an arbitrary break point), then the user should indicate to the model that the sites use two different frequencies. If the difference is less than 1 MHz, then the user could indicate only one frequency.

The bottom of Figure 2 shows four sites with a rather complex arrangement of carrier frequencies between the master, remote, and relay stations.

Month of operation

The number of meteors available to the channel changes through the year. Figure 3 shows the relative rate of meteor arrivals versus time of year from measured data (Spezio, 1978). Since the model uses this set to estimate meteor rates, the user selects the appropriate month of operation.

Reliability

The user selects the probability of reliable communications required from the meteor burst channel. For example, if 95% is selected, then the resultant output might read "for a message time of 200 ms, the waiting time to transfer the complete message is predicted to not exceed 74 sec for 95% of the cases." Similarly, if 99% had been selected, the result might be "for a message time of 200 ms, the waiting time is predicted not to exceed 106 sec for 99% of the cases."

User-defined message time

Message time is the time required to transfer data at an uninterrupted rate. For example, if the user's system transmits data at 1000 bits per second and if 7 bits are required for each character, the message time required to transmit 65 characters would be 455 ms. If the user's transmission rate were 16 kbps, then the message time would be 28 ms. Estimated waiting times already are computed by the program for message times of 50, 100, 200, 400, 800, and 1600 ms. The user is allowed to enter one additional message time that may be more appropriate for his/her system. The message time does not include protocol, synchronization, preamble, or transit times. Those times are lumped into one value called system overhead.

Message transfer option

There are two ways the user can select to transfer messages between the master and remote stations. The first is complete message transfer on a single

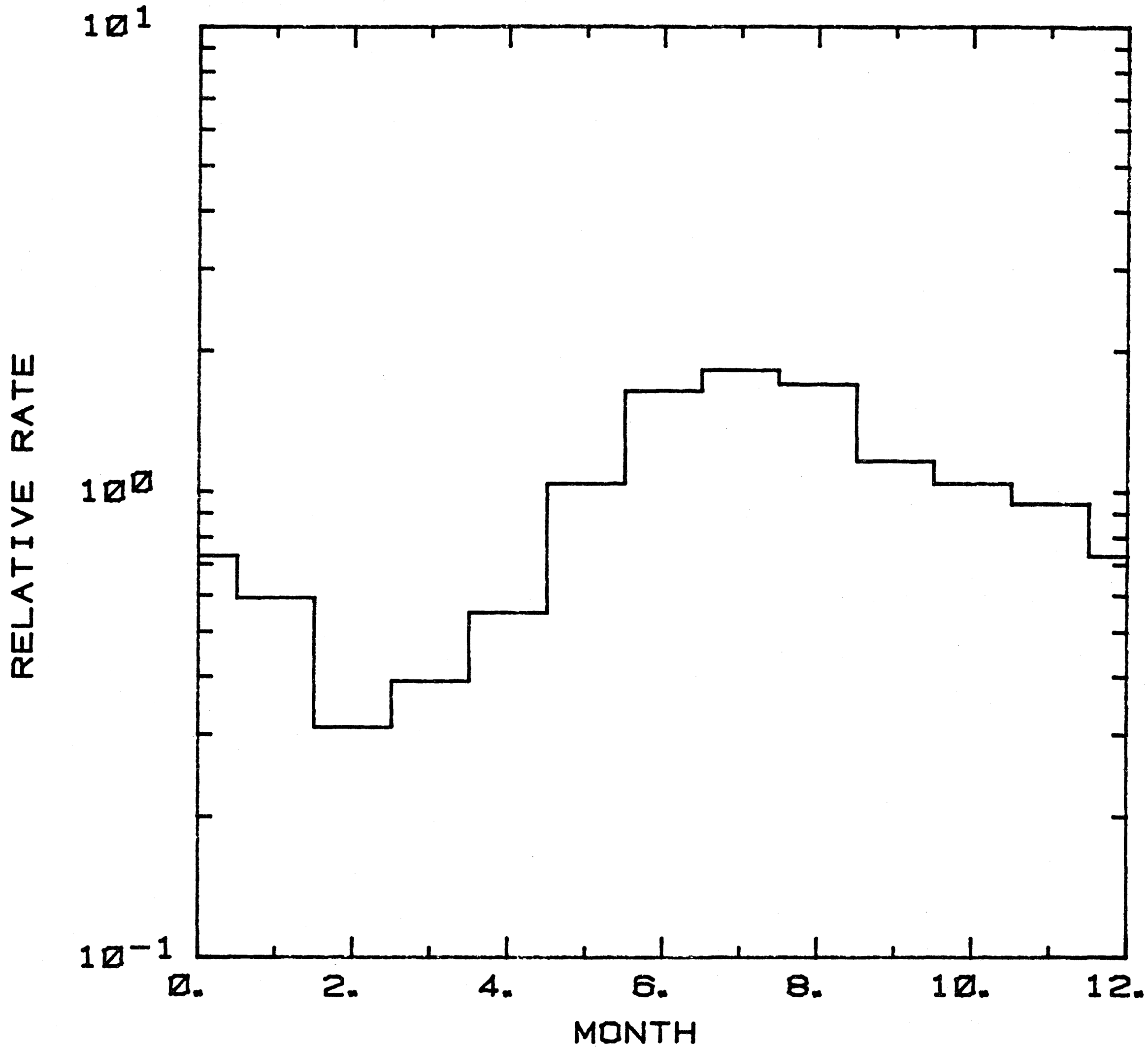


Figure 3. Typical seasonal variation of the relative meteor arrival rate (adopted from Spezio, 1978).

meteor burst. The second is message transfer by data piecing on multiple meteor bursts. The first method will work when there is a small amount of data to be sent on the meteor burst channel. For this case, the model rejects all meteor bursts that are less than the time required to complete the system overhead and the entire message. The second method uses all meteor events that are of sufficient duration to complete all of the system overhead and to transfer at least part of the data. On succeeding bursts, additional data are sent until the entire message has been transferred. Note that the current model will compute waiting time estimates for either message piecing or single burst transfer for a single meteor burst link, but only will compute waiting times for message piecing when a meteor burst network is selected.

3.2 Site Parameters

Site location

The site location is entered by providing the site's latitude and longitude. Either decimal degrees or degrees, minutes, and seconds can be entered. Positive values imply degrees North latitude and degrees East longitude. Negative values imply South latitude and West longitude.

Obstacles

At each site, the user can specify up to four obstacles relative to the station location. The primary purpose for this option is to compute signal blocking when directional antenna patterns are specified. The obstacles have no meaning when antenna patterns are not utilized in the model. Each obstacle is specified by giving its bearing or azimuth relative to North and its elevation relative to the local horizon.

Noise environment

The noise environment is used to compute the system noise power. The user has a choice of four qualitative levels to specify the man-made noise environment; they are 1) BUSINESS, 2) RESIDENTIAL, 3) RURAL, and 4) QUIET RURAL.

3.3 System Characteristics

Frequency

The peak received power from a meteor burst trail is inversely proportional to the system frequency. The normal range of this parameter is from 30 MHz to

120 MHz. Below 30 MHz, other modes of propagation besides meteor burst will dominate. Above 120 MHz, the space loss is so great that waiting times are intolerably long.

Antenna selection

Normally, if the locations of the master and remote station sites are known to each other, their antennas are positioned such that the main beams of the antennas are pointing along or slightly to the side of the great circle arc joining the master and remote stations. In addition, the main beam is slightly elevated above the local horizon. With this arrangement, the maximum interception of useful meteor trails is possible. If, on the other hand, the locations are not known to each other, the main beams from the master and remote stations may not intercept each other. For this case the model allows the user to specify a power gain pattern for the master and the remote stations. The user also specifies the main beam's azimuth and elevation angles for both stations' antennas. Antenna power gain patterns for several antenna types, e.g., dipole, are supplied by the model. The model then convolves the antenna gains for the two antennas given their main beam pointing angles relative to the great circle axis, the antenna types, and the distance separating the master and remote stations. Superimposed on the resultant gain pattern is a weighting function that accounts for the relative signal contributions from the various parts of the meteor region. This technique has been described by Heritage et al. (1977). The spatial distribution for useful meteor trails is shown in Figure 4. The weighting grid used by Heritage is shown in Figure 5. The grid assumed a path length of 1000 km; we will assume the grid weights stay the same regardless of the path length. But the grid size will shrink or expand as the path length changes. The user may specify the transmit and receive antennas either by their main beam gains or by a directional pattern.

Directional pattern

If the directional pattern option is chosen, the user will have to specify which pattern number is to be used by the model. Presently, three patterns are available: 1) OMNIDIRECTIONAL, 2) DIPOLE, and 3) HUNCHBACK (an inverted V-antenna). The omnidirectional pattern is available to compare directional pattern runs with

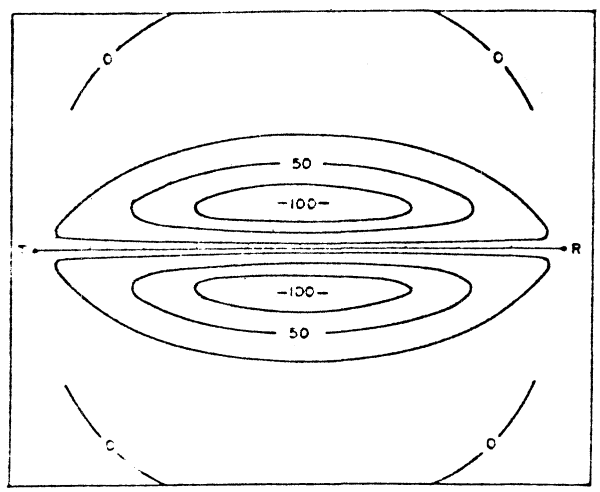
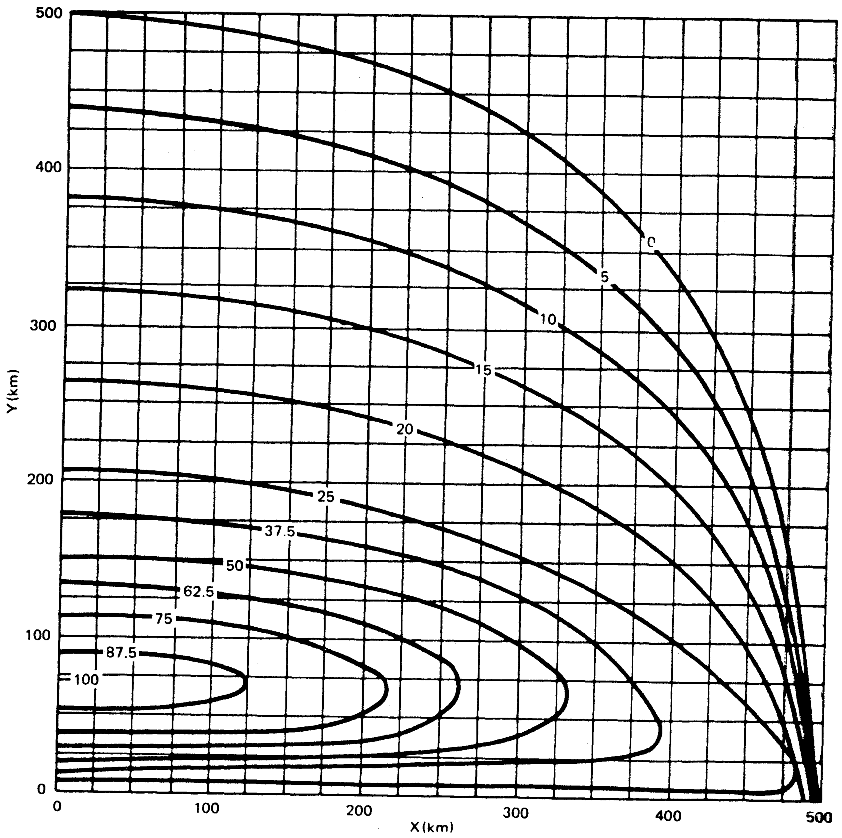


Figure 4. Relative effectiveness of meteor regions to support meteor burst communications between locations T and R (from Forsyth et al., 1957).



1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	3	3	3	2	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0
5	5	5	4	4	4	3	3	2	2	1	0	0	0	0	0	0	0	0	0
7	7	7	7	7	6	6	5	4	4	3	2	1	0	0	0	0	0	0	0
9	9	8	8	8	8	8	7	7	6	5	4	3	1	0	0	0	0	0	0
11	11	11	11	11	10	10	10	9	8	7	6	5	3	1	0	0	0	0	0
14	13	13	13	13	13	12	12	11	11	10	8	7	6	4	1	0	0	0	0
16	16	16	15	15	15	15	14	13	13	12	11	10	8	7	4	1	0	0	0
18	18	18	18	17	17	17	16	16	15	14	13	12	11	9	7	4	0	0	0
20	20	20	20	20	19	19	18	18	17	16	16	15	13	11	10	7	2	0	0
22	22	22	22	22	21	21	21	20	20	19	18	17	15	14	12	9	5	0	0
24	24	24	24	23	23	23	23	22	22	21	20	19	18	17	15	12	8	1	0
36	35	34	32	31	29	28	27	26	24	23	22	21	20	19	17	15	11	3	0
45	45	44	43	41	40	39	37	35	32	29	26	24	23	22	20	17	14	6	0
62	61	60	58	56	53	51	49	47	43	39	36	32	27	24	22	20	17	10	0
76	76	75	73	71	69	66	63	58	55	51	46	41	35	31	26	23	20	14	2
88	88	87	85	83	81	77	75	70	63	59	54	50	44	38	32	27	23	18	5
97	94	91	89	88	83	81	78	75	68	62	59	53	48	43	37	72	26	23	8
70	70	70	70	70	68	67	63	60	57	54	50	45	43	40	38	34	31	26	15
31	32	31	30	30	30	30	31	27	24	26	23	22	21	21	23	24	24	24	13

Figure 5. One quadrant grid showing weights for meteor effectiveness (from Heritage et al., 1977).

main beam gain runs. The dipole pattern is for a dipole that is 10 m above the ground at 50 MHz. Its gain versus elevation angle is shown in Figure 6. The hunchback pattern is at 37 MHz and its pattern is given in Figure 7. Along with the directional pattern number, the user will have to specify the pattern's main beam bearing angle relative to North and elevation angle relative to the local horizon. Because the pattern data is stored by the computer to the nearest integer value of gain, the patterns in Figures 6 and 7 are discrete rather than smooth curves.

Transmitter power

The peak received power is directly proportional to transmit power. Increasing the transmit power (and/or increasing antenna gains and/or decreasing the system noise power) increases the number of useful meteors to the communication system. This in turn lowers the waiting time to complete successful communications.

Transmitter and receiver line losses

If the transmitter power is known at the antenna terminals, then the transmitter line losses can be set to zero. Otherwise, the user supplies the line losses. The receiver line losses from the antenna terminals to the input to the receiver are needed to compute the system noise power.

Transmitter and receiver antenna power gain

The main beam gains are required if the user does not specify that the model is to use directional pattern data. Practical limits on antenna gain are 10 to 24 dBi. Below 10 dBi, the antenna illuminates too much of the sky which does not contain useful meteors. Above 24 dBi, the antenna size or antenna arrays are too large to be of use.

Receiver noise power

The receiver noise power is calculated from the receiver's noise figure and baseband bandwidth. As the data rate is increased, the bandwidth and noise power increases. Meteors that would have been available to the channel at the lower noise power are no longer acceptable at the higher noise power. This is offset by the higher data rate, however, since more data can be transferred on meteors that are available. A calculation of external noise is made to combine its level with the receiver noise power. The user is required to supply the receiver noise figure at the receiver's input and the receiver IF noise bandwidth. From these values and the man-made noise environment for the site, the model computes the system noise power.

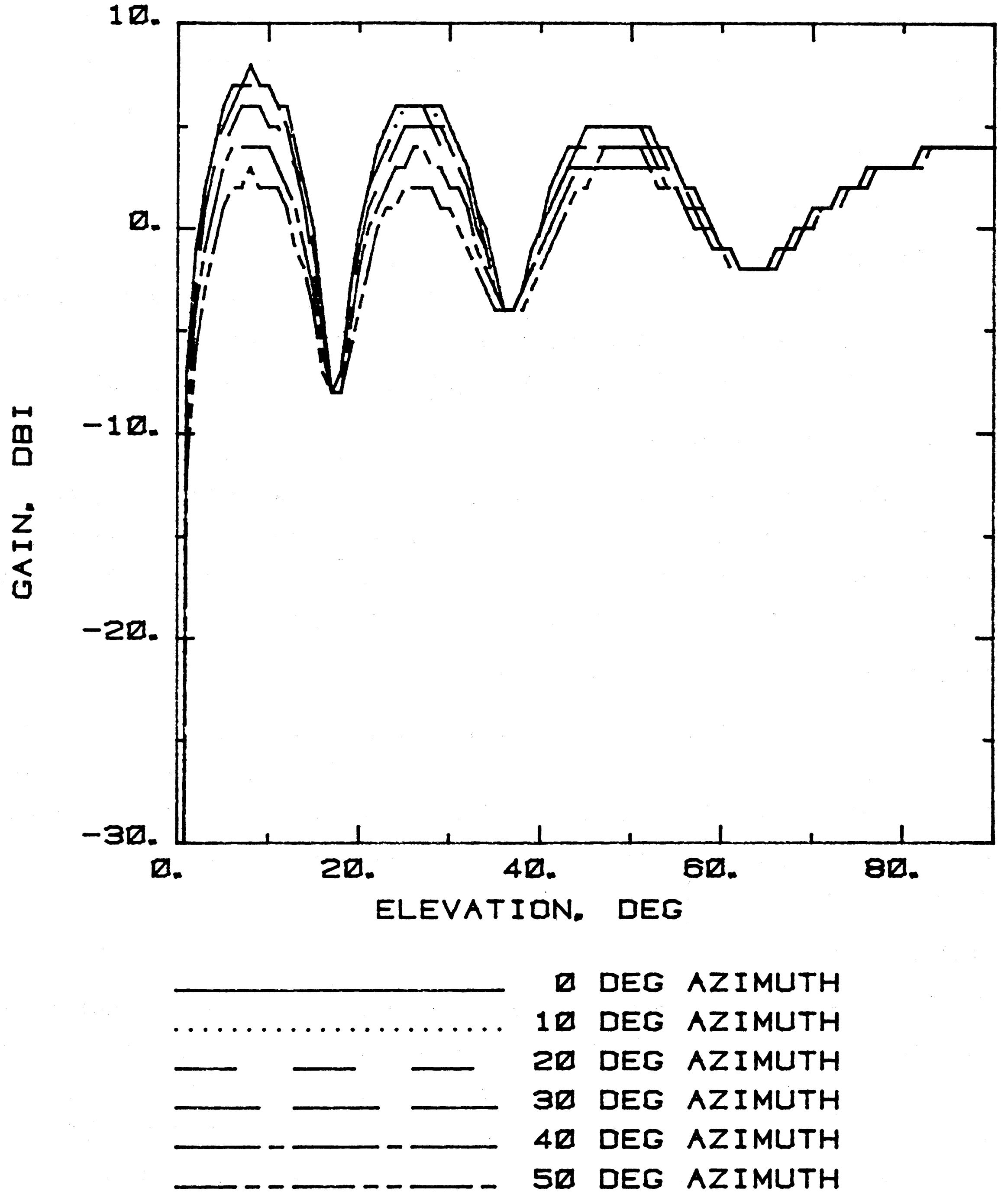


Figure 6. Power gain pattern for a dipole antenna, 10 m above ground, at 50 MHz.

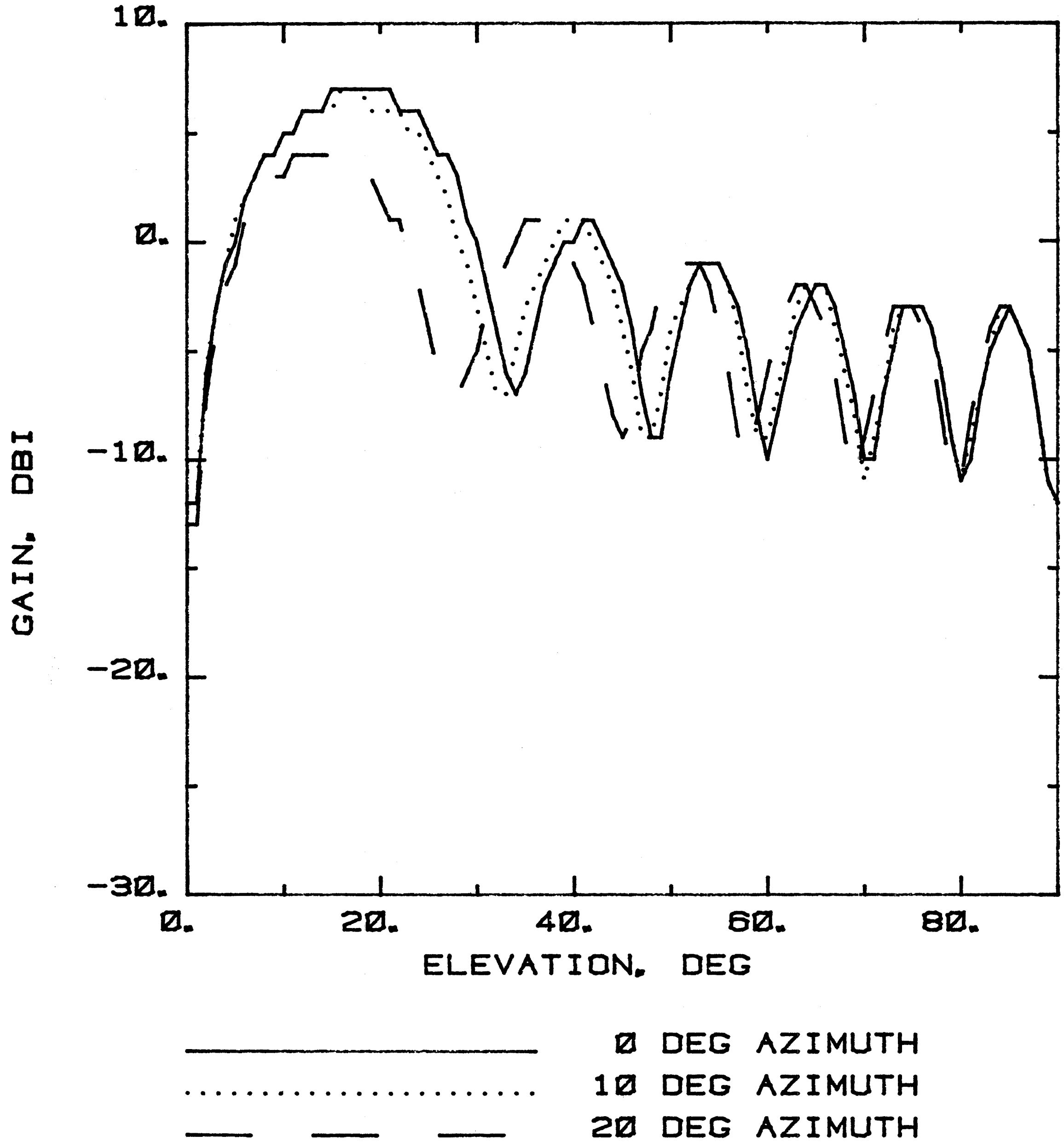


Figure 7. Power gain pattern for a hunchback antenna at 37 MHz.

Required predetection signal-to-noise threshold setting

The received signal threshold normally is set at that signal-to-noise ratio required to ensure a desired bit error rate. For example, a noncoherent FSK system requires 10-dB S/N to provide a bit error rate of one error bit in 1000 bits. The user can set the threshold higher than required to obtain the desired bit error rate. This may be done to allow only those meteor bursts with a high initial peak power to be used by the channel.

System overhead

System overhead is the required time on each new burst trail for synchronization, encryption, transmitter-receiver switching, and propagation delays. Examples of different system configurations and protocols are shown in Figure 8. Since there are so many different protocols that are possible, the user will supply a single number, the required overhead time per burst, rather than have the model ask for individual components of the system overhead.

3.4 Burst Statistics

Meteor arrival rates

Meteor burst communications systems that have monitored the arrival of available meteor trails have shown that the useful meteors arrive following a Poisson distribution. That is, the probability of exactly n useful meteors in time T is:

$$p(n|T) = \frac{(\bar{A}T)^n}{n!} \exp(-\bar{A}T)$$

where

$$\bar{A} = \text{average arrival rate of bursts.}$$

The parameter $\bar{A}$ is given in the literature as an empirical value. Its value depends upon the system characteristics, i.e., transmit power, antenna gains, and receiver threshold, and the time of year and time of day. The correspondence between $\bar{A}$ of a new system and $\bar{A}'$ of an operational system is given by the empirical relation:

Legend:

- P = probe
- S = sync and address
- M = message
- T_1 = idle time between probes $>2(DT)+T_2$
- T_2 = switching time from receive to transmit, remote
- T_3 = switching time from receive to transmit, master
- DT = one way delay time due to propagation
- T_4 = switching time from transmit to receive, master $<2(DT)+T_2$
- T_5 = switching time from transmit to receive, remote $<2(DT)+T_3$

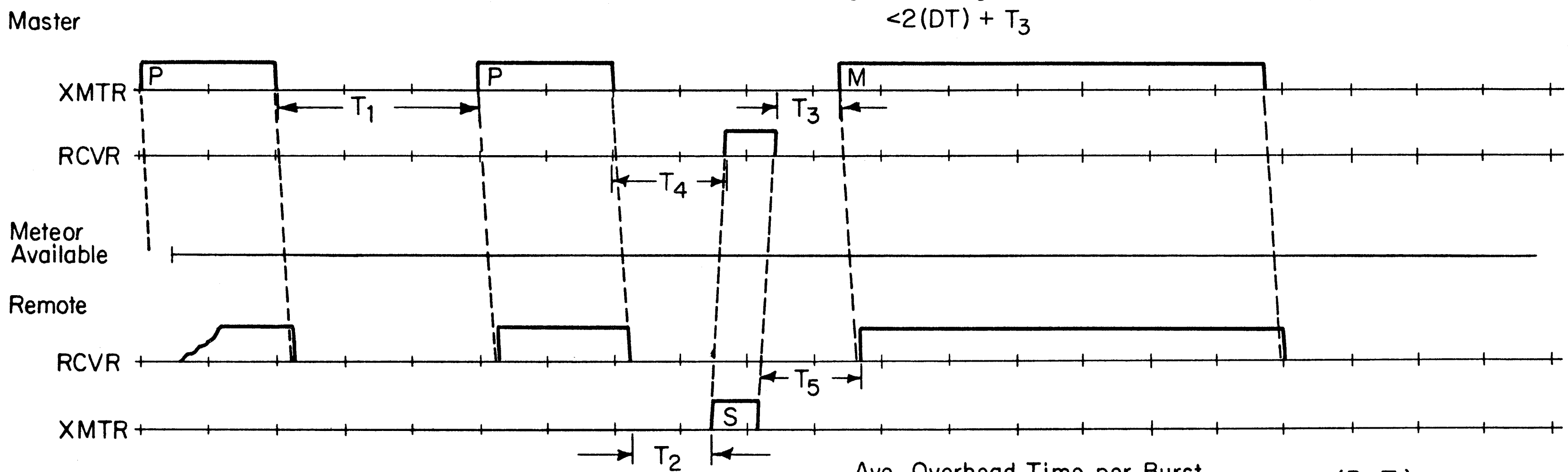
SYSTEM CONFIGURATION

Master-Simplex   Remote-Simplex

MESSAGE DIRECTION

Master to Remote

TIMING DIAGRAM



Ave. Overhead Time per Burst

$$T_{OH} = P + DT + T_2 + S + DT + T_3 + DT + \frac{(P+T_1)}{2}$$

Figure 8. Sample system configurations and timing diagrams to show how system overhead time per burst is derived.

SYSTEM CONFIGURATION

Master-Simplex Remote-Simplex

MESSAGE DIRECTION

Remote to Master

TIMING DIAGRAM

Legend:

- P = probe
- S = sync and address
- M = message
- T_1 = idle time between probes $>2(DT) + T_2$
- T_2 = switching time from receive to transmit, remote
- DT = one way delay time due to propagation
- T_3 = switching time from transmit to receive, master $<2(DT) + T_2$

Ave. Overhead Time per Burst

$$T_{OH} = P + DT + T_2 + S + DT + \frac{P+T_1}{2}$$

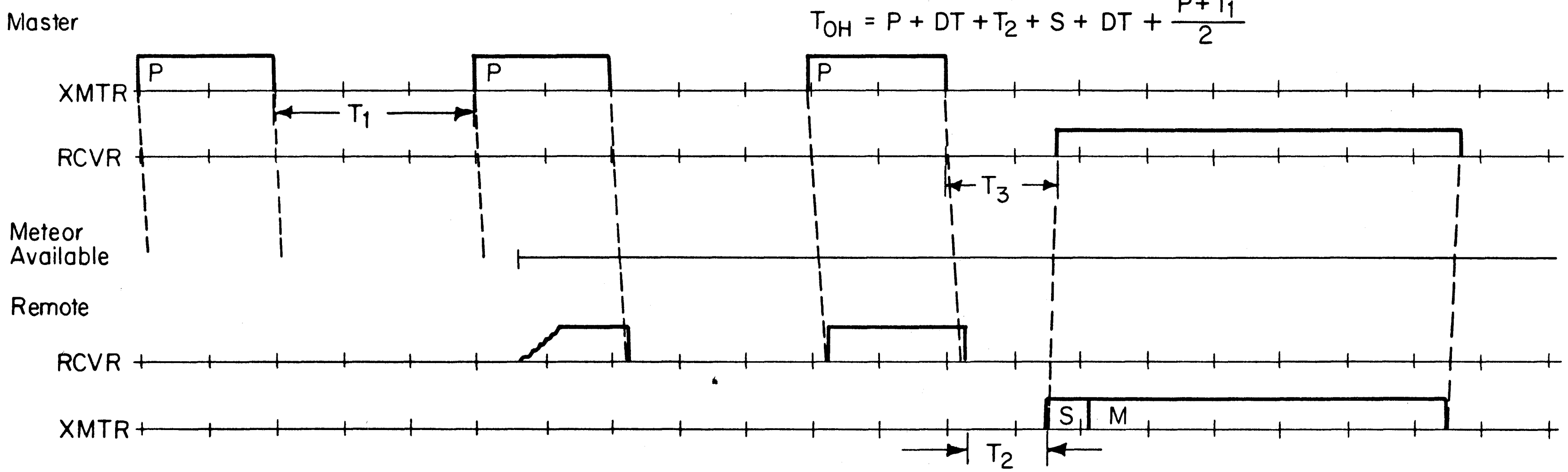


Figure 8. (Continued)

SYSTEM CONFIGURATION

Master-Duplex Remote-Simplex

MESSAGE DIRECTION

Master to Remote

Legend:

- P = probe
- S = sync and address
- M = message
- T_1 = switching time from receive to transmit, remote
- T_2 = switching time from transmit to receive, remote $< 2*DT$
- DT = one way delay time due to propagation

TIMING DIAGRAM

Ave. Overhead Time per Burst

$$T_{OH} = P + DT + T_1 + S + DT + DT + \frac{P}{2}$$

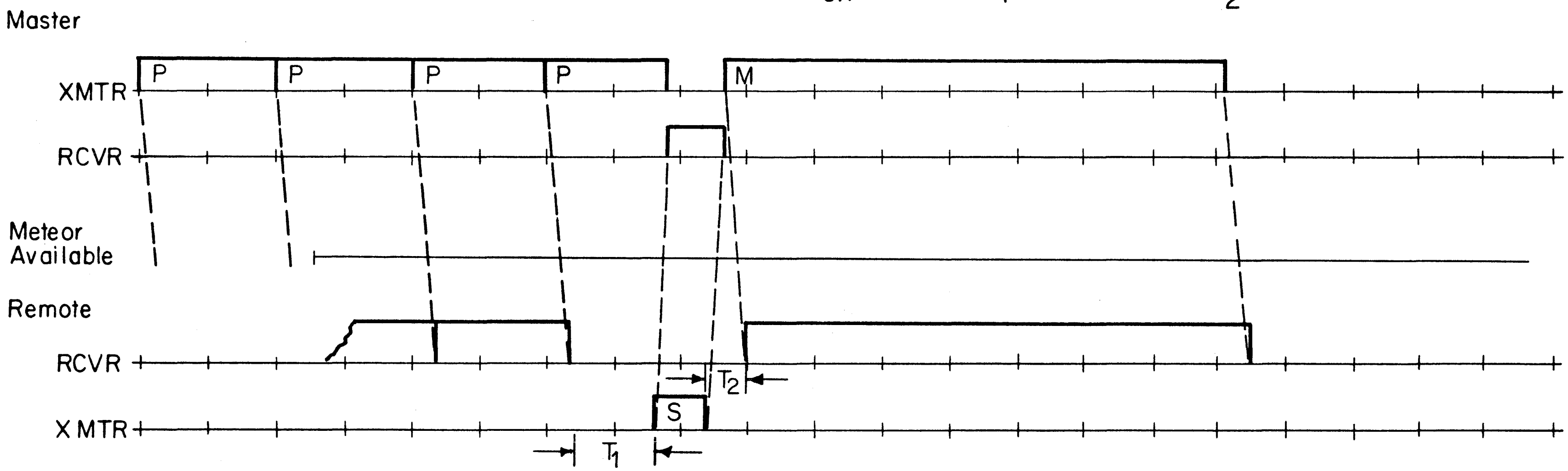


Figure 8. (Continued)

SYSTEM CONFIGURATION

Master-Duplex   Remote-Simplex

MESSAGE DIRECTION

Remote to Master

Legend:
- P = probe
- S = sync and address
- M = message
- T_1 = switching time from receive to transmit, remote
- DT = one way delay time due to propagation

Ave Overhead Time per Burst

$$T_{OH} = P + DT + T_1 + S + DT + \frac{P}{2}$$

TIMING DIAGRAM

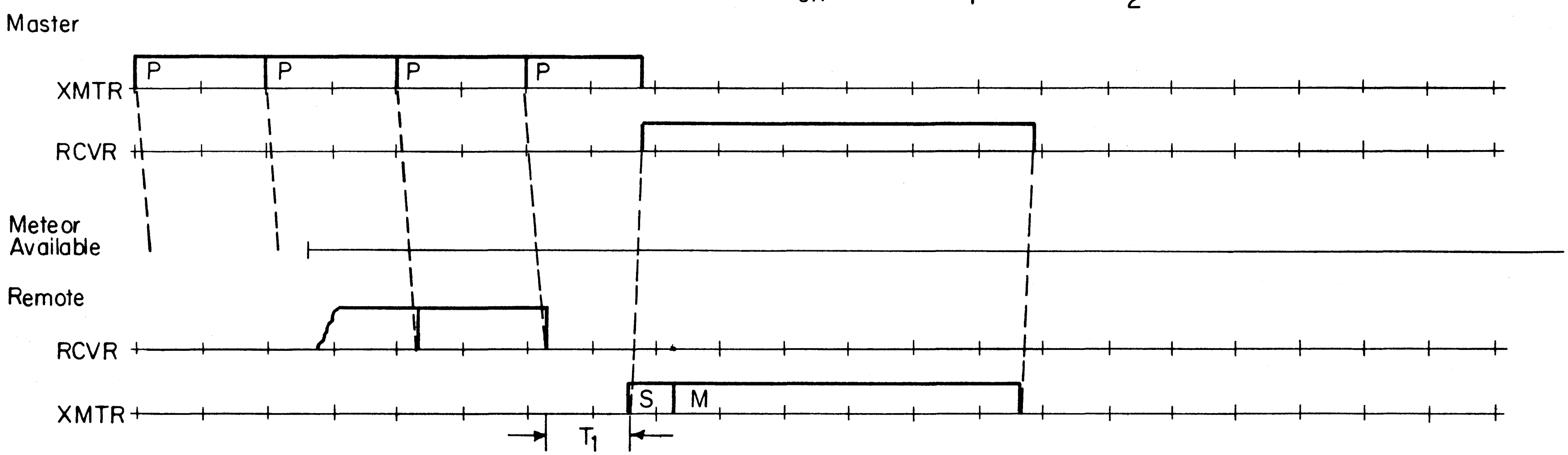


Figure 8. (Continued)

SYSTEM CONFIGURATION

Master-Broadcast   Remote-Receive Only

MESSAGE DIRECTION

Master to Remote

Legend:
P = probe
M = message
P+M < ave. burst time duration
N = number of repetitions of message

TIMING DIAGRAM

N(P+M) > Ave. Time between bursts

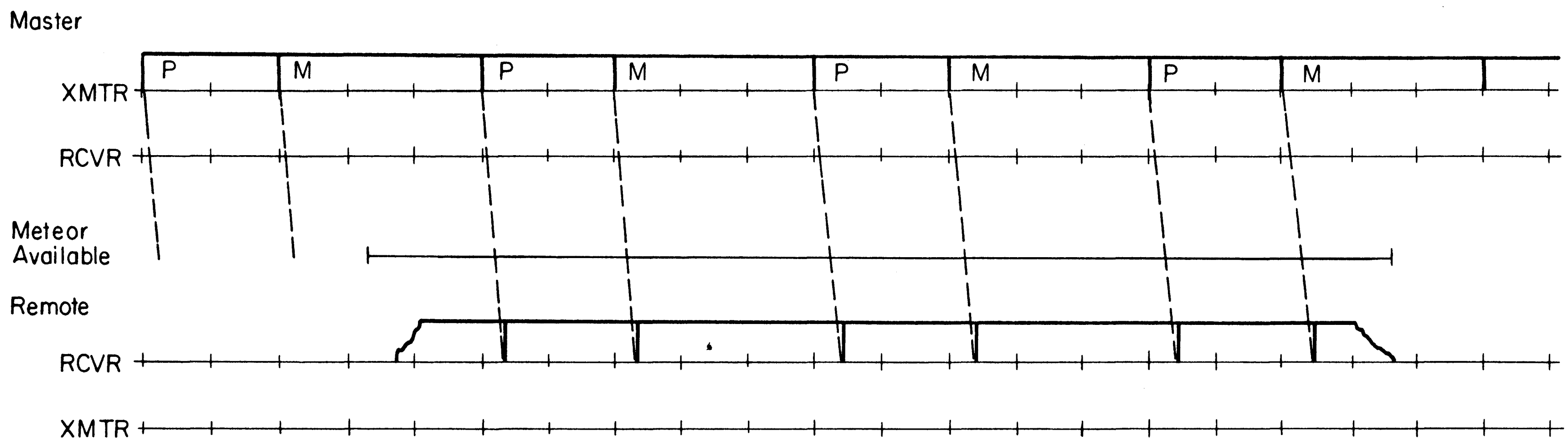


Figure 8. (Continued)

$$\overline{A} = \overline{A}' \left(\frac{P \ G_t \ G_r \ R'}{P' \ G_t' \ G_r' \ R} \right)^{1/2} \left(\frac{f'}{f} \right)^{3/2}$$

where

P = transmit power

G_t = transmit antenna gain

G_r = receive antenna gain

R = receive threshold

f = carrier frequency

The primed parameters refer to values obtained from the operational system. The value of $\overline{A}$ is the yearly average arrival rate. To determine rates for a particular month and hour, $\overline{A}$ is modified by two factors. F_M is the multiplier which accounts for the variations in meteor arrivals over the year, and F_H is the multiplier that adjusts $\overline{A}$ for the local time of day variations. Thus, the predicted instantaneous meteor arrival rate, A, is

$$A = \overline{A} \ F_M \ F_H \quad .$$

The data used as F_M and F_H by the model are shown in Figures 3 and 9.

Oetting (1980) states that A varies as a function of distance separation between the master and remote stations. He relates A at distances between 200 and 2000 km to A at 1000 km by:

$$A = A(1000) \ g(d)$$

where

$$g(d) = \begin{cases} 0.58 & 200 < d < 480 \text{ km} \\ d/770 & 480 < d < 770 \text{ km} \\ 1 & 770 < d < 1280 \text{ km} \\ 1 - 0.0006(d-1280) & 1280 < d < 2000 \text{ km.} \end{cases}$$

Duration Times

The time duration of the meteor burst trail is exponentially distributed; that is, the probability that the received signal will last exactly the time t is:

$$p(t) = \frac{\exp(-t/T_D)}{T_D}$$

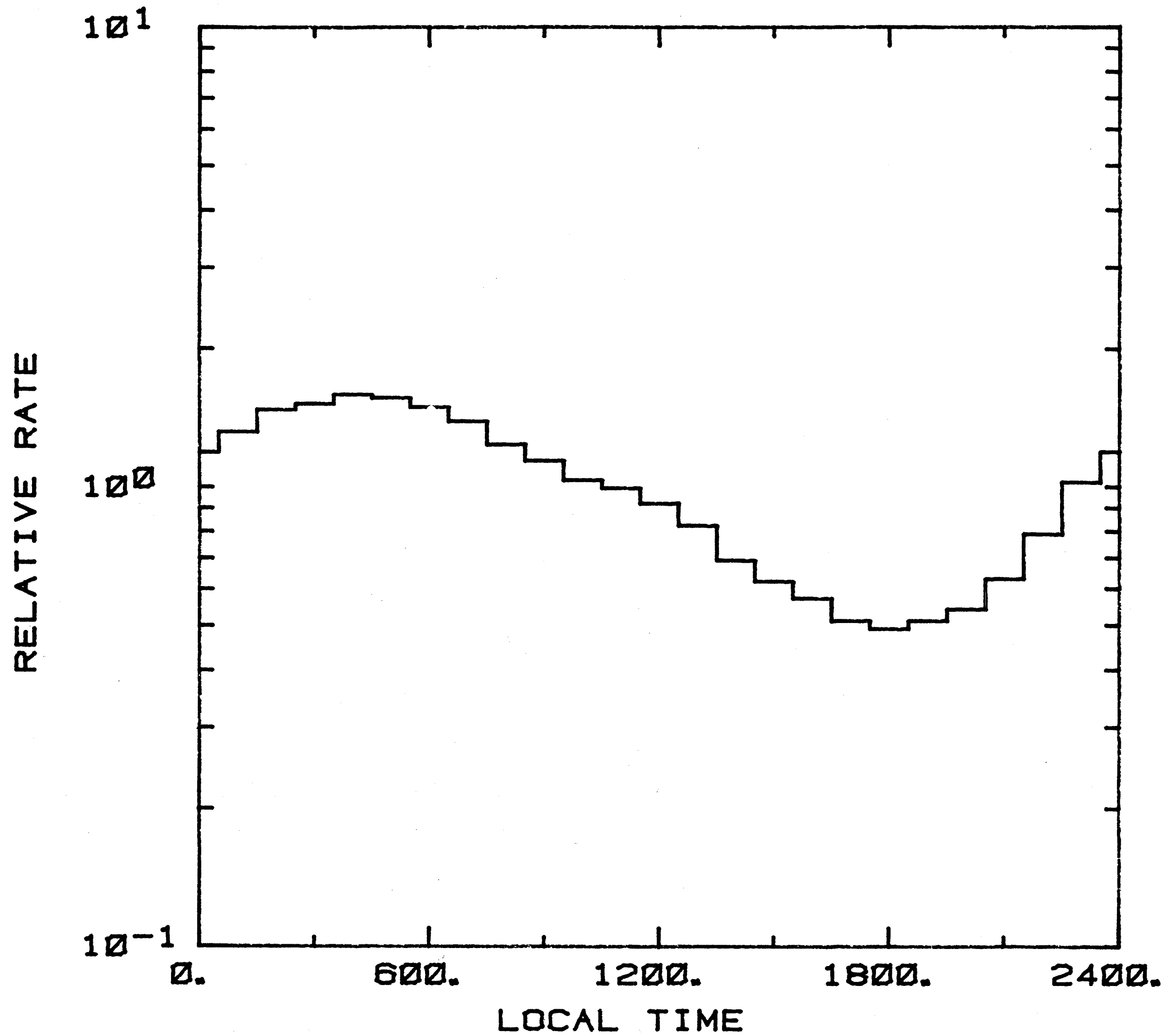


Figure 9. Typical diurnal variation of the relative meteor arrival rate (adopted from Forsyth et al., 1977).

where

$$T_D = \text{average burst duration.}$$

The value of T_D varies as function of the distance separation between the master and remote stations and the frequency (see Eq. 9, pg. 123, Sugar, 1964):

$$T_D = \frac{\lambda \sec(a)}{4\pi} \cdot \frac{1}{D}$$

where

a = one-half of the forward scattering angle
D = ambipolar diffusion coefficient, m^2/s
= 1 to 10 (set to 8 in the model).

Under-dense and over-dense trails

Meteor trails fall into two categories, under-dense and over-dense. Meteors that have ionized the air with free electrons of 10^{14} electrons per meter or greater are called over-dense trails. Meteors leaving trails with less than 10^{14} electrons per meter are called under-dense. The received signal from the two types of trails have different time waveforms as shown by Figure 10. The under-dense trails are more numerous but require more system sensitivity or greater transmitter power, etc., to detect. Because the waiting times are too long to operate only with over-dense trails, most meteor burst communications systems are designed to work with under-dense trails. This model is developed for the under-dense case. The literature indicates that the switch from an under-dense to an over-dense situation can occur from changes in system sensitivity as small as 6-dB in some cases or as large as 20 or 30-dB in other cases. The literature implies that actual measurements on the particular system are required to determine where the switch from under-dense to over-dense occurs. Meteor Communications Consultants (1980) have estimated, presumably from their own experience, that the switch occurs at a particular power factor level. This model will inform the user whenever the calculated power factor has dropped below MCC's critical level. The model does not attempt to estimate waiting times based on over-dense trails.

Waiting times

The user can select two different methods for computing waiting times. The first method waits until there is a burst of sufficient duration that allows

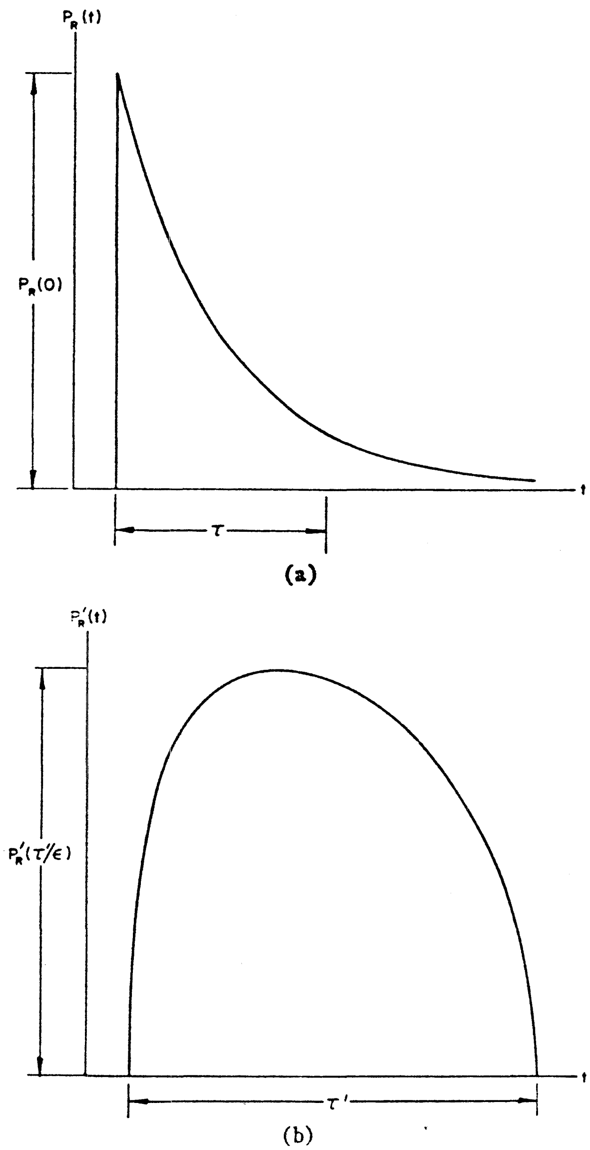


Figure 10. Idealized time variations in signals from (a) under-dense and (b) over-dense meteor trails (from Forsyth et al., 1977).

completion of the protocol and full message transfer. The second method waits until there are bursts of sufficient duration to complete all of the protocol and part of the message or data transfer. On successive available meteor trails, the protocol and more of the message is sent. Waiting time performance can be calculated for the first method that is identified as single burst message transfer. The model first eliminates all meteors that are too short to allow complete message transfer. Recall that the distribution of burst durations is exponentially distributed. Eliminating the short duration bursts result in:

$$A_S = A \exp(-S/D)$$

where

A_S = the meteor arrival rate that exceed the complete message time and exceed the receiver threshold

A = the meteor arrival rate that exceeds the receiver threshold

S = the time required to complete the protocol and transfer the entire message

D = the average burst time duration.

Finally, the probability of completing the single burst message transfer in time T is:

$$P(T) = 1 - \exp(-A_S T).$$

The second method is called message transfer by data piecing on multiple meteor bursts. The number of available meteors is reduced in a manner similar to that used for single burst transfer analysis. The probability of completing the message on multiple bursts requires finding the sum of n bursts having time durations exponentially distributed with an average duration of D seconds. This follows a gamma distribution. Details of the analysis are in the report by Oetting (1980).

Network

The network calculations are patterned after the work of Berry (1982). Using Figure 2, we outline the procedure that is followed with the following notation:

yABCD - Defines the communications link that starts at terminal A and ends at terminal D with intermediate hops to terminals B and C. If the link is direct from A to D, the link is noted as yAD, etc.

fABCD - Defines the probability density function for communications along the link from A to B to C to D. If the link is a single hop from A to D, the probability density function is noted as fAD, etc.

pABCD - Defines the probability distributions along the link from A to B to C to D, etc.

1. Compute the probability density functions (pdf) for all direct links:

   links: y12, y13, y14, y23, y24, y32, y34
   pdfs : f12, f13, f14, f23, f24, f32, f34

2. Compute pdfs of three- and four-node paths by convolving pdfs of direct links (assume node 1 and node 4 are the master and remote sites):

   paths: y124, y134, y1234, y1324
   pdfs : f124, f134, f1234, f1324

3. Compute probability distributions (pd) of paths by integrating individual pdfs:

   paths: y14, y124, y134, y1234, y1324
   pds : p14, p124, p134, p1234, p1324

4. Compute pds of independent subnetworks:

   P(A) network A: y14, y124, y134
   P(B) network B: y1234, y1324

5. Compute approximate pd of the network where the bounds are:

   P < = P(A) + P(B) - P(A)P(B
   P > maximum of (P(A) and P(B))

6. Find the time t such that:

   p(t) = desired communications reliability by interpolation.

Figure 11 gives a complete sample of the input and output for program BURST when the network option is selected. Initially four sites are selected for the network and the user provides the data describing the sites and associated stations. The program computes waiting time estimates to move a message from site 1 to site 2. The user then edits the data set to eliminate site 4. The program then computes the waiting time estimates based on three sites in the network. Finally, the user edits the data set to remove the third site and commands the program to compute waiting time estimates for just the two sites in the network. Notice that the minimum waiting times occurred with the four site network.

```
Enter command (first four characters is enough): BURST


          INSTITUTE FOR TELECOMMUNICATION SCIENCES

             METEOR BURST COMMUNICATIONS MODEL
                        VERSION 1.0

                 WED 22 SEP 1982  10:56:40


CHOOSE FROM THE MENU:
     H=HELP
     D=PROGRAM DESCRIPTION
     C=CONCISE DIALOG
     V=VERBOSE DIALOG
     E=EDIT DATA
     S=SUMMARY OF DATA
     P=PROCESS LAST DATA SET ENTERED
     Q=QUIT

MENU(VERBOSE)=? C          <----------   concise dialog selected


ENTER INPUT DATA
 1) NO. OF SITES( 2)? 4    <----------   while entering data in the
 2) MONTH OF OPERATION( 5)?              concise dialog, detailed
 3) RELIABLITY(99.00 %)?                 parameter descriptions are
 4) MESSAGE TIME(   75.0 MS)?            not given; to get a verbose
 5) MESSAGE OPT(MESS PIECING)?           description, type ?? in
                                         response to the question.

ENTER DATA FOR SITE  1
10) SITE  1 LAT( 40.5000 DEG N OR  40,30, 0 DMS N)? 30.5
10) SITE  1 LON( 105.7500 DEG W OR  105,45, 0 DMS W)?
11) NO. OF OBSTACLES( 0)?
14) NOISE(QUIET RURAL )?
15) NO. OF FREQUENCIES( 1)?


ENTER DATA FOR SITE  1  FREQUENCY  1
20) FREQ(   30.0 MHZ)?
21) ANT OPTION(GAIN ONLY )?
25) XMTR PW(      30.0 DBW)?
26) XMTR LINE LOSS(   2.0 DB)?
27) XMTR GN(  15.0 DBI)?
```

Figure 11. Simple dialog between a user and program BURST for three combinations of a network.

```
30) RCVR GN(  15.0 DBI)?
31) ANT CKT LOSS(    0.0 DB)?
32) RCVR LINE LOSS(    2.0 DB)?
33) RCVR NOISE FIG( 10.0)?
34) RCVR IF BW(  2.000 KHZ)?
35) REQ'D S/N(    3.0 DB)?
36) SYS OVERHEAD(   83.0 MS)?


ENTER DATA FOR SITE  2
10) SITE  2 LAT( 49.5788 DEG N OR  49,34,44 DMS N)? 42.084
10) SITE  2 LON( 115.9818 DEG W OR  115,58,54 DMS W)? -105.75
11) NO. OF OBSTACLES( 0)?
14) NOISE(QUIET RURAL )?
15) NO. OF FREQUENCIES( 1)?


ENTER DATA FOR SITE  2  FREQUENCY  1
20) FREQ(   30.0 MHZ)?
21) ANT OPTION(GAIN ONLY )?
25) XMTR PW(      30.0 DBW)?
26) XMTR LINE LOSS(    2.0 DB)?
27) XMTR GN(    7.0 DBI)?
30) RCVR GN(    7.0 DBI)?
31) ANT CKT LOSS(    0.0 DB)?
32) RCVR LINE LOSS(    2.0 DB)?
33) RCVR NOISE FIG( 10.0)?
34) RCVR IF BW(  2.000 KHZ)?
35) REQ'D S/N(    3.0 DB)?
36) SYS OVERHEAD(   83.0 MS)?


ENTER DATA FOR SITE  3
10) SITE  3 LAT( 34.5436 DEG N OR  34,32,37 DMS N)? 35.2868
10) SITE  3 LON( 112.2342 DEG E OR  112,14, 3 DMS E)? -89.4479
11) NO. OF OBSTACLES( 0)?
14) NOISE(  BUSINESS  )? QU
15) NO. OF FREQUENCIES( 1)?


ENTER DATA FOR SITE  3  FREQUENCY  1
20) FREQ(   34.0 MHZ)? 30
21) ANT OPTION(GAIN ONLY )?
25) XMTR PW(      23.0 DBW)?
26) XMTR LINE LOSS(    1.0 DB)? 2
27) XMTR GN(  17.0 DBI)? 15
30) RCVR GN(    9.0 DBI)? 15
31) ANT CKT LOSS(    0.0 DB)?
32) RCVR LINE LOSS(    1.0 DB)? 2
33) RCVR NOISE FIG(  6.0)? 9
34) RCVR IF BW(  1.500 KHZ)? 2
35) REQ'D S/N(    8.0 DB)? 3
36) SYS OVERHEAD(   76.0 MS)? 83
```

Figure 11. (Cont.)

```
ENTER DATA FOR SITE  4
10) SITE  4 LAT( 46.7886 DEG N OR  46,47,19 DMS N)? 34.7603
10) SITE  4 LON( 109.7444 DEG E OR  109,44,40 DMS E)? -125.7930
11) NO. OF OBSTACLES( 3)? 1
12) OBS BEAR( 330.0 DEG)? 20
13) OBS ELEV(    4.0 DEG)? 1.5
14) NOISE(QUIET RURAL )?
15) NO. OF FREQUENCIES( 1)?


ENTER DATA FOR SITE  4   FREQUENCY  1
20) FREQ(    30.7 MHZ)? 30.
21) ANT OPTION(GAIN ONLY )?
25) XMTR PW(      30.0 DBW)?
26) XMTR LINE LOSS(    2.0 DB)?
27) XMTR GN(   17.0 DBI)?
30) RCVR GN(    7.0 DBI)? 17
31) ANT CKT LOSS(    0.0 DB)?
32) RCVR LINE LOSS(    2.0 DB)?
33) RCVR NOISE FIG(   3.0)?
34) RCVR IF BW(  2.000 KHZ)?
35) REQ'D S/N(     3.0 DB)?
36) SYS OVERHEAD(    83.0 MS)?

INPUT OF DATA IS COMPLETE

DO YOU WANT A SUMMARY OF THE INPUT DATA? (Y OR N) Y
```

METEOR BURST INPUT SUMMARY

1)	NUMBER OF SITES	4
2)	MONTH OF OPERATION	MAY
3)	RELIABILITY	99.0 %
4)	MESSAGE TIME	75. MS
5)	MESSAGE OPTION	MESSAGE PIECING

10) LOCATION

SITE	LATITUDE (DEG)	LATITUDE (D M S)	LONGITUDE (DEG)	LONGITUDE (D M S)
1	30.5000 N	30 30 0 N	105.7500 W	105 45 0 W
2	42.0840 N	42 5 2 N	105.7500 W	105 45 0 W
3	35.2868 N	35 17 12 N	89.4479 W	89 26 52 W
4	34.7603 N	34 45 37 N	125.7930 W	125 47 35 W

Figure 11. (Cont.)

OBSTACLE DATA

SITE	11) NUMBER	12) BEARING (DEG E OF N)	13) ELEVATION (DEG ABOVE HORIZON)	14) NOISE ENVIRONMENT	15) NO. OF FREQUENCIES
1	0			QUIET RURAL	1
2	0			QUIET RURAL	1
3	0			QUIET RURAL	1
4	1	20.0	1.5	QUIET RURAL	1

				ANTENNA PATTERN DATA			TRANSMITTER DATA		
SITE	FREQ NO.	20) FREQ	21) ANT OPTION	22) NO.	23) BEARING (DEG E OF N)	24) ELEVATION (DEG ABOVE HORIZON)	25) POWER (DBW)	26) LINE LOSSES (DB)	27) ANT GAIN (DBI)
1	1	30.00	GAIN				30.00	2.0	15.00
2	1	30.00	GAIN				30.00	2.0	7.00
3	1	30.00	GAIN				23.00	2.0	15.00
4	1	30.00	GAIN				30.00	2.0	17.00

RECEIVER DATA

SITE	FREQ NO.	30) ANT GAIN (DBI)	31) ANT CKT LOSS (DB)	32) LINE LOSSES (DB)	33) NOISE FIGURE (DB)	34) IF BANDWIDTH (KHZ)	35) REQ'D SIG-TO-NOISE (DB)	36) SYS OVERHEAD (MS)
1	1	15.0	0.0	2.0	10.0	2.000	3.0	83.
2	1	7.0	0.0	2.0	10.0	2.000	3.0	83.
3	1	15.0	0.0	2.0	9.0	2.000	3.0	83.
4	1	17.0	0.0	2.0	3.0	2.000	3.0	83.

DO YOU WANT TO PROCESS THIS DATA? (Y OR N) Y

To stop the listing, type the BREAK key. The computer will print
    S=XX COMMAND ?
Then you type
    BR <carriage return>
The listing should stop after a few lines.

METEOR BURST CALCULATIONS

CALCULATIONS OF ESTIMATED WAITING TIME OPTION
  S = SINGLE LINK
  N = NETWORK, ALL POSSIBLE LINKS
CALCULATIONS OPTION (SINGLE LINK)? N

Figure 11. (Cont.)

```
SITE NUMBER FOR THE NETWORK'S  INITIAL STATION (1 TO  4)
NETWORK'S  INITIAL SITE NO. ( 1)? 1

SITE NUMBER FOR THE NETWORK'S TERMINAL STATION (1 TO  4)
NETWORK'S TERMINAL SITE NO. ( 4)? 2

SITE 1-TO-SITE 2 LINK CARRIER FREQUENCY, MHZ
NODE 1-TO-NODE 2 TRANSMIT FREQ (30.0 MHZ)?

SITE 2-TO-SITE 1 LINK CARRIER FREQUENCY, MHZ
NODE 2-TO-NODE 1 TRANSMIT FREQ (30.0 MHZ)?

SITE 1-TO-SITE 3 LINK CARRIER FREQUENCY, MHZ
NODE 1-TO-NODE 3 TRANSMIT FREQ (30.0 MHZ)?

SITE 3-TO-SITE 1 LINK CARRIER FREQUENCY, MHZ
NODE 3-TO-NODE 1 TRANSMIT FREQ (30.0 MHZ)?

SITE 1-TO-SITE 4 LINK CARRIER FREQUENCY, MHZ
NODE 1-TO-NODE 4 TRANSMIT FREQ (30.0 MHZ)?

SITE 4-TO-SITE 1 LINK CARRIER FREQUENCY, MHZ
NODE 4-TO-NODE 1 TRANSMIT FREQ (30.0 MHZ)?

SITE 2-TO-SITE 3 LINK CARRIER FREQUENCY, MHZ
NODE 2-TO-NODE 3 TRANSMIT FREQ (30.0 MHZ)?

SITE 3-TO-SITE 2 LINK CARRIER FREQUENCY, MHZ
NODE 3-TO-NODE 2 TRANSMIT FREQ (30.0 MHZ)?

SITE 2-TO-SITE 4 LINK CARRIER FREQUENCY, MHZ
NODE 2-TO-NODE 4 TRANSMIT FREQ (30.0 MHZ)?

SITE 4-TO-SITE 2 LINK CARRIER FREQUENCY, MHZ
NODE 4-TO-NODE 2 TRANSMIT FREQ (30.0 MHZ)?

SITE 3-TO-SITE 4 LINK CARRIER FREQUENCY, MHZ
NODE 3-TO-NODE 4 TRANSMIT FREQ (30.0 MHZ)?

SITE 4-TO-SITE 3 LINK CARRIER FREQUENCY, MHZ
NODE 4-TO-NODE 3 TRANSMIT FREQ (30.0 MHZ)?

            COMPLETE MESSAGE TRANSFER BY MESSAGE PIECING
                        ON MULTIPLE BURSTS
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Figure 11. (Cont.)

LOCAL TIME MIDPOINT BETWEEN MASTER AND REMOTE	AVERAGE INTERVAL BETWEEN BURSTS	USER-DEFINED 75 MS	50 MS	100 MS	200 MS	400 MS	800 MS	1600 MS
		WAITING TIMES NOT EXCEEDED FOR 99.00% OF THE TIME FOR THE GIVEN MESSAGE TIME						
	(SEC)	(SEC)	(SEC)	(SEC)	(SEC)	(SEC)	(SEC)	(SEC)
0	1.6	9	9	9	9	10	13	18
200	1.4	8	8	8	9	10	11	15
400	1.3	8	8	8	8	9	11	15
600	1.5	9	8	9	9	10	12	17
800	1.8	10	9	10	10	12	14	21
1000	2.1	11	11	11	12	14	17	24
1200	2.5	13	13	14	15	17	21	28
1400	3.4	17	17	18	19	21	26	37
1600	4.1	20	20	21	22	26	33	46
1800	4.1	20	20	21	22	26	33	46
2000	3.3	17	17	17	19	21	26	37
2200	2.0	11	10	11	12	13	17	23

Estimated waiting times with 4 stations in the network.

MENU(CONCISE)=? E

QUESTION NUMBER? 1
 1) NO. OF SITES(4)? 3 ← Change to 3 stations in the network.

QUESTION NUMBER?

DO YOU WANT A SUMMARY OF THE INPUT DATA? (Y OR N) N

DO YOU WANT TO PROCESS THIS DATA? (Y OR N) Y

METEOR BURST CALCULATIONS

CALCULATIONS OPTION (SINGLE LINK)? N
NETWORK'S INITIAL SITE NO. (1)?
NETWORK'S TERMINAL SITE NO. (3)? 2
NODE 1-TO-NODE 2 TRANSMIT FREQ (30.0 MHZ)?
NODE 2-TO-NODE 1 TRANSMIT FREQ (30.0 MHZ)?
NODE 1-TO-NODE 3 TRANSMIT FREQ (30.0 MHZ)?
NODE 3-TO-NODE 1 TRANSMIT FREQ (30.0 MHZ)?
NODE 2-TO-NODE 3 TRANSMIT FREQ (30.0 MHZ)?
NODE 3-TO-NODE 2 TRANSMIT FREQ (30.0 MHZ)?

COMPLETE MESSAGE TRANSFER BY MESSAGE PIECING
ON MULTIPLE BURSTS

Figure 11. (Cont.)

LOCAL TIME MIDPOINT BETWEEN MASTER AND REMOTE	AVERAGE INTERVAL BETWEEN BURSTS	WAITING TIMES NOT EXCEEDED FOR 99.00% OF THE TIME FOR THE GIVEN MESSAGE TIME						
		USER-DEFINED 75 MS	50 MS	100 MS	200 MS	400 MS	800 MS	1600 MS
	(SEC)	(SEC)	(SEC)	(SEC)	(SEC)	(SEC)	(SEC)	(SEC)
0	3.1	14	14	14	15	17	21	27
200	2.7	12	12	13	13	15	18	24
400	2.6	12	12	12	13	15	18	23
600	3.0	13	13	14	15	16	20	26
800	3.6	16	16	16	18	20	24	31
1000	4.2	18	18	19	20	23	27	36
1200	5.0	22	22	23	24	27	33	43
1400	6.6	29	28	30	32	36	43	57
1600	8.1	35	34	36	38	43	53	69
1800	8.1	35	34	36	38	43	53	69
2000	6.5	29	28	29	31	35	43	56
2200	4.0	18	18	18	20	22	27	35

Estimated waiting times with 3 stations in the network.

MENU(CONCISE)=? EDIT

QUESTION NUMBER? 1
1) NO. OF SITES(3)? 2 ← Change to 2 stations in the network.

QUESTION NUMBER?

DO YOU WANT A SUMMARY OF THE INPUT DATA? (Y OR N) N

DO YOU WANT TO PROCESS THIS DATA? (Y OR N) Y

METEOR BURST CALCULATIONS

CALCULATIONS OPTION (SINGLE LINK)? N
NETWORK'S INITIAL SITE NO. (1)?
NETWORK'S TERMINAL SITE NO. (2)?
NODE 1-TO-NODE 2 TRANSMIT FREQ (30.0 MHZ)?
NODE 2-TO-NODE 1 TRANSMIT FREQ (30.0 MHZ)?

COMPLETE MESSAGE TRANSFER BY MESSAGE PIECING
ON MULTIPLE BURSTS

Figure 11. (Cont.)

LOCAL TIME MIDPOINT BETWEEN MASTER AND REMOTE	AVERAGE INTERVAL BETWEEN BURSTS	WAITING TIMES NOT EXCEEDED FOR 99.00% OF THE TIME FOR THE GIVEN MESSAGE TIME: USER-DEFINED 75 MS	50 MS	100 MS	200 MS	400 MS	800 MS	1600 MS
	(SEC)	(SEC)	(SEC)	(SEC)	(SEC)	(SEC)	(SEC)	(SEC)
0	3.1	18	17	18	19	21	25	31
200	2.7	15	15	16	17	18	22	27
400	2.6	15	15	15	16	18	21	26
600	3.0	17	16	17	18	20	23	29
800	3.6	20	20	21	22	24	28	35
1000	4.2	23	23	23	25	28	32	41
1200	5.0	28	27	28	30	33	39	49
1400	6.6	36	35	37	39	44	51	65
1600	8.1	44	43	44	47	53	63	79
1800	8.1	44	43	44	47	53	63	79
2000	6.5	36	35	36	39	43	51	64
2200	4.0	22	22	23	24	27	32	39

Estimated waiting times with 2 stations in the network.

MENU(CONCISE)=? Q

END BURST COMMUNICATIONS MODEL

Figure 11. (Cont.)

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14. SUPPLEMENTARY NOTES

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

The meteor burst communications model is a user-interactive computer model that predicts the reliability of a communications system that uses meteor bursts as the communications channel. The model predicts the waiting times required to complete the transfer of messages from a master station to a remote station as a function of frequency, transmitter and receiver characteristics, system protocol, distance separation, time of year, and time of day. The model also allows the user to specify a network of stations including the master, remote, and relay stations. Waiting time estimates are computed for the entire network. The model is implemented on a mini-computer operated by the Institute for Telecommunication Sciences. Model users remotely access the computer from their own terminals over telephone lines.

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

Key words: communications; meteor burst; radio propagation model; VHF

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