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NASA CR- 122340

SATELLITE BROADCASTING SYSTEM STUDY

REPORT NO. 4124-011

FINAL REPORT

Prepared for

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

JANUARY 1972

(NASA-CR-122340) SATELLITE BROADCASTING SYSTEM STUDY Final Report (Computer Sciences Corp.) Jan. 1972 269 p CSCL 17B

N72-17111

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6565 Arlington Boulevard

Falls Church, Virginia 22046

Major Offices and Facilities Throughout the World

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SECTION 1

INTRODUCTION

The primary objective of this study is to develop a system model and computer program which is representative of broadcasting satellite systems employing community-type receiving terminals. The program provides a user-oriented tool for (1) evaluating performance/cost tradeoffs, (2) synthesizing minimum cost systems for a given set of system requirements, and (3) performing sensitivity analyses to identify critical parameters and technology.

The performance/costing philosophy and what is meant by a minimum cost system is shown graphically in Figure 1-1. As the space segment cost decreases, implying less flux density at the ground, the ground terminal (segment) cost must increase to provide a specified level of performance. The total system cost is the sum of the space and ground segment costs and a minimum cost system can be defined. The minimum cost system requires a more expensive satellite and a less expensive ground terminal as the number of ground terminals increases. A family of these curves can be calculated to define costs for different levels of system performance. The curves are idealized in that they are shown as smooth contours. The actual curves have irregularities due to launch vehicle costs, model particulars, etc., as shown in the examples contained in Section 6.

The approach used in developing the system model and program is shown in Figure 1-2. The overall control is provided by the Main Line program. The system model is constructed in "building block" fashion, with the major divisions being the ground segment and space segment performance and costing models. These two segments are composed of many submodels, interconnected in the proper fashion, which are used to calculate performance factors, subsystem weights, costs, etc. The inputs to the program, therefore, become inputs to the individual performance and subsystem

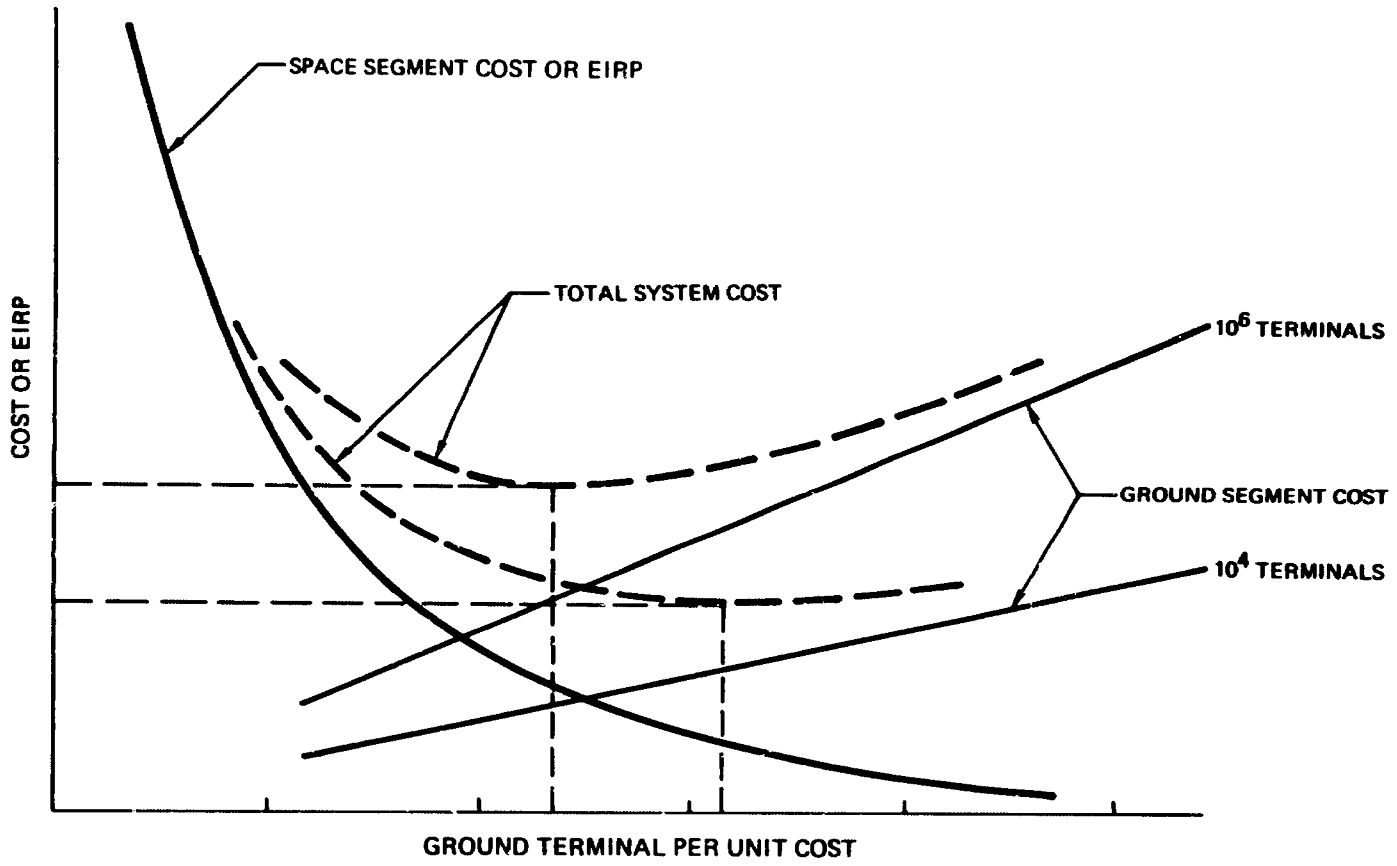


Figure 1-1. Graphical Representation of Performance/Cost Trade-offs

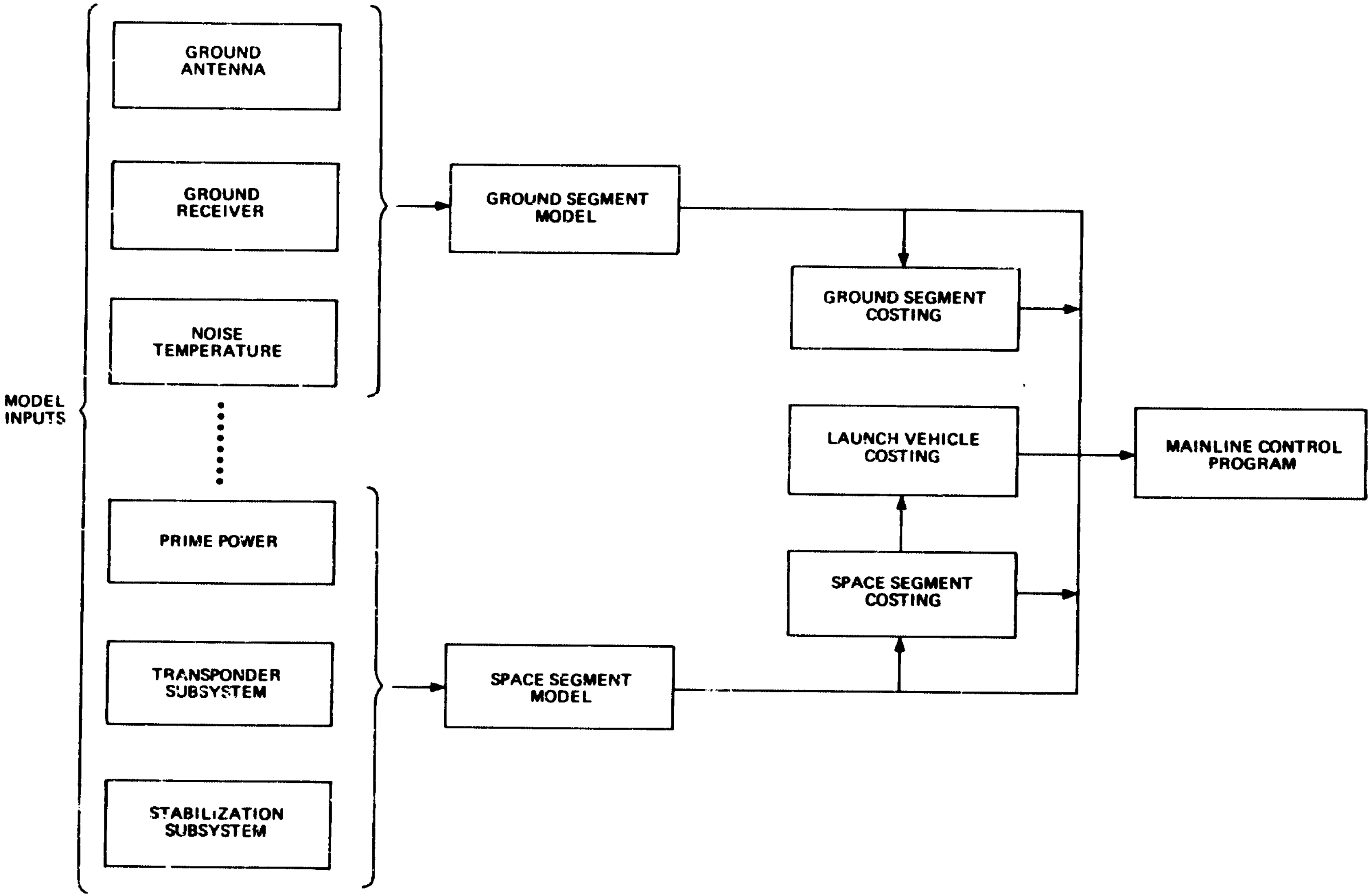


Figure 1-2. System Model Development

models. In this manner, the overall system is synthesized and the final system performance, cost, and parameter delineation is the result of a general parametric system design rather than a "top level" estimate based on one or more so-called key parameters. This approach also makes it possible to provide an accurate estimate of critical system parameters such as spacecraft weight, which is a primary input into the space segment costing model.

The system model has been developed using 1972-74 technology as a data base. Where little or no near term technology is available, a general design procedure is followed to model the various subsystems.

The program has been written for the UNIVAC 1108, using FORTRAN V. Since any model must change with time as new technology, data, etc., become available, the program must be capable of being updated easily. This is accomplished by using a modular approach in constructing the program, i.e., employing subroutines for the various performance and subsystem models. Finally, the program is flexible in that it responds to 48 different system requirements contained on input data cards.

The system model and program are described in detail in the following sections. The report is organized under the following headings: (1) Main Line Control Program, Section 2; (2) Ground Segment Model, Section 3; (3) Space Segment Model, Section 4; and (4) Cost Models and Launch Vehicle Selection, Section 5. Section 6 contains several examples of minimum cost systems resulting from the computer program. Appendix A contains a listing of the computer program. Appendix B defines the variables contained in the computer program.

SECTION 2

MAIN LINE CONTROL PROGRAM

The Main Line control program of the broadcasting satellite system model initializes computer operation and controls the iterative process between the ground, space and costing routines. The ground and space segment calculations are made by calling subroutines GRDSG and SPASEG respectively, while the Main Line program performs the costing calculations, based on the models described in Section 5. The program also reads in data cards which contain the requirements imposed on the system, calculates a minimum cost system curve and outputs a complete listing of system performance and costing parameters which describe the minimum cost system.

A sample running deck is shown in Figure 2-1, assuming the system program has been previously stored in the computer. The first card is a control card used to initiate the program. The deck contains four to nine input data cards depending on the number of individual antenna beams required. There are no column specifications on the input cards since the data is read in free form, with commas separating each variable. This simplifies the generation of the program input for the engineer working at a teletype.

The first data card is the System Parameter Card. The parameters on this card are defined in Table 2-1. The Frequency Plan Card is the second data card and its parameters are defined in Table 2-2. The parameters which define the link associated with a particular antenna beam are contained on the Beam Characteristics Card, which is the third data card in the deck. A separate card is required for each beam. The cards describe beam center and receiver locations, environmental conditions and other required parameters as defined in Table 2-3. The Receiver Characteristics card is the last data card read in. It describes the required receiver and signal characteristics as defined in Table 2-4.

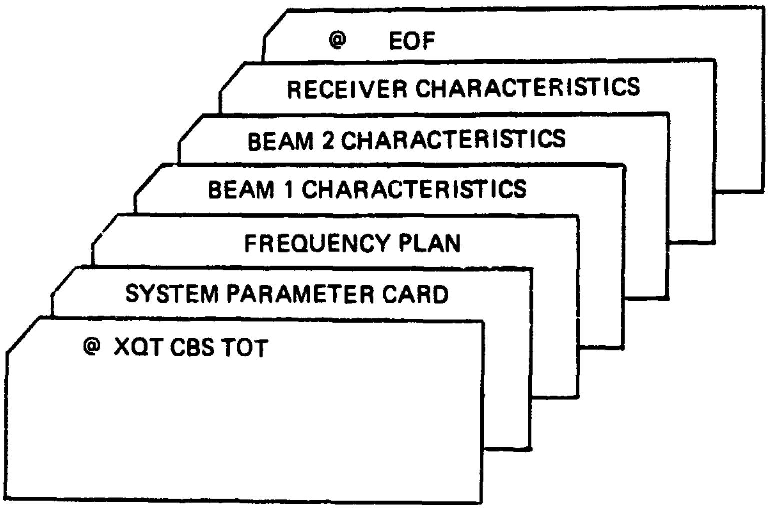


Figure 2-1. Sample Running Deck for Two Beams

TABLE 2-1

SYSTEM PARAMETER CARD

PARAMETER	DESCRIPTION
Satellite Longitude	Longitude in degrees; 0-360° (East direction). Decimal point is required.
Satellite Latitude	Latitude in degrees; + denotes North-South. Decimal point is required.
Satellite Life	Integer value; 2 or 5 years.
Number Satellites	Integer value.
Number of Antenna Beams	An integer value, 1-6.
Number of Video Channels	An integer value; 1,3 or 6.
Start Year	Starting year of mission. An integer value.
Pointing Error	Satellite antenna pointing error in degrees. A decimal value.
Broadcast Time	Hours of broadcasting/day. An integer value.
Stabilization Mode Key	1 = 3-axis only 2 = Spin/despin 3 = Both
Number of Calculated Points	Additional points required to refine system cost/EIRP curve. Should be an even integer.

TABLE 2-2

FREQUENCY PLAN CARD

PARAMETER	DESCRIPTION
Carrier Frequency TV Channel 1	Exponential value in Hz, (i.e., 700 MHz = 7.0 E8) A decimal point is required.
Carrier Frequency TV Channel 2	Same as above.
Carrier Frequency TV Channel 3	Same as above.
Carrier Frequency TV Channel 4	Same as above.
Carrier Frequency TV Channel 5	Same as above.
Carrier Frequency TV Channel 6	Same as above.
Spectrum Factor	A decimal value in dB.*
Minimum Ground Antenna Beamwidth	Antenna beamwidth in degrees. A decimal value.
Satellite Antenna Efficiency	A decimal value.
EIRP Maximum	An exponential value in watts.*

---

* See Section 3.

TABLE 2-3

BEAM CHARACTERISTICS CARD

PARAMETER	DESCRIPTION*
Receiver Longitude	Longitude in degrees. Decimal point is required.
Receiver Latitude	Latitude in degrees. Decimal point is required.
Beam Center Longitude	Longitude in degrees. Decimal point is required.
Beam Center Latitude	Latitude in degrees. Decimal point is required.
Satellite Antenna Beamwidth	Beamwidth in degrees. Decimal point is required.
Maximum Allowable Video Bandwidth	Exponential value in Hz. Decimal point is required.
Maximum Allowable Audio Bandwidth	Exponential value in Hz. Decimal point is required.
Satellite Antenna Efficiency	Decimal fraction.
Rain Rate	Rain rate in millimeters per hour. Decimal point is required.
Man-Made Noise Key	1 = rural 2 = suburban 3 = urban
Relative Humidity Key	1 = dry 2 = average 3 = humid
Stellar Noise Key	1 = general 2 = galactic plane 3 = quiet sun 4 = disturbed sun

---

* See Section 3.

TABLE 2-3

(CONTINUED)

PARAMETER	DESCRIPTION*
Number Receivers	Integer value of ground receivers within beam.
Receiver Type	0 = no preamp 1 = transistor 2 = TDA 3 = paramp 4 = pick best available
Scintillation Probability	A decimal value.

TABLE 2-4

RECEIVER CHARACTERISTICS CARD

PARAMETER	DESCRIPTION*
Video-Audio Subcarrier Guard Band	Exponential value in Hz. Decimal point is required.
Subcarrier-Subcarrier Guard Band	Same as above.
Peak Deviation of Subcarriers	Same as above.
FM Threshold	Value in dB. Decimal point is required.
Video Threshold Margin	Same as above.
Audio Subcarrier Threshold Margin	Same as above.
Maximum RF Bandwidth	Exponential value in Hz.
RF Bandwidth K Factor	Decimal fraction.
Video K Factor	Value in dB. Decimal point is required.
Required Video S/N	Same as above.
Required Audio $(S/N)_s$	Same as above.
Cable Loss	Same as above.

---

* See Section 3.

The last card in the deck is an end of file card, for terminating the program.

The flow chart for the Main Line program is shown in Figure 2-2 and the program CBSTOT is shown in Figure 2-3. After the data cards are read in IKEY (entry to subroutine GRDSG) is set equal to JKEY and to 1 which calls subroutine GRDSG for evaluation of the ground segment, for antenna beam number 1. The first ground segment iteration is performed based on a maximum allowable value of EIRP. This value is either obtained directly from an input data card or is calculated by GRDSG based on WARC recommendations. GRDSG also calculated the maximum ground antenna diameter DIA based on the minimum allowable beamwidth. Using EIRP and DIA, along with the required input parameters, GRDSG defines the ground terminal performance which is required to provide the specified system performance, e.g., video signal quality. Antenna diameter, receiver noise figure and related parameters are then used by the Main Line program to determine the ground terminal cost which is the cost of the candidate antenna and receiver. This cost is stored for comparison with future values.

The ground antenna diameter is now decreased by 20% and IKEY is set to 2. GRDSG calculates a new ground terminal configuration, having the same figure of merit, say G/T, as when the maximum antenna diameter was used. The new configuration is costed out and the cost is compared to the previous stored value. If the new value is less than the stored value, it is recorded and the process is repeated until the ground terminal cost increases or a receiver of the required performance cannot be found. At this point the parameters calculated during the previous iteration are chosen to define the candidate ground system for beam number 1 and the maximum value of EIRP.

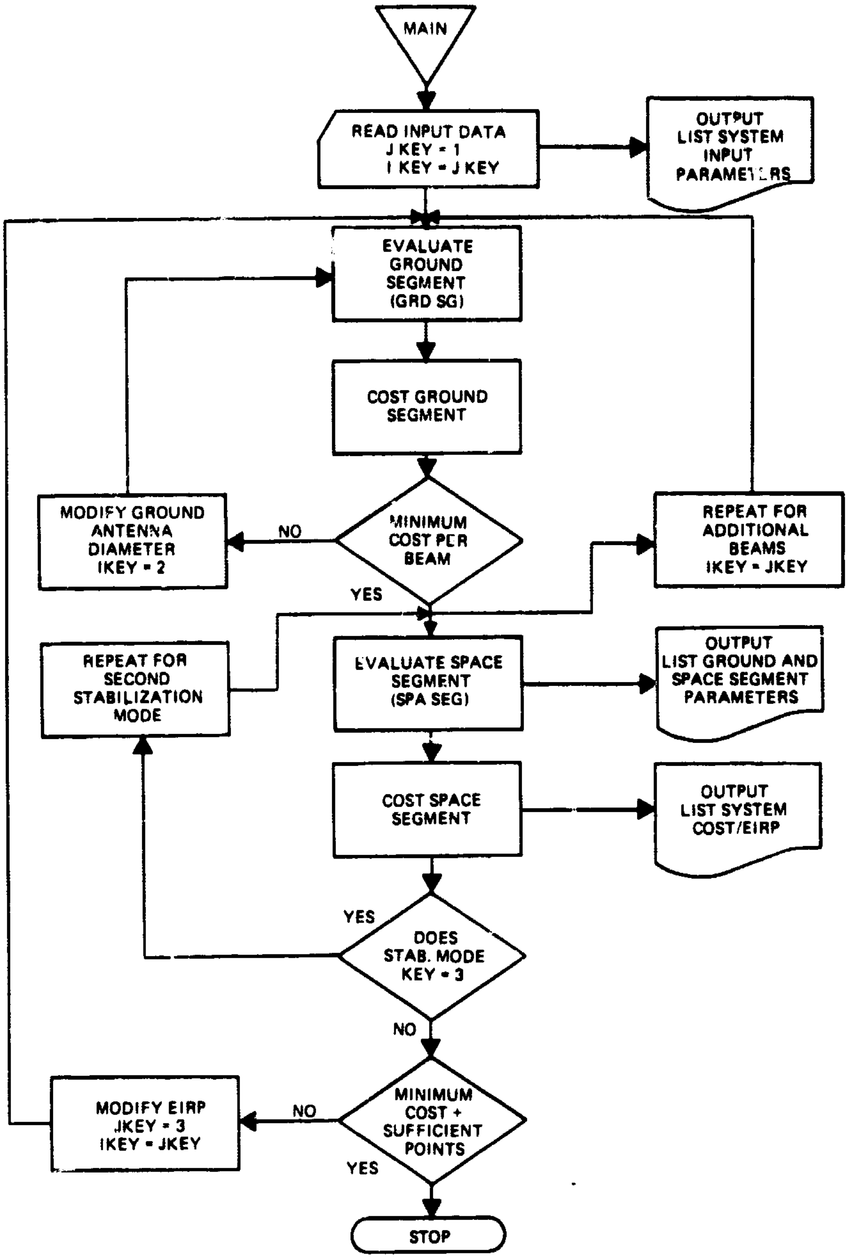


Figure 2-2. Main Line Control Program Flow Chart

```
 CBSTOT,CBSTOT
LEVEL 23.8  CSCX FORTRAN V
      DIMENSION RFPWR(6,6),RFBW(6),ACOST(6),RCOST(6), INDR(6),ANTD(6)
      DIMENSION RLAT(6),RLONG(6),BCLAT(6),BCLON(6),AEFF(6),SABW(6)
      DIMENSION  RFPR(6)
      DIMENSION RAINR(6), KMMN(6),KRH(6),KGN(6),NRECV(6),ABWMX(6),
     1VBWMX(6),IRCVT(6),POR(6),SYTEMP(6),ERPM(6)
      DIMENSION FREQ(6),GNDCT(6)
      DIMENSION FR(6),ARADB(6),SCNDB(6),EIRP(6)
      DATA IN,IOUT /5,6/
      DATA (GNDCT(I),I=1,6)/6*10. E16/
C     READ SYSTEM PARAMETER CARD
      ITC=1
      TSYS=9.E16
      READ(IN,8000)SLONG,SLAT,LIFE,NOSAT,NBEAM,NTVCH,NAVDC,
     1ISTYR,PTERR,ITIMBC,MODSTB,NPTS
      WRITE(IOUT,9500)SLONG,NOSAT,ITIMBC,SLAT,NTVCH,LIFE,PTERR,
     1NBEAM,ISTYR,MODSTB,NAVDC,NPTS
C     FREQUENCY PLAN
      READ (IN,8000) FREQ,SPECF,GABWM,SAEFF,ERPMX
        WRITE(IOUT,9501)(FREQ(I),I=1,NTVCH)
       WRITE (IOUT,9507)SPECF,GABWM,SAEFF,ERPMX
C     BEAM CHARACTERISTICS
      IZOOM=0
      DO 10 I=1,NBEAM
      ANTD(I)=100.
      READ(IN,8000)RLONG(I),RLAT(I),BCLON(I),BCLAT(I),SABW(I),
     1VBWMX(I),ABWMX(I),AEFF(I),RAINR(I),KMMN(I),KRH(I),KGN(I),
     2NRECV(I),IRCVT(I),POR(I)
      WRITE(IOUT,9502)I,RLONG(I),RLAT (I),BCLCN(I),BCLAT(I),SABW(I),
     1AEFF(I),VBWMX(I),ABWMX(I),RAINR(I),KMMN(I),KRH(I),KGN(I),
     2NRECV(I),IRCVT(I),POR(I)
   10 ERPM(I)=ERPMX
      READ (IN,8000) VASCG,SSGB,PDVSC,FMTHR,VTHRM,ASCTM,RFMBW,RFBWK,
     1VKFAC, RVSN,RASN,CABLS
      WRITE(IOUT,9503)VASCG,SSGB,PDVSC,FMTHR,VTHRM,ASCTM,RFMBW,
     1RFBWK,VKFAC,RVSN,RASN,CABLS
C     29 INPUT VARIABLES
        JKEY =1
 4000 DO 100 I=1,NBEAM
      ANTMX=1.9925E10/SQRT(FREQ(1)*(FREQ(NTVCH)))/GABWM
      INDR(I)=9999
      IT=0
      ERPMZ=ERPM(I)
      IF(IZOOM.EQ.1)GO TO 7000
      IF(JKEY.EQ.3)ERPM(I)=ERPM(I)*0.5
```

Figure 2-3. Main Line Program CBSTOT

```
      GO TO 4005
 7C00 ERPM(I)=ERPM(I)+DELERP
 4005 ANTDM=ANTD(I)*SQRT(ERPMZ/ERPM(I))*2.0
      ERPMZ=ERPM(I)
      N=ALOG(ANTDM/ANTMX)/ALOG(.8)  + 1.
      ANTDM=ANTMX*(.8)**N
      IF(ANTDM.GT.ANTMX)ANTDM=ANTMX
      IKEY=JKEY
       GNDCT(I)=10.E16
      WRITE(IOUT,9997)ERPMZ
 90   CALL GRDSG(SLONG,SLAT,NTVCH,NAVDC,RLONG(I),RLAT(I),BCLON(I),
     1BCLAT(I),VBWMX(I),ABWMX(I),AEFF(I),GABWM,RAINR(I),KMMN(I),
     2KRH(I),KGN(I),FREQ,VASCG,SSGB,PDVSC,FMTHR,VTHRM,ASCTM,
     3RFMBW,RFBWK,VKFAC,RVSN,RASN,CABLS,IKEY,SABW(I),SPECF,SAEFF,
     4ERPMZ,POR(I),SYTEM,RCVNS,ANTDM,RFPR,RFBWX,FR,ELARD,ARADB,
     5SCNDB,GOGT,SAGDB,ABMWD,EIRP,CONVT,VTIR)
       STYR=ISTYR
        RECNM=NRECV(I)
      CALL ANCTP(ANTDM,RECNM,ACST)
      CALL RCCST (FREQ(1),RCVNS,RECNM,STYR,IRCVT(I),RCST,IND)
      IF(GNDCT(I)-(RCST+ACST))15,15,14
 14    IF(IND-100) 16,15,15
 15   WRITE(IOUT,9600)IT,ACOST(I),RCOST(I),ANTD(I),INCR(I),SAGDB,
     1RCVN,ABMWD,ELARD,RVSN,SYTEMP(I),CONVT,RFBW(I),VTIR
      WRITE(IOUT,9620)(RFPWR(J,I),EIRP(J),J=1,NTVCH)
      GO TO 100
 16   ACOST(I)=ACST
      RCCST(I)=RCST
      GNDCT(I)=ACST+RCST
      INDR(I)=IND
         RCVN=RCVNS
      SYTEMP(I)=SYTEM
      IT=IT+1
          DO 18 J=1,NTVCH
  18   RFPWR(J,I)=RFPR(J)
      RFBW(I)=RFBWX
      ANTD(I)=ANTDM
      ANTDM=ANTDM*0.8
      IKEY=2
      GO TO 90
 1C0  CONTINUE
        ERPM(I)=ERPMZ
       MODES=MODSTB
      IF(MODSTB.EQ.3) MODES=1
        SLIFE=LIFE
        FREK=FREQ(1)/1.E9
```

Figure 2-3. Continued

```
      DO 200 I=1,NTVCH
      TOT=0
       DO 201 J=1,NBEAM
201    TOT=TOT+RFPWR(I,J)
200   RFPR(I)=TOT
      XSYS=10.E16
      TGD=0.
      DO 300 I=1,NBEAM
300   TGD=TGD+GNDCT(I)*NRECV(I)
      CTGD=TGD/(1.E6)
      XSYS=10.E16
150     CALL SPASEG(FREK,SABW,NTVCH,NBEAM,PTERR,RFPR,MODES
     1,SLIFE,ITIMBC,SLONG,ANTWT,ANTDIA,COMPWR,HDSPLD,PWRBOL,XPNWT,
     2PPSWT,ARAREA,STABWT,THRMWT,STRCWT,SATWT)
      WRITE(IOUT,9650)SATWT,ANTWT,ANTDIA,XPNWT,COMPWR,PPSWT,
     1HDSPLD,STABWT,PWRBOL,THRMWT,ARAREA,STRCWT
      MODAKM=0
140    CALL LANCHV(SATWT,MODES,MODAKM,IVHCL,VCOST)
      WRITE(IOUT,9660)MODES,MODAKM,IVHCL,VCOST
      IF(MODES.EQ.1) GO TO 160
      IF (MODAKM.EQ.1) GO TO 155
      COSTV=VCOST
      IV=IVHCL
      MODAKM=1
      GO TO 140
155    IF(COSTV.LT.VCOST)VCOST=COSTV
160   EU=5.1
      SATCST=0.158*(SATWT**0.6158)*((NOSAT+EU)**0.9684)
      SPCOST=NOSAT*VCOST+SATCST
      CSYS=CTGD+SPCOST
      WRITE(IOUT,9800)CSYS,CTGD,SPCOST
      IF(MODSTB.NE.3)GO TO 170
      IF (MODES.EQ.2) GO TO 170
      XSYS=CSYS
      MODES=2
      GO TO 150
170   ITC=ITC+1
      IF(XSYS.LT.CSYS)CSYS=XSYS
      IF(IZOOM.EQ.0)GO TO 301
      ICNT=ICNT+1
      IF(ICNT.EQ.NPTS)GO TO 99
      GO TO 4000
301   IF(TSYS.LT.CSYS)GO TO 98
      TSYS=CSYS
      JKEY=3
      WRITE(IOUT,9998)JKEY
```

Figure 2-3. Continued

```
     GO TO 4000
98   IZOOM=1
     DELERP=3.*ERPM(I)/(NPTS+1)
     ICNT=0
     WRITE(IOUT,9999)IZOOM
     GO TO 4000
99   CALL EXIT
8CCC FORMAT()
9500 FORMAT('1SYSTEM DESCRIPTION'/5X,'SAT LONG',F10.4,6X,
    1'SATELLITES',I4,6X,'BROADCAST',I5,' HRS'/5X,'SAT LAT',
    2F11.4,6X,'TV CHAN',I7,6X,'SAT LIFE',I6,' YRS'/5X,'PT ERR',
    3F12.4,6X,'NO. BEAMS',I5,6X,'START YR',I9/5X,'STAB MODE',
    4I4,11X,'AUD CHAN/TV',I3,6X,'NO POINTS',I5/)
9501 FORMAT('OFREGUENCY PLAN',/(5X,E12.8,' HZ'))
9507 FORMAT(5X,'SPECF',F11.2,' DB',6X,'GRD ANT BW',F6.2,' DEG'/
    15X,'SAT ANT EFF',F6.3,8X,'ERP MAX',E13.8,' WATTS'/)
9502 FORMAT('OBEAM CHARACTERISTICS NO.',I3,' ******'/
    15X,'REC LONG',F11.4,14X,'REC LAT',F13.4/
    25X,'BC LONG',F12.4,14X,'BC LAT',F14.4/
    35X,'SAT ANT BW',F9.4,14X,'GRD ANT EFF',F9.4/
    45X,'MAX VID BW',E16.8,' HZ',4X,'MAX AUD BW',E17.8,' HZ'/
    55X,'RAIN RATE',F9.2,3X,'MM/HR',7X,'MAN MADE NOISE',I5/
    65X,'REL HUMICITY',I5,16X,'GALACTIC NOISE',I5/
    75X,'NO RECEIVERS',I8,13X,'REC SPECIFIED',I6/
    85X,'PROB SCINT',F10.4,2X,' '/)
9503 FORMAT('ORECEIVER CHARACTERISTICS'/5X,'VIDEO SUB GUARD',
    1E12.6,' HZ',5X,'SUB CAR GUARD',E14.6,' HZ'/5X,
    2'CAR PEAK DEV',E15.6,' HZ',5X,'FM THRESHHOLD',F7.2,' DB'/5X,
    3'VIDEO T MRG',F10.3,6X,' DB',5X,'AUD-SC T MRG',F8.2,' DB'/5X,
    4'MAX RF BW',6X,E12.6,' HZ',5X,'RF-BW-K-FAC',F10.3/5X,
    5'VIDEO K-FAC',F10.3,6X,' DB',5X,'REQ VIDEO S/N',F8.3,' DB'/
    65X,'REQ AUD S/N',F10.3,6X,' DB',5X,'CABLE LOSS',F11.3,' DB')
9600 FORMAT('1GROUND SEGMENT CHARACTERISTICS',10X,I3/5X,
    1'GRD ANT COST',F10.2,' $',10X,'RECEIVR COST',F10.2,' $'/
    25X,'GRD ANT DIAM',F10.2,' MET',8X,'RECEIVR TYPE',I8/5X,
    3'SAT ANT GAIN',F10.2,' DB',9X,'REC NOISE T ',F1C.2,' DEG K'/
    45X,'GRB ANT BMWD',F10.2,' DEG',8X,'REC ELEV ANG',F10.2,
    5' DEG'/5X,'REQ VIDEO S/N',F9.2,' DB',9X,'SYS NOISE T ',
    6F10.2,' DEG K'/5X,'C/N VID THRS',F10.2,' DB',9X,
    7'RF BANDWIDTH',E10.7,' HZ'/5X,'VID THRS IMP',F10.2,' SEC'/)
9620 FORMAT((5X,''FPWR/TV CHAN',F9.2,' WATTS',8X,'EIRP',8X,F9.2,
    1' WATTS')/)
9660 FORMAT('OLAUNCH VEHICLE'/5X,'STAB MODE',I3,5X,'AKM MODE',
    1I3,5X,'VEHICLE',I3,5X,'COST $',F8.5/)
9800 FORMAT('OCOSTS'/5X,'SYSTEM',F10.5,' M$',5X,'GRCUND',F10.5,
    1' M$',5X,'SPACE',F10.5,' M$'/)
```

Figure 2-3. Continued

```
9650 FORMAT('0SATELLITE CHARACTERISTICS'/5X,'SAT WEIGHT',F9.2,
    1'   LBS',9X,'ANT WEIGHT',F9.2,'  LBS'/5X,'ANT DIAMTR',
    2F9.2,'  FEET',9X,'XPONDER WT',F9.2,'  LBS'/5X,
    3'COMM POWER',F9.2,' WATTS',9X,'PWR SYS WT',F9.2,'  LBS'/
    45X,'HEAT DISSP',F9.2,' WATTS',9X,'STAB-AC WT',F9.2,'  LBS'/
    55X,'POWER, BOL',F9.2,' WATTS',9X,'THERM CONT',F9.2,'  LBS'/
    65X,'ARRAY AREA',F9.2,' SQ FT',9X,'STRUCTURE',F10.2,'  LBS'/)
9998 FORMAT('0JKEY=',I3/)
9999 FORMAT('0IZCOM=',I3/)
9997 FORMAT('0ERPMZ=',E15.8/)
       END
```

Figure 2-3. Continued

The above procedure is repeated for each antenna beam. Once all beams have been evaluated, the vector RFPR(I) is calculated which gives the RF power per channel required to support the total number of beams. Also, the total ground segment cost is determined as:

$$\mathrm{GCOST} = \sum_{I=1}^{\mathrm{NBEAM}} \left[\mathrm{ACOST}(I) + \mathrm{RCOST}(I)\right] N_{\mathrm{REC}}(I) \qquad (2\text{-}1)$$

where

ACOST is the antenna cost

RCOST is the receiver cost

N_{REC} is the number of receivers

Subroutine SPASEG is now entered with a value for RFPR(I) and satellite stabilization mode. SPASEG determines the satellite configuration and weight. The weight and stabilization mode are used by the Main Line program to select a launch vehicle.

The space segment cost is determined from the relationship (see Section 5):

$$\begin{aligned}\mathrm{SPCOST} = {} & 0.158(\mathrm{SATWT})^{0.6158} (\mathrm{NOSAT} + \mathrm{EU})^{0.9684} \\ & + (\mathrm{NOSAT})(\mathrm{VCOST}) \qquad (2\text{-}2)\end{aligned}$$

where

SATWT is the satellite weight

NOSAT is the number of satellites

EU is an equivalent unit

VCOST is the cost of the launch vehicle

The total system cost is, therefore:

$$\mathrm{TCOST} = \mathrm{GCOST} + \mathrm{SPCOST} \qquad (2\text{-}3)$$

If the stabilization mode is such that both dual spin and 3-axis systems are to be evaluated, the mode is changed and a new satellite and launch vehicle are configured and another space segment cost determined. The stabilization mode which results in the least cost space segment is selected and the associated costs are recorded as the current system cost and a candidate system is established.

The initial value of EIRP is decreased by 50% and IKEY is set to 3 to again call GRDSG. A new ground terminal is configured and the sequence shown in Figure 2-2 is repeated, and a new system cost determined. This process is repeated until a "near" minimum cost system is identified. At this time N additional points, lying between the last 3 calculated points, are calculated to refine the final estimate. For example, in Figure 2-4, 4 additional points N are generated to smooth the curve and approximate the minimum cost. The initial points denoted by x are calculated by halving the maximum value of EIRP twice. Once a near minimum is found, i.e., $COST_{i+1} > COST_i$, it is known that a minimum exists between $COST_{i+1}$ and $COST_{i-1}$. This interval is divided into N + 1 intervals and N additional points, ⊙, are determined. This localizes the minimum value and smooths the curve. N is a program input and should be chosen as an even number to eliminate redundant points.

The final output from the Main Line program is a printout of all the performance and cost parameters associated with each candidate system. The system costs associated with each candidate system are those denoted by X and ⊙ in Figure 2-4.

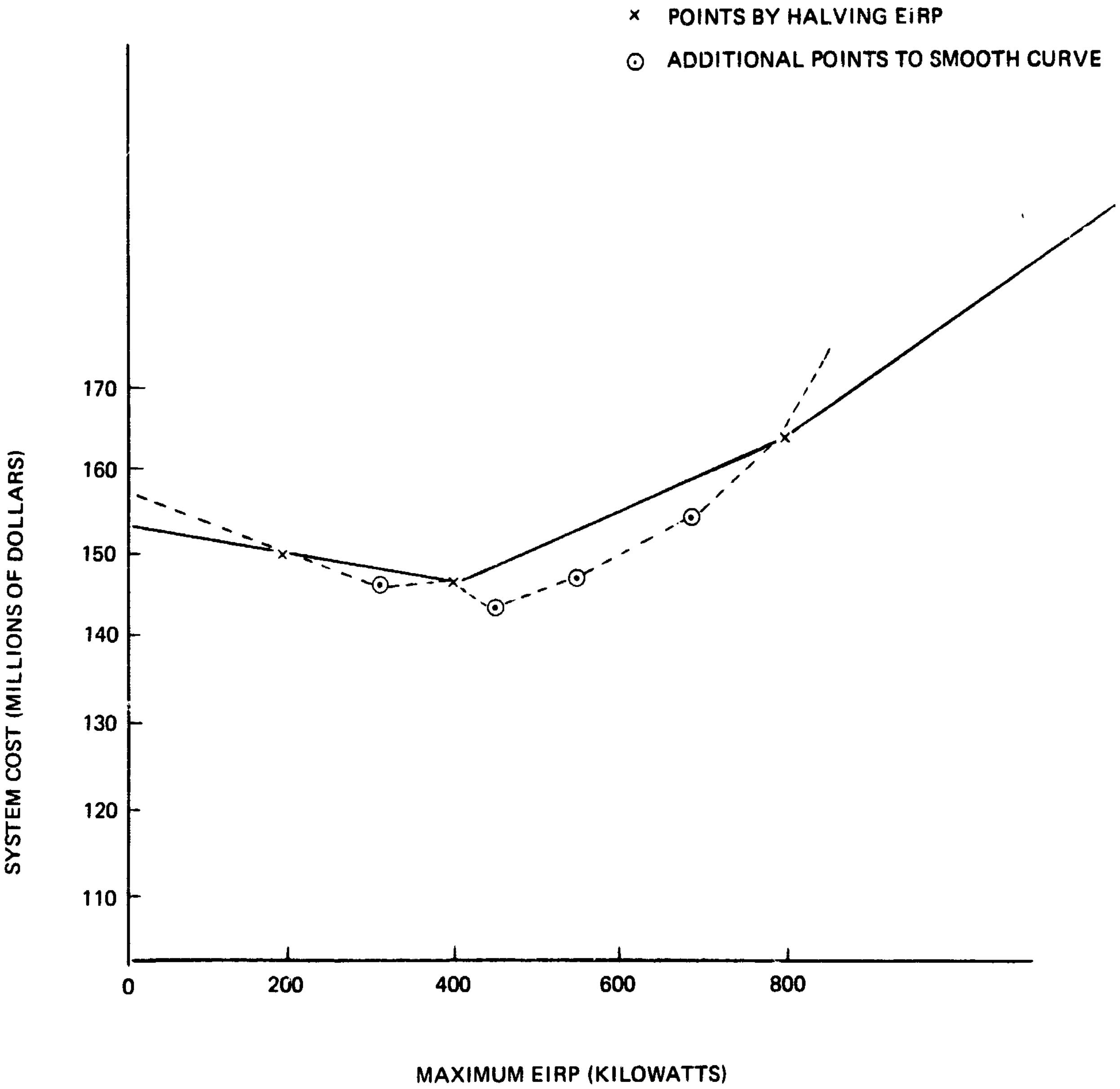


Figure 2-4. Example Calculation of Minimum System Cost Curve

SECTION 3
GROUND SEGMENT MODEL

A functional block diagram of the ground segment model is shown in Figure 3-1 and a data flow diagram in Figure 3-2. The model contains parametric relationships for calculating the maximum allowable satellite effective isotropically radiated power (EIRP), downlink transmission losses, the carrier-to-noise ratio required to satisfy the desired output signal quality, the signal plan per channel, and the ground antenna gain and system noise temperature which result in the minimum ground terminal cost for the particular local interference and atmospheric environment.

The maximum allowable value of EIRP is calculated based on World Administrative Radio Conference (WARC) recommendations, or is provided from the Main Line program as an independent estimate. This is the first value of EIRP used in iterating downward to arrive at a minimum-cost system. Next, the transmission losses due to scintillation and rain are determined for use in calculating the power received at a particular earth station, most likely chosen for its poor location with respect to the satellite beam. The received signal power is also dependent on the effective area of the receiving antenna, which is iterated downward from some maximum value based on the minimum beamwidth allowable for good pointing accuracy.

The gain pattern is determined for a candidate ground antenna for use in calculating the antenna noise temperature at each carrier frequency. Antenna temperature, along with system carrier-to-noise temperature, $\frac{C}{T}$, is then used to determine the receiver noise temperature required to provide a given signal quality. At this point the ground terminal performance is defined for each channel, therefore, the satellite EIRP at each carrier frequency can be adjusted to provide the same value of $\frac{C}{T}$ or signal quality in all channels of the ground receiver. The RF power

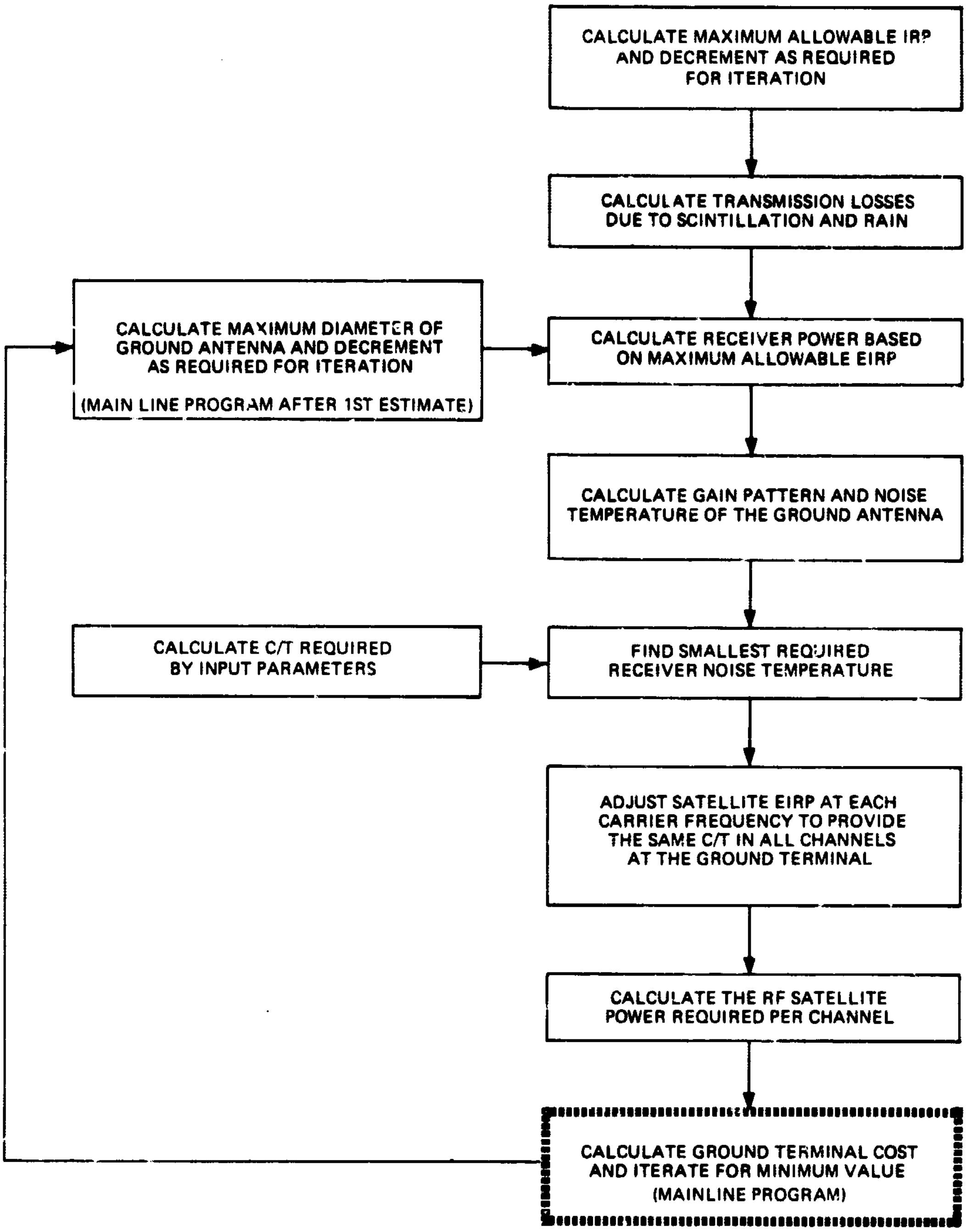


Figure 3-1. Ground Segment Model Functional Block Diagram

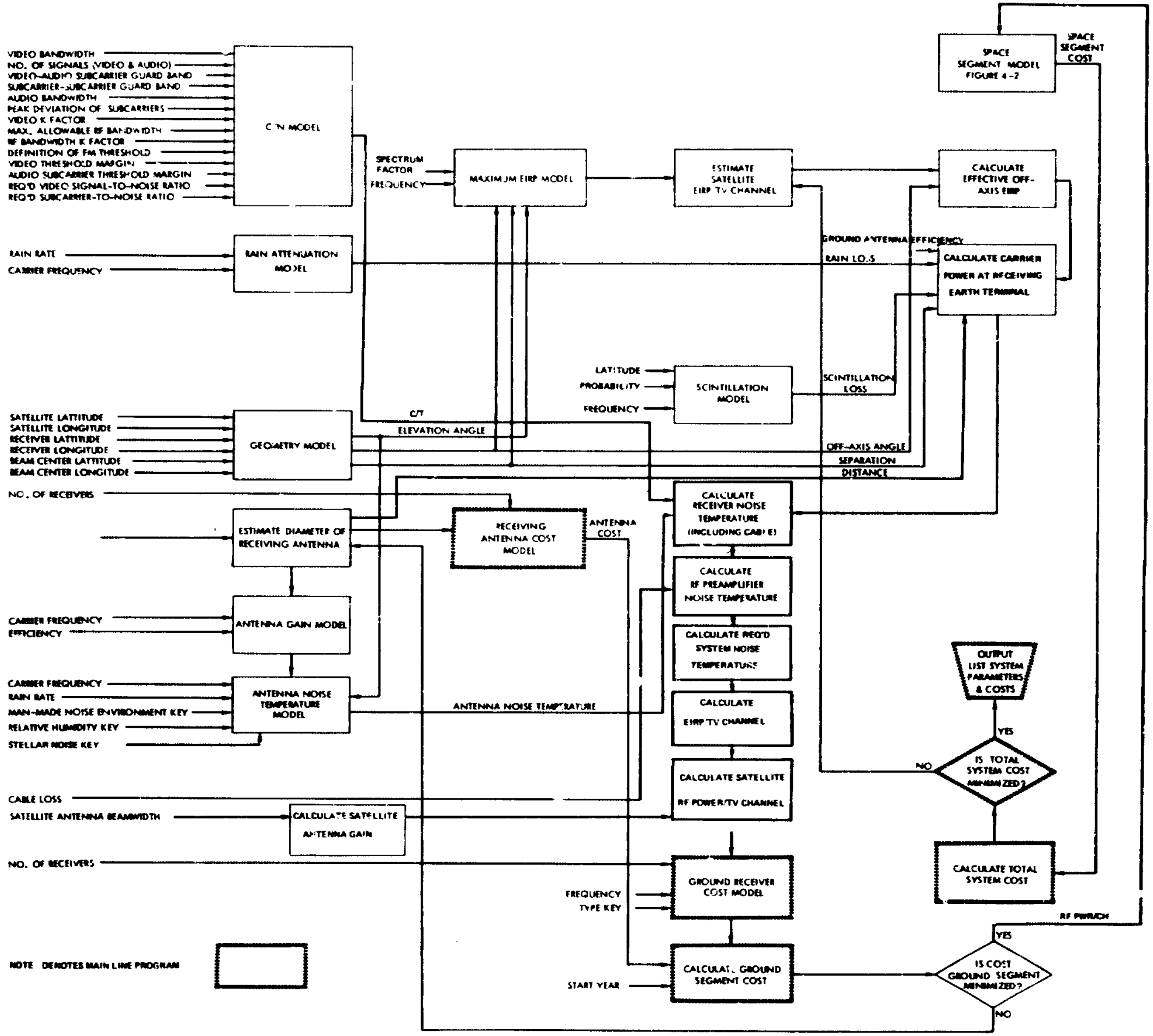


Figure 3-2. Ground Segment Model Functional Data Flow Diagram

at the input to satellite antenna is now calculated knowing the antenna gain.

The minimum ground segment cost for a given value of EIRP is found by iterating the size of the ground antenna downward and reconfiguring the ground terminal. This loop is controlled by the Main Line program as discussed in Section 2.

The subroutines required for the ground segment model are described in the following paragraphs.

3.1 GROUND SEGMENT SUBROUTINE GRDSG

Subroutine GRDSG is used by the Main Line control program to call other ground segment subroutines for complex calculations and to perform directly the simpler calculations relating to the ground segment. The flow chart for GRDSG is shown in Figure 3-3 and the subroutine itself is shown in Figure 3-4. The subroutine utilizes 35 input parameters provided by the Main Line program and calculates 15 output parameters. A vector is considered as a single parameter. The required input parameters are

1. SLOD - Longitude in degrees of the satellite subpoint.

2. SLAD - Latitude in degrees of the satellite subpoint.

3. N - Number of carrier frequencies.

4. NS - Total number of signals modulating the RF carrier, including the video signal and all the audio subcarriers.

5. RLOD - Longitude in degrees of the receiver being considered on the surface of the earth.

6. RLAD - Latitude in degrees of the receiver being considered on the surface of the earth.

7. PLOD - Longitude in degrees of the point on the earth's surface at which the satellite beam center is pointing.

8. PLAD - Latitude in degrees of the point on the earth's surface at which the satellite beam center is pointing.

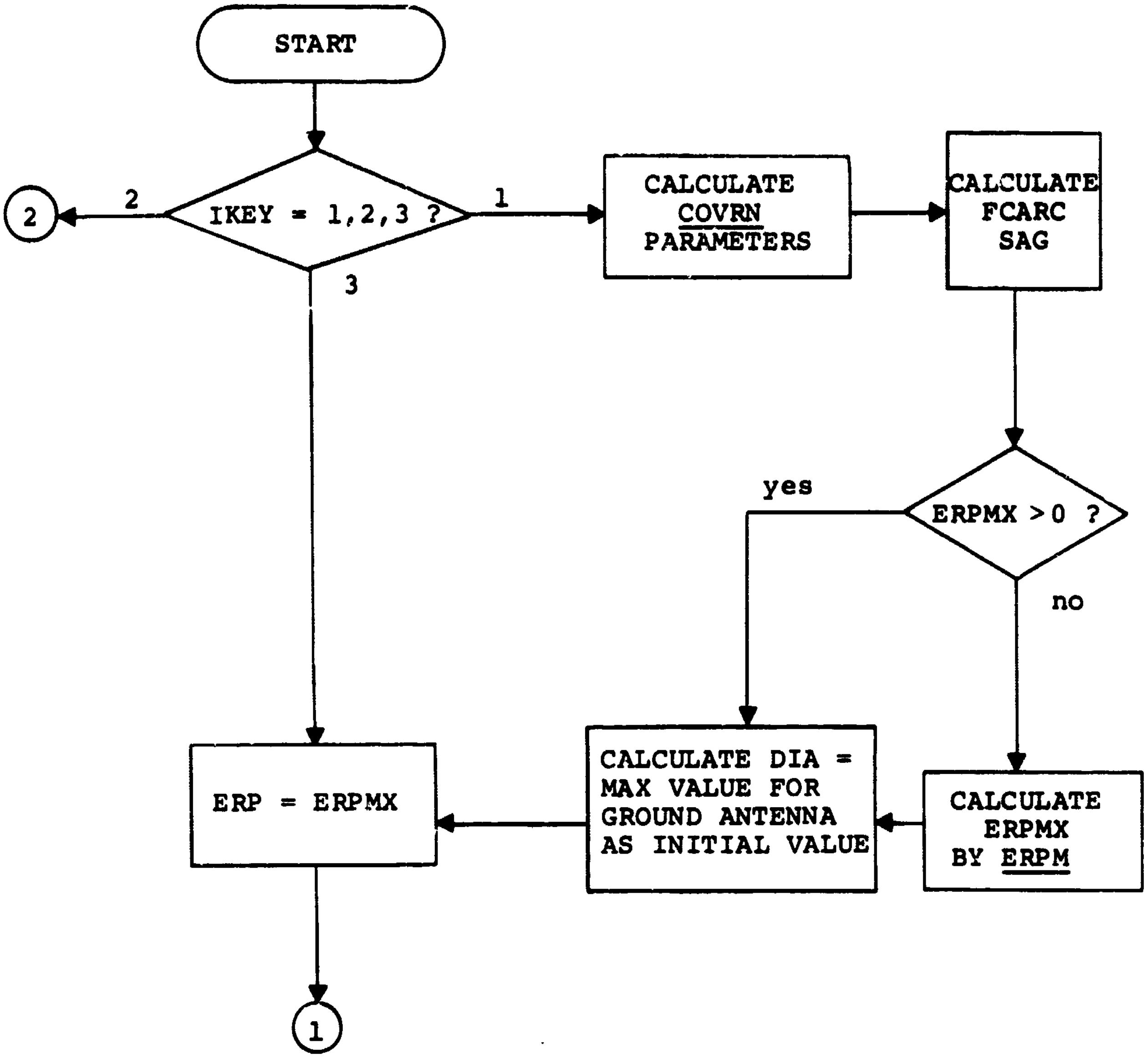


Figure 3-3. Flow Chart of Subroutine GRDSG

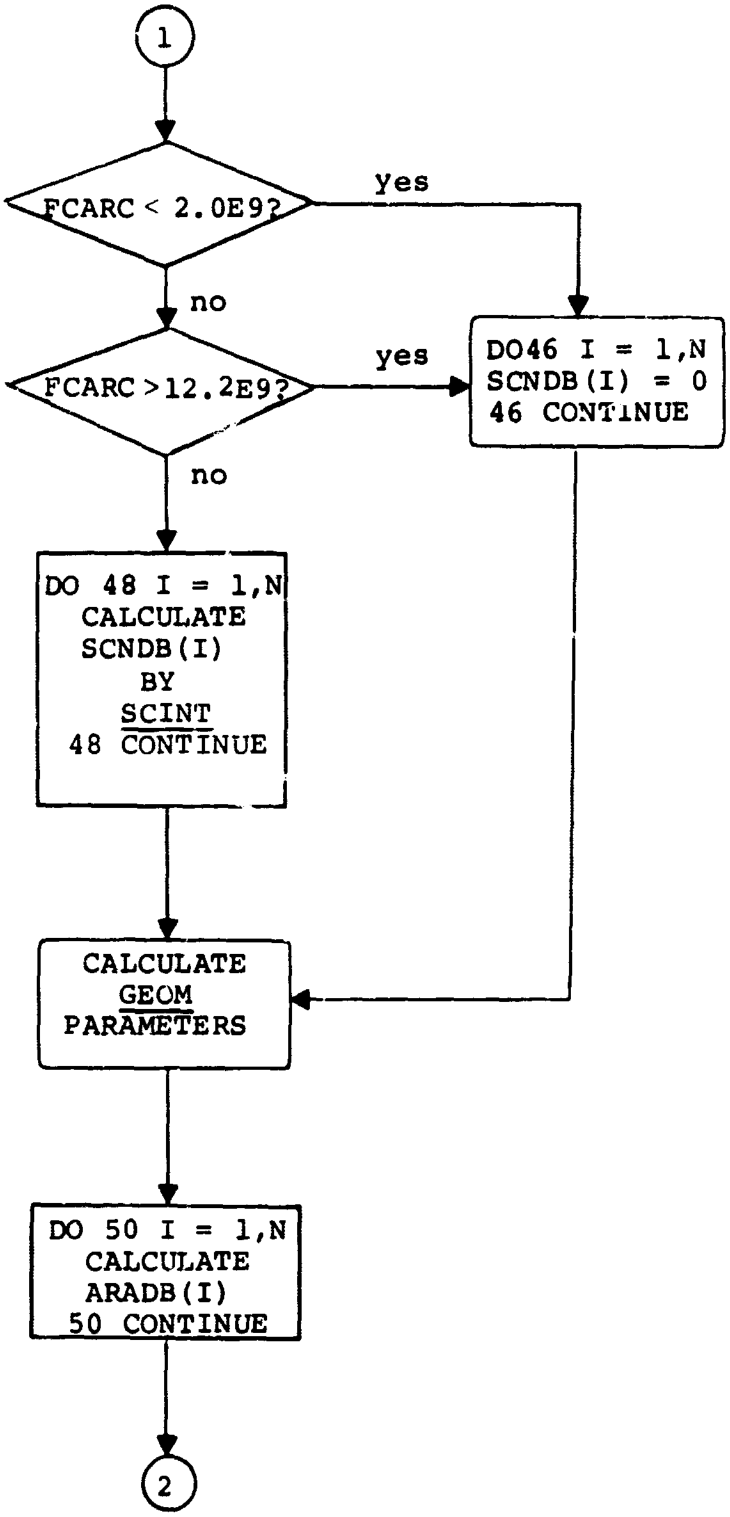


Figure 3-3. Continued

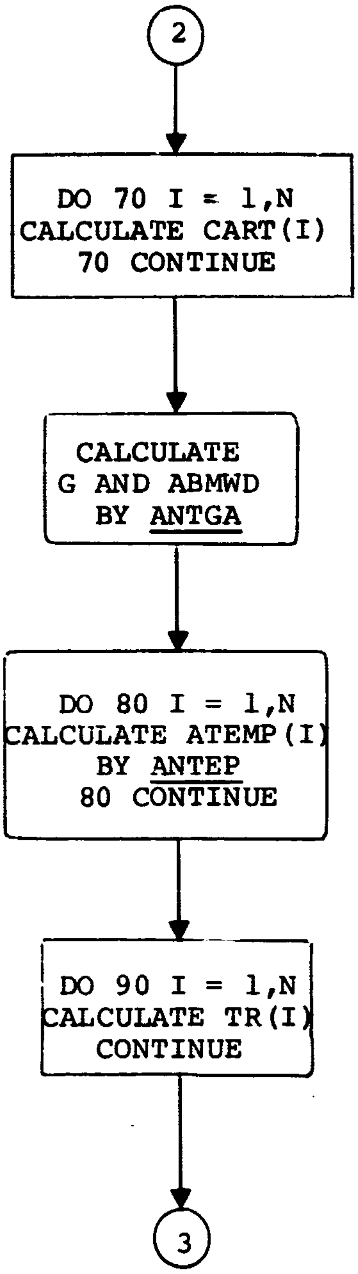


Figure 3-3. Continued

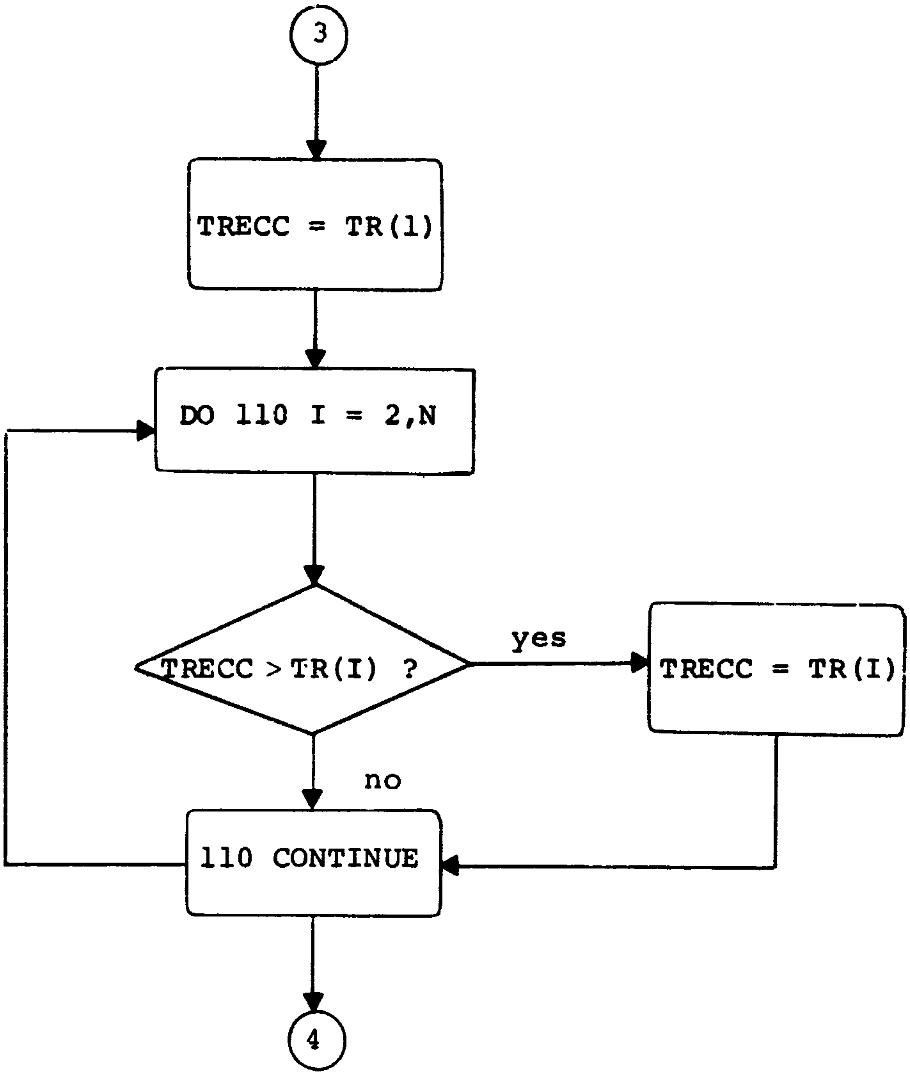
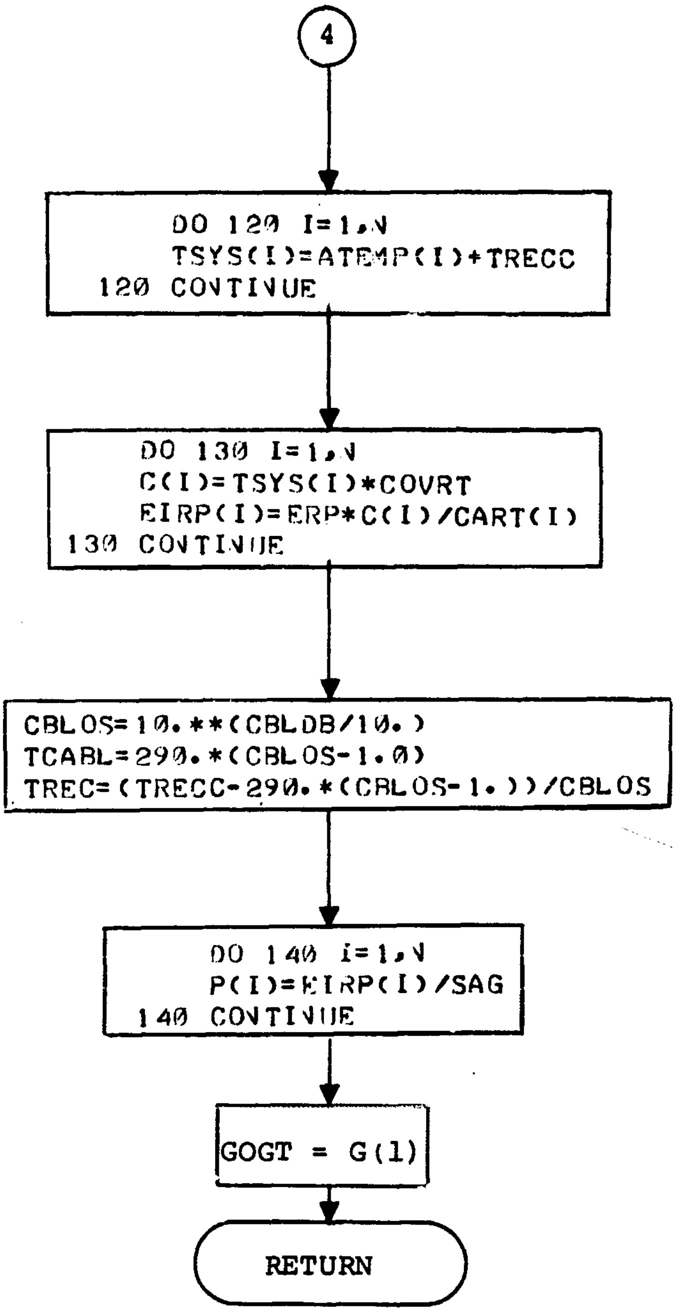


Figure 3-3. Continued



```
      DO 120 I=1,N
      TSYS(I)=ATEMP(I)+TRECC
  120 CONTINUE

      DO 130 I=1,N
      C(I)=TSYS(I)*COVRT
      EIRP(I)=ERP*C(I)/CART(I)
  130 CONTINUE

      CBLOS=10.**(CBLDB/10.)
      TCABL=290.*(CBLOS-1.0)
      TREC=(TRECC-290.*(CBLOS-1.))/CBLOS

      DO 140 I=1,N
      P(I)=EIRP(I)/SAG
  140 CONTINUE

      GOGT = G(1)
```

Figure 3-3. Continued

```
      SUBRØUTINE GRDSG(SLØD,SLAD,N,NS,RLØD,RLAD,PLØD,PLAD,
     1 FV,FA,AEFFC,ABWMN,RR,IENV,IHUMD,IG,FCAR,BGVSC,BGSSC,DA,
     2 T,VTMDB,ATMDB,BMAX,BWK,VKFDB,SNRVD,SNRSD,CBLDB,IKEY,
     3 SABWD,SPECF,SAEFC,ERPMX,PØR, TSYS,TREC,DIA,P,B,
     4FR,ELARD,ARADB,SCNDB,GØGT,SAGDB,ABMWD,EIRP,CØNVT,VTIR)
      DIMENSIØN FCAR(1),ARADB(1),CART(6),ATEMP(6),TR(6),TSYS(1)
      DIMENSIØN C(6),EIRP(1),SCNDB(6),P(1)
      DIMENSIØN FR(1),X(10),G(200)
      IF(IKEY-2)10,60,41
10    CALL CØVRN(FV,NS,BGVSC,BGSSC,FA,DA,VKFDB,BMAX,
     1 BWK,T,VTMDB,ATMDB,SNRVD,SNRSD, CØNDB,CØVRT,B,X,DP,FR,BIF,
     2CØNVT,VTIR)
      FCARC=SQRT(FCAR(1)*FCAR(N))
      SAG=SAEFC*(208.8/SABWD)**2
      SAGDB=10.*ALØG(SAG)/ALØG(10.)
      IF(ERPMX) 14,14,40
   14 CALL ERPM(FCARC,SABWD,SLAD,SLØD,PLAD,PLØD,SPECF, ERPMX)
40    DIA=1.99251E10/FCARC/ABWMN
41    ERP=ERPMX
      IF(FCARC-2.0E9)44,42,42
42    IF(FCARC-12.2E9)47,47,44
   44 DØ 46 I=1,N
      SCNDB(I)=0
   46 CØNTINUE
      GØ TØ 49
   47 DØ 48 I=1,N
      CALL SCINT(PØR,RLAD,FCAR(I), SCNDB(I))
   48 CØNTINUE
   49 CALL GEØM(SLAD,SLØD,RLAD,RLØD,PLAD,PLØD, ELARD,ANPRD,DISTR)
      DØ 50 I=1,N
      ARADB(I)=0.14*RR**1.155*(FCAR(I)/1.6E10)**3
   50 CØNTINUE
```

Figure 3-4. Subroutine GRDSG

```
 60 DO 70 I=1,N
    CART(I)=ERP*AEFFC*(FCARC*DIA/FCAR(I)/4./DISTR)**2*10.**
   1(-1.20412*(ANPRD/SABWD)**2)*10.**((ARADB(I)+SCNDB(I))/10.)
 70 CONTINUE
    CALL ANTGA(FCARC,DIA,AEFFC, G,ABMWD)
    DO 80 I=1,N
    CALL ANTEP(FCAR(I),RR,IENV,IHUMD,IG,ELARD,G, ATEMP(I))
 80 CONTINUE
    DO 90 I=1,N
    TR(I)=CART(I)/COVRT-ATEMP(I)
 90 CONTINUE
    TRECC=TR(1)
    DO 110 I=2,N
    IF(TRECC-TR(I)) 110,110,100
100 TRECC=TR(I)
110 CONTINUE
    DO 120 I=1,N
    TSYS(I)=ATEMP(I)+TRECC
120 CONTINUE
    DO 130 I=1,N
    C(I)=TSYS(I)*COVRT
    EIRP(I)=ERP*C(I)/CART(I)
130 CONTINUE
    CBLOS=10.**(CBLDB/10.)
    TCABL=290.*(CBLOS-1.0)
    TREC =(TRECC-290.*(CBLOS-1.))/CBLOS
    DO 140 I=1,N
    P(I)=EIRP(I)/SAG
140 CONTINUE
    GOGT=G(1)
    RETURN
    END
```

Figure 3-4. Continued

9. FV - Highest video frequency in Hz.

10. FA - Highest audio frequency in Hz.

11. AEFFC - Efficiency of the ground terminal antenna specified as a positive value less than one.

12. ABWMN - Minimum allowable antenna beamwidth in degrees of the ground terminal.

13. RR - Rain rate in mm/hr.

14. IENV - Integer which describes the man-made noise environment of the ground terminal as follows:

0 - No man-made noise
1 - Rural noise
2 - Suburban noise
3 - Urban noise

15. IHUMD - Integer which describes the relative humidity of the ground terminal environment as follows:

1 - Dry
2 - Average
3 - Humid

16. IG - Integer which describes the stellar noise level for the receiving ground terminal antenna pointed directly at the following:

1 - Cassiopeia (general galactic noise)
2 - Galactic plane
3 - Quiet sun
4 - Disturbed sun

17. FCAR - Vector of dimension N giving the frequency in Hz for each of the RF carriers in order from the lowest FCAR(1) to the highest FCAR(N).

18. BGVSC - Width of the guard band in Hz between the highest video frequency and the lowest frequency of the first subcarrier passband.

19. BGSSC - Width of the guard band in Hz between the edges of the bands of adjacent audio subcarriers.

20. DA - Peak deviation in Hz of the audio modulated FM subcarrier.

21. T - Value in dB defining the FM threshold by the deviation of the demodulator output signal-to-noise ratio from that predicted by the formula for performance above threshold.

22. VTMDB - Value in dB of the desired carrier-to-noise margin above threshold for the video channel.

23. ATMDB - Value in dB of the desired carrier-to-noise ratio margin above threshold for the most critical audio subcarrier channel.

24. BMAX - Maximum RF bandwidth in Hz that the modulated RF carrier is allowed to utilize.

25. BWK - Factor greater than or equal to one, which has the effect of reducing the RF bandwidth of a modulated FM carrier below that which would be predicted by Carson's formula.

26. VKFDB - Video improvement factor in dB, including both the effects of preemphasis and spectral weighting.

27. SNRVD - Required picture (black-to-white) signal-to-weighted noise ratio in dB at the ground station.

28. SNRSD - Required sound subcarrier-to-noise ratio in dB at the output of the demodulator. The same value is used for all subcarrier channels.

29. CBLDB - Cable loss in dB between the antenna terminals and the preamplifier, or converter if no preamplifier is used.

30. IKEY - Integer used as a key indicating which of the three entry points of the GRDSG subroutine is to be used. The designations are as follows:

1 - This indicates the entry point on the first iteration for each satellite beam.

2 - This indicates the entry point for subsequent iterations of the same beam, but ERPMX and DIA are calculated by the Main Line control program and are used as input parameters. ERPMX is the same as that last used for IKEY = 1.

3 - This indicates the entry point for the change in beam when a new value of ERPMX and a new value of DIA are both calculated by the Main Line control program.

31. SABWD - Satellite antenna beamwidth in degrees.

32. SPECF - Spectrum factor in dB defining the ratio of the power of the modulated carrier to the power in the 4.0 kHz bandwidth having the highest power.

33. SAEFC - Positive number less than one defining the satellite antenna efficiency.

34. ERPMX - Maximum satellite EIRP in watts allowed for a particular satellite beam.

35. POR - Probability in percent that the scintillation is less than the value to be calculated.

The output parameters are described below. Some of these parameters are used as input parameters part of the time, depending on the particular iteration.

1. TSYS - N dimensional vector of the required ground system noise temperature for each of the N carrier frequencies. This temperature vector is referenced to the terminals of the receiving antenna. The units are Kelvin degrees.

2. TREC - N dimensional vector of the receiver noise temperature referenced to the input terminals of the first active device. The units are Kelvin degrees.

3. DIA - Diameter in meters of the ground-terminal parabolic antenna.

4. P - N dimensional vector of the satellite RF power required at the antenna input for each of the N carrier frequencies for the satellite beam being considered. The units are watts.

5. B - RF bandwidth in Hz required by each modulated RF carrier.

6. FR - NS dimensional vector of frequency in Hz defining the frequency plan of the composite baseband signal modulating an RF carrier.

7. ELARD - Elevation angle in degrees of the ground terminal antenna pointing at the satellite.

8. ARADB - Rain attenuation in dB.

9. SCNDB - Scintillation attenuation in dB that is not exceeded POR percent of the time.

10. GOGT - Gain of the ground terminal antenna in dB.

11. SAGDB - Satellite antenna gain in dB.

12. ABMWD - Ground antenna beamwidth in degrees.

13. EIRP - N dimensional vector of satellite EIRP values in watts for each of the carriers in the beam.

14. CONVT - Carrier-to-noise ratio in dB at video threshold.

15. VTIR - Video threshold impulse rate given in impulses per second. This includes both positive and negative going pulses.

The value of IKEY is first checked to determine the path to be followed through the subroutine. If IKEY is one, the subroutine COVRN is called for calculating the parameters that are determined by the required output video and audio signal qualities and RF bandwidth constraint. The parameters are calculated to provide the lowest carrier power consistent with the imposed constraints. Next, the geometric center of the band of carrier frequencies FCARC and the satellite antenna gain SAG are calculated. SAG is used later in the subroutine to calculate RF power, knowing the EIRP. FCARC is used by the subroutine ERPM to calculate ERPMX, the maximum allowable value of EIRP, unless a positive value of ERPMX is provided as an input to the subroutine. A positive input value indicates that the first estimate of ERPMX is obtained from an input data card, hence ERPM is bypassed. The maximum diameter of the ground antenna is then calculated on the basis of the geometric mean frequency FCARC and the minimum allowable beamwidth ABWMN. Then ERP, the working value of EIRP, takes on the value of ERPMX.

If IKEY has the value three, rather than one, ERP is immediately set to the value of ERPMX calculated in the Main Line control program. Whether IKEY has a value of one or three, the rest of the subroutine performs the same after ERP, the working value of EIRP, has been established.

The value of the scintillation attenuation is next calculated for each carrier frequency. If the geometric center frequency is less than 2.0 GHz or greater than 12.2 GHz the scintillation attenuation is set at 0.0 dB. Otherwise the N dimensional vector SCNDB is calculated by subroutine SCINT for each carrier frequency.

Next the elevation angle of the ground antenna pointing at the satellite, angle of the ground terminal off the satellite beam axis, and the distance between the satellite and ground terminal are calculated by subroutine GEOM. The rain attenuation is also calculated for each carrier frequency.

Scintillation attenuation, rain attenuation, the geometrical parameters, and the effective area of the ground antenna are used along with ERP, the working value of EIRP for each carrier, to calculate CART, an N dimensional vector of power in watts received by the ground antenna at each of the carrier frequencies. The value of this vector is temporary and is used only internally in calculation. The final values of carrier-to-noise ratio for each channel are made equal by adjusting the EIRP per channel. The vector CART is calculated during each iteration independent of the state of the entry key IKEY.

The ground antenna gain pattern G in dB is a vector calculated by subroutine ANTGA at the geometric center frequency FCARC. G is used in calculating the N dimensional vector ATEMP which is the antenna temperature in Kelvin degrees at each carrier frequency.

Next, an N dimensional vector TR is calculated, and, like CART, is also an intermediate calculation. TR is the system noise temperature, less the antenna temperature, required to provide the desired output signal quality under the assumption that ERP, the working value of EIRP, is being transmitted at each carrier frequency resulting in CART at the receiving antenna terminals. Then TRECC is chosen to be the smallest component of the vector TR. This is the value of system noise temperature, less antenna temperature, that is required to satisfy the requirement of the most critical TV-sound channel. Thus, TRECC is the required receiver temperature as measured at the antenna input. It is assumed that this value is independent of frequency over the usage band.

The system temperature is calculated at each frequency by adding the antenna temperature at each RF carrier frequency to TRECC. The result is an N dimensional vector TSYS. The carrier power required at the ground antenna terminals at each frequency is calculated from the TSYS vector and the required value of carrier-to-noise temperature. The carrier power C is, thus, an N dimensional vector.

The EIRP of the satellite beam is then reduced in all but the most critical channel by the ratio C(I)/CART(I) given for the Ith channel. The satellite EIRP becomes an N dimensional vector called EIRP in the subroutine.

The temperature TREC of the active receiver is calculated by subtracting out the effect of the cable loss between it and the antenna.

By dividing the EIRP vector by the satellite antenna gain SAG, a new vector P results. P is the vector describing in watts the powers required to feed the satellite antenna at each RF carrier frequency.

Finally, the gain of the ground antenna GOGT which is assumed constant across the frequency band and is calculated at the geometric center frequency is specified as G(1) the on-axis gain taken from the gain pattern previously calculated.

The subroutines called by GRDSG are described in the following paragraphs.

3.2 FM CARRIER-TO-NOISE RATIO

The flow chart for the COVRN subroutine is shown in Figure 3-5 and the subroutine itself is shown in Figure 3-6. The subroutine requires 14 input parameters and calculates nine output parameters. The required input parameters are FV, NS, BGVSC and BGSSC (see Figure 3-7), FA, DA, VKFDB, BMAX, BWK, T (see Figure 3-8), VTMDB, ATMDB, SNRVD, and SNRSD as defined in Section 3.1.

The nine output parameters are

1. Carrier-to-noise ratio CONDB in dB required at the input to the FM demodulator.

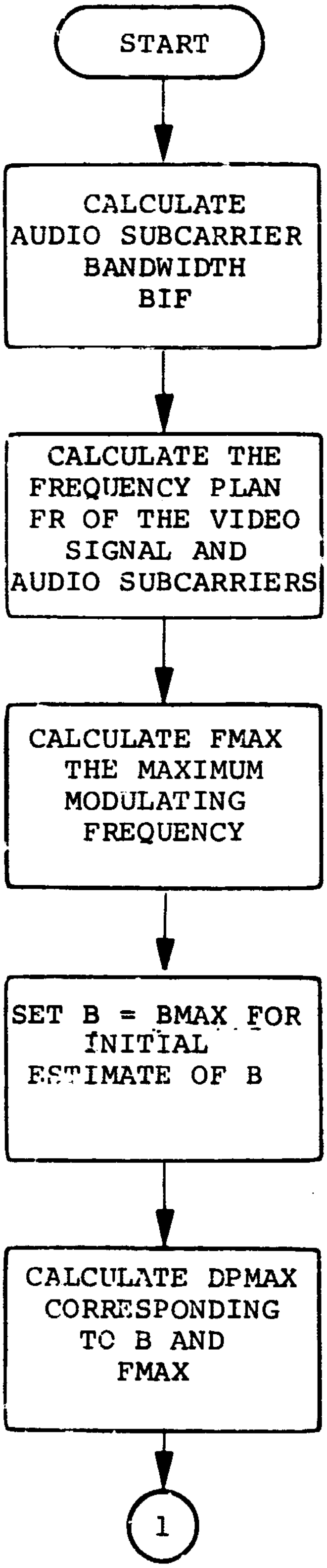


Figure 3-5. Flow Chart of COVRN Subroutine

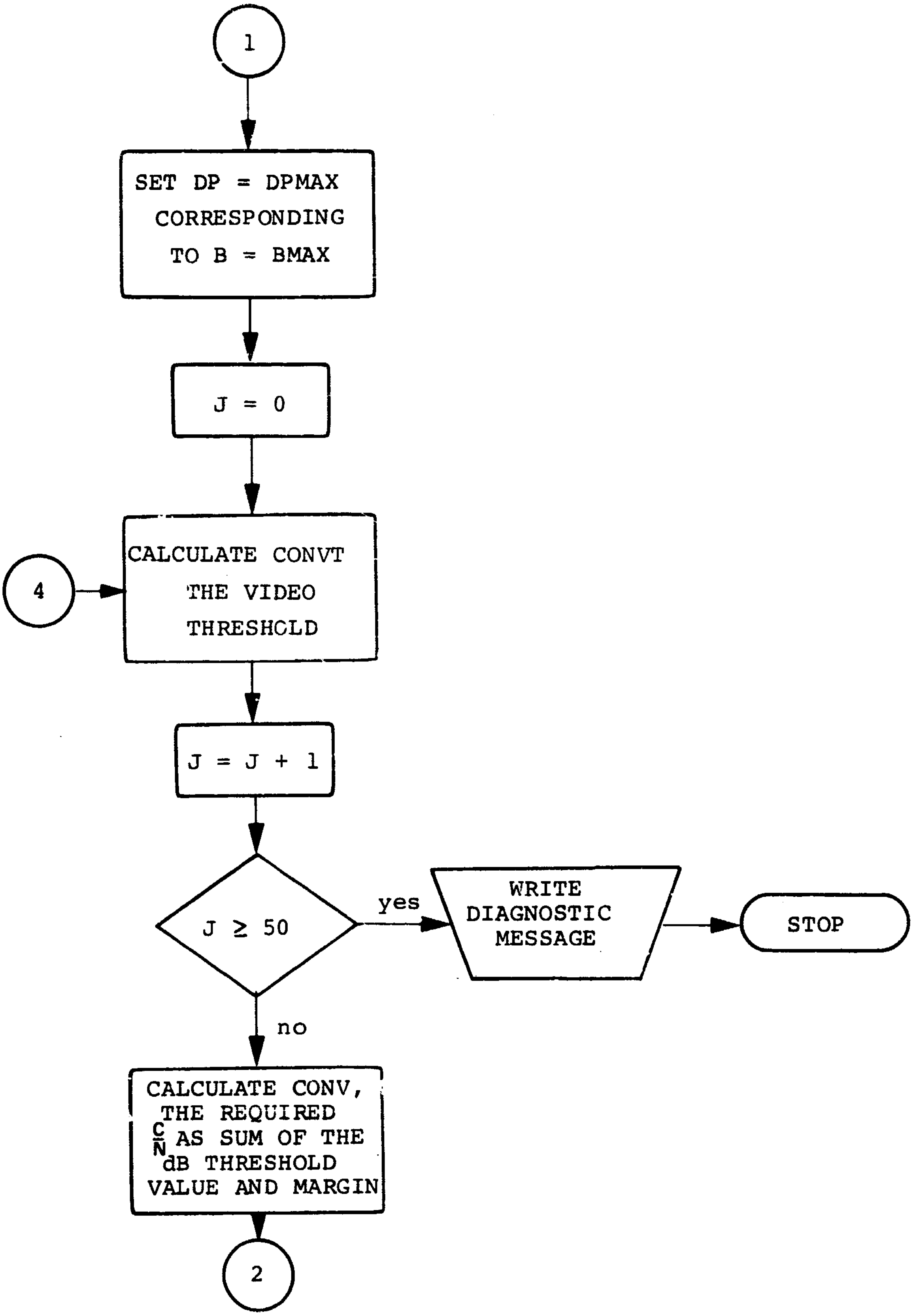


Figure 3-5. Continued

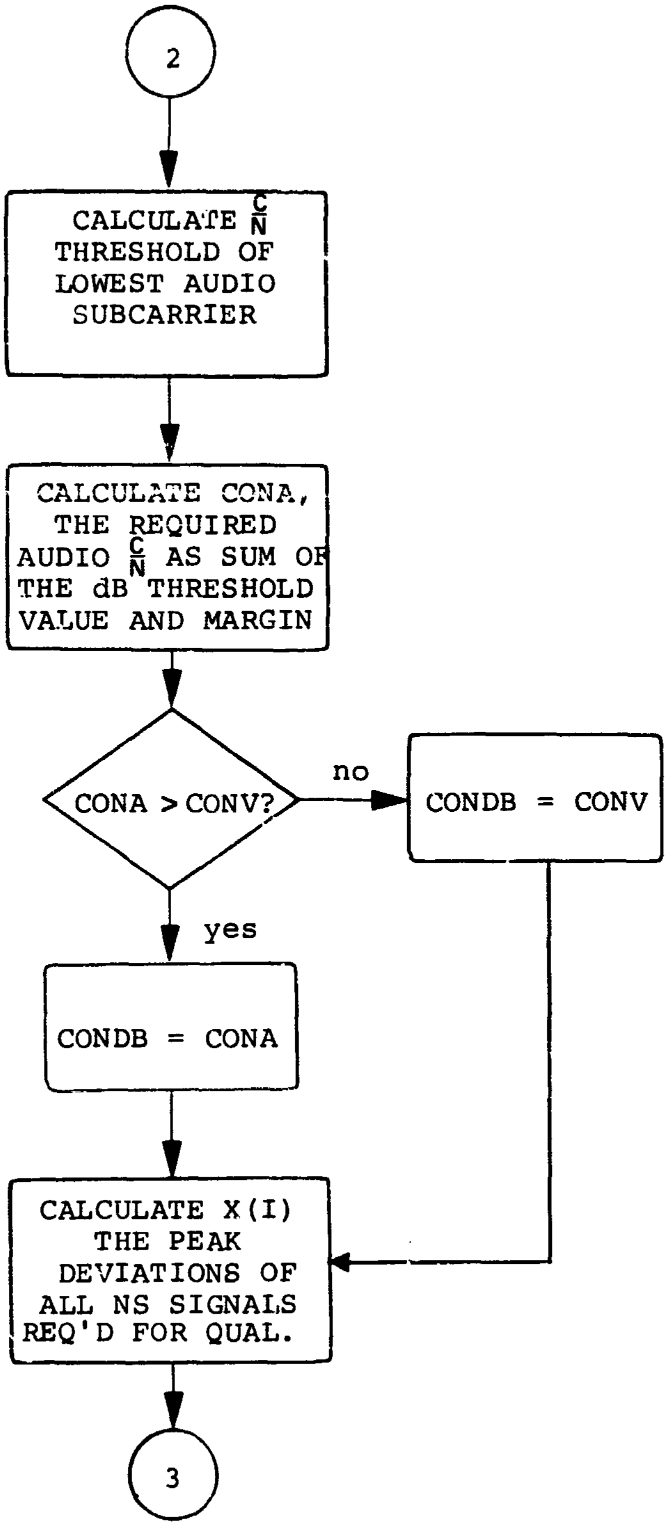


Figure 3-5. Continued

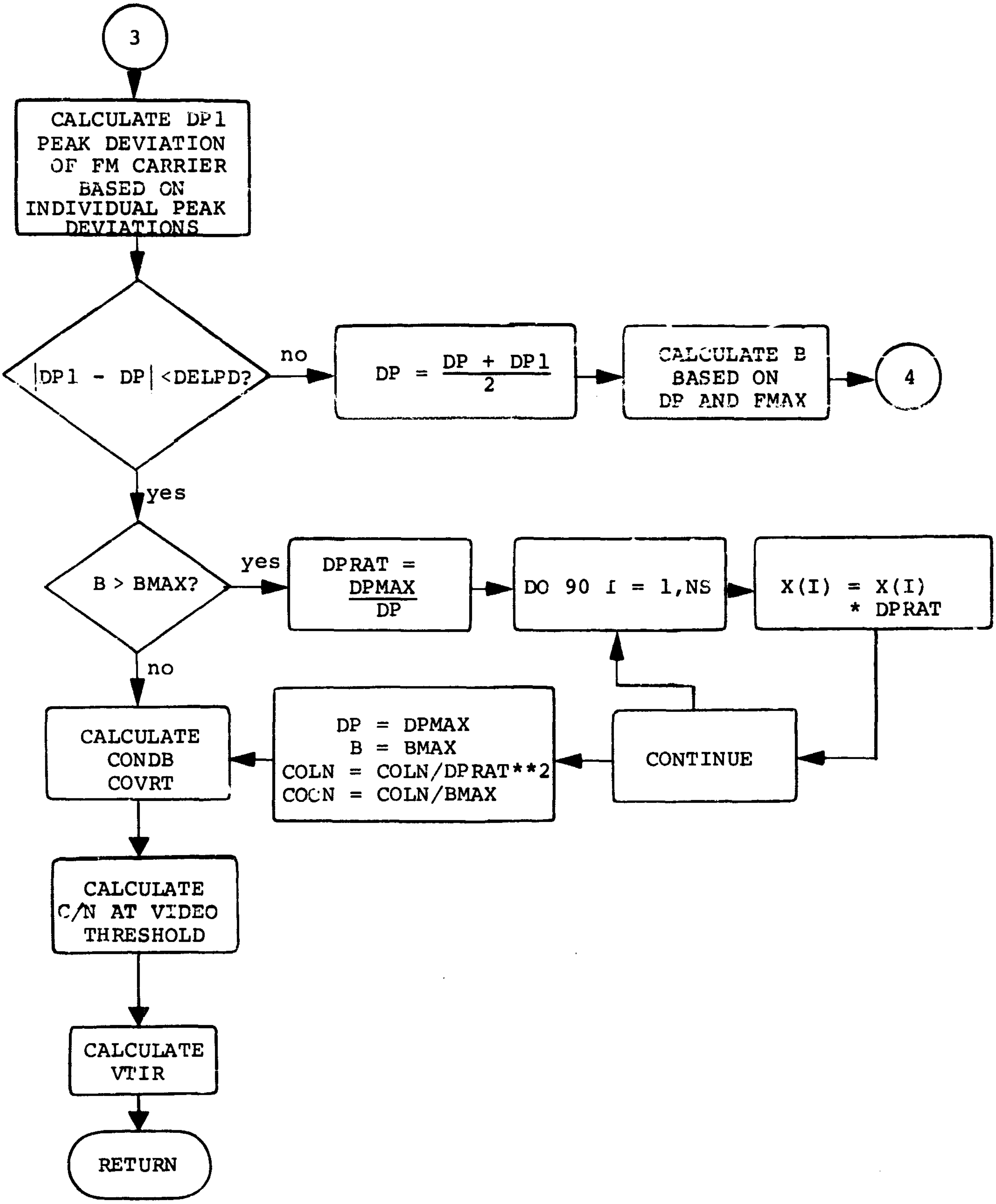


Figure 3-5. Continued

```
      SUBROUTINE COVRN(FV,NS,BGVSC,BGSSC,FA,DA,VKFDB,BMAX,
     1 BWK,T,VTMDB,ATMDB,SNRVD,SNRSD, CONDB,COVRT,B,X,DP,FR,BIF,
     2CONVT,VTIR)
C FV=VIDEO BANDWIDTH,NS=NO. OF SIGNALS=VIDEO+AUDIO SUBCARRIERS
C BGVSC=VIDEO-SUBCARRIER GUARD BAND
C BGSSC=SUBCARRIER-SUBCARRIER GUARD BAND
C FA=HIGHEST AUDIO FREQUENCY - DA=PEAK DEVIATION OF SUBCARRIER
C VKFDB=VIDEO K FACTOR (DB) - BMAX=MAX RF CARRIER BANDWIDTH
C BWK=RF BANDWIDTH K FACTOR - T=FM THRESHOLD DEFINITION (DB)
C VTMDB=VIDEO THRESHOLD MARGIN (DB) - ATMDB=AUDIO SUBCARRIER
C THRESHOLD MARGIN (DB) - SNRVD=REQD VIDEO SNR (DB)
C SNRSD=REQD SOUND SUBCARRIER TO NOISE RATIO (DB)
C CONDB=REQD CARRIER-TO-NOISE RATIO (DB)
C B=REQD RF BANDWIDTH
C X(I)=PEAK DEV RESULTING FROM ITH SIGNAL ONLY
C DP=PEAK DEV OF RF CARRIER
C FR(1)=FV=VIDEO BANDWIDTH - FR(I)=SUBCARRIER FREQ FOR I>1
C BIF=BANDWIDTH OF SUBCARRIER
      DIMENSION FR(1),X(1)
      PKDV(B,BWK,FMAX)=BWK*(B/2.0-FMAX)
      BW(DP,BWK,FMAX)=2.0*(FMAX+DP/BWK)
      NUFDB(DB)=10.0**(DB/10.0)
      FR(1)=FV
      DELFD=0.1E6
      IOUT=6
      VKF=NUFDB(VKFDB)
      SNRV=NUFDB(SNRVD)
      SNRA=NUFDB(SNRSD)
      BIF=BW(DA,1.0,FA)
      DO 10 I=2,NS
      FR(I)=FR(1)+BGVSC+BIF/2.0+(BIF+BGSSC)*(I-2)
   10 CONTINUE
      FMAX=FR(NS)+BIF/2.0
      B=BMAX
      DPMAX=PKDV(B,BWK,FMAX)
      DP=DPMAX
      J=0
```

Figure 3-6. Subroutine COVRN

```
 15 CALL THRES(T,0,FR(1),B,DP, CONVT)
    J=J+1
    IF(J-50) 18,16,16
 16 WRITE(IOUT,17)J
 17 FORMAT(1X,'J=',I3)
    STOP
 18 CONV=CONVT+VTMDB
    F1=FR(2)-BIF/2.0
    F2=FR(2)+BIF/2.0
    CALL THRES(T,F1,F2,B,DP, CONAT)
    CONA=CONAT+ATMDE
    IF(CONA-CONV) 20,30,30
 20 CONDB=CONV
    GO TO 40
 30 CONDB=CONA
 40 COCN=NUFDB(CONDE)
    COLN=B*COCN
    X(1)=SQRT(SNFV*FR(1)**3/6.0/COLN/VKF)
    DO 50 I=2,NS
    F1=FR(I)-BIF/2.0
    F2=FR(I)+BIF/2.0
    X(I)=SQRT(2.0*SNFA*(F2**3-F1**3)/3.0/COLN)
 50 CONTINUE
    CALL PDEV(X,NS, DP1)
    DEL=DP1-DP
    IF(ABS(DEL)-DELPD)70,70,60
 60 DP=(DP+DP1)/2.0
    B=BW(DP,BWK,FMAX)
    GO TO 15
 70 IF(B-BMAX) 100,100,80
 80 DPRAT=DPMAX/DP
    DO 90 I=1,NS
    X(I)=X(I)*DPRAT
 90 CONTINUE
    DP=DPMAX
    B=BMAX
    COLN=COLN/DPRAT**2
    COCN=COLN/BMAX
100 CONDB=10.0*ALOG(COCN)/ALOG(10.0)
    COVRT=1.38054E-23*B*COCN
    CALL THRES(T,0,FV,B,DP,CONVT)
    CNVTR=NUFDB(CONVT)
    CALL NTCON(B,DP,CNVTR,Y)
    VTIR=Y/CNVTR
    RETURN
    END
```

Figure 3-6. Continued

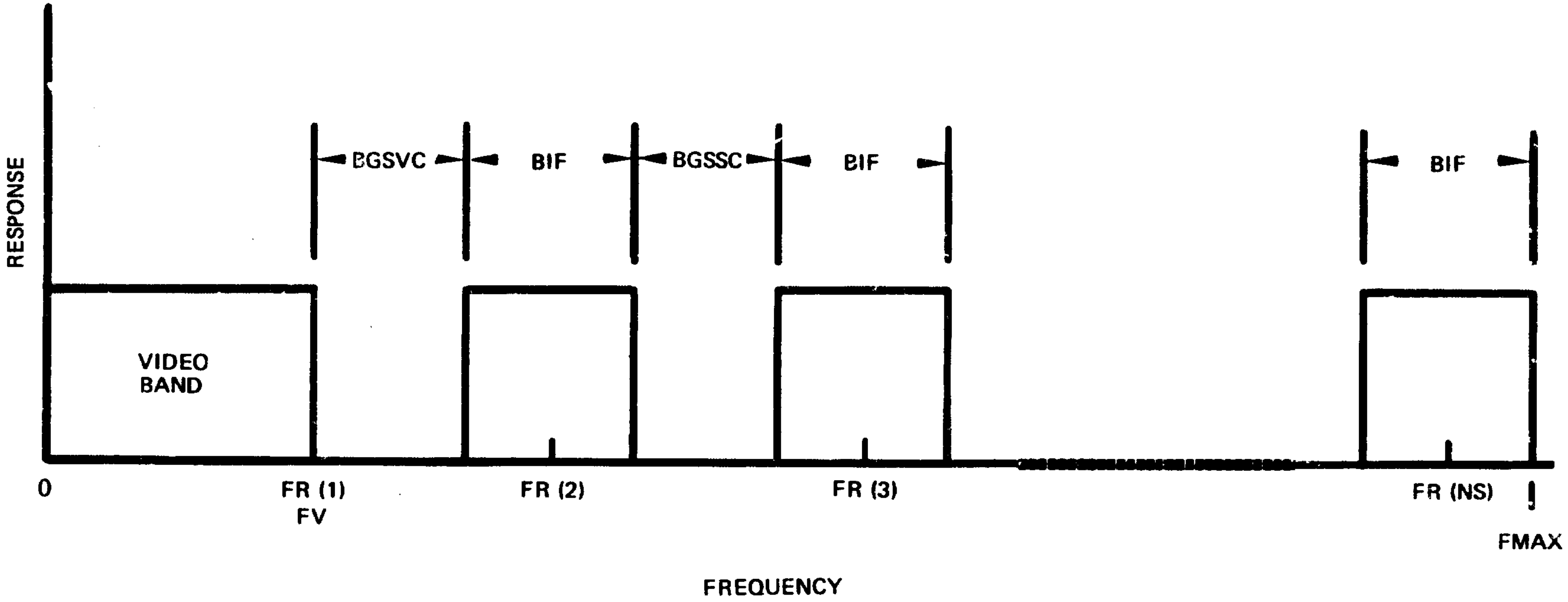


Figure 3-7. Frequency Plan of the Composite Signal Modulating the RF Carrier

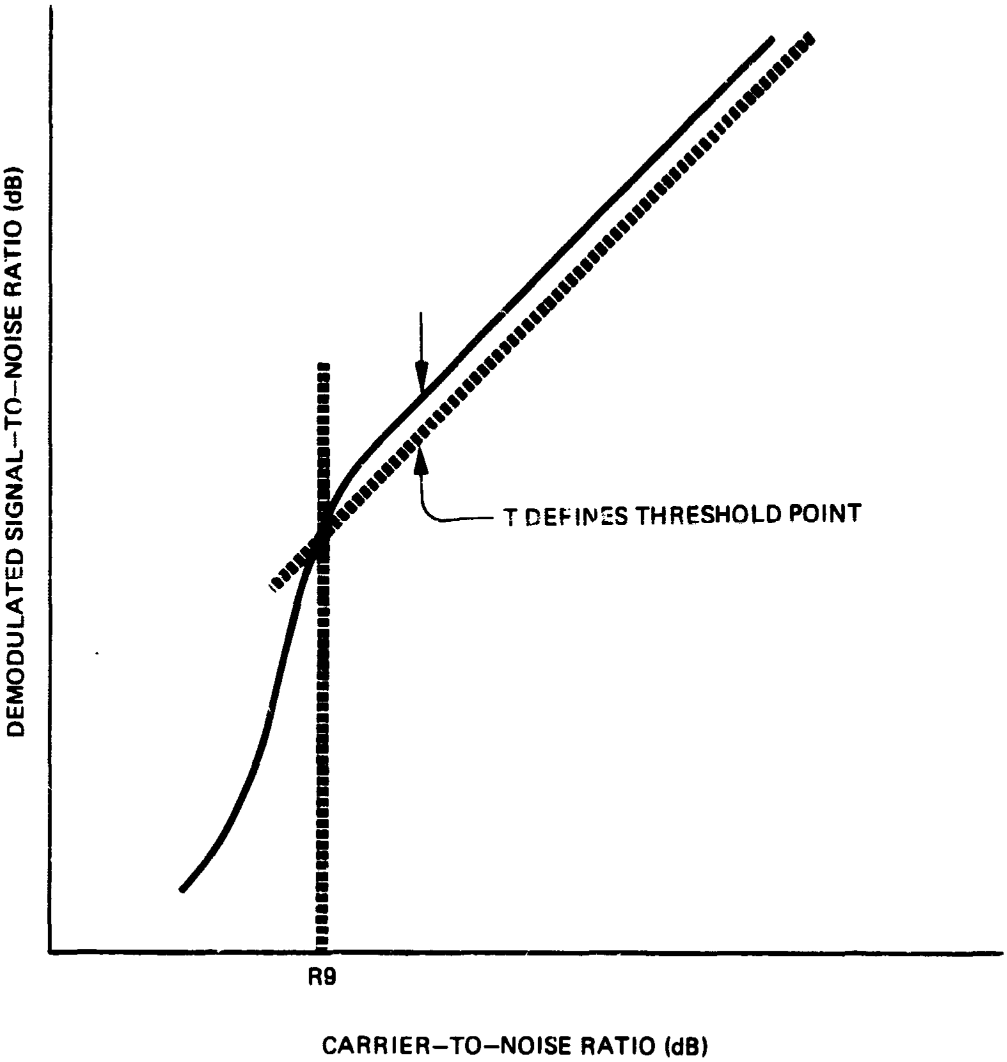


Figure 3-8. Typical Curve of Demodulated Signal-to-Noise Ratio as a Function of Carrier-to-Noise Ratio in an FM Receiver

2. Carrier-to-noise temperature ratio COVRT in dB required at the input to the FM demodulator.

3. The RF bandwidth B in Hz required for the modulated carrier.

4. The vector X defining each component peak deviation X(I) in Hz produced by the Ith of NS modulating signals for all values of I from 1 to NS.

5. The peak deviation DP in Hz of the modulated FM carrier.

6. The vector FR in Hz defining the frequency plan of the composite modulating signal (see Figure 3-7).

7. The common bandwidth BIF in Hz of the audio modulated subcarriers.

8. Carrier-to-noise ratio CONVT in dB at video threshold.

9. Video threshold impulse rate VTIR given in impulses per second, including both positive and negative going pulses.

The primary purpose of the COVRN subroutine is to calculate the smallest value of carrier-to-noise ratio $\frac{C}{N}$ that is consistent with the restrictions imposed by the input parameters. The program is described below.

The audio subcarrier bandwidth BIF, which is assumed to be the same for all subcarriers, is first calculated for use in determining the frequency plan of the composite modulating signal shown in Figure 3-7. The frequency plan is calculated by starting at the upper end of the video band and adding values of specified guard bands and multiples of $\frac{BIF}{2}$. The highest frequency FMAX modulating the RF carrier is also found in this manner. The RF bandwidth B and peak deviation DP, related by a modified form of Carson's rule, are at first assumed to be as large as possible in accordance with the specified maximum allowable RF bandwidth BMAX.

This value of DP is the first estimate of the peak deviation of the RF carrier. This estimate is used to calculate CONVT, the video threshold carrier-to-noise ratio defined by the video bandwidth, the assumed peak deviation DP, the threshold definition T, and the related RF bandwidth B. The $\frac{C}{N}$ required by the receiver to maintain a specified margin above video threshold is then calculated by adding the decibel values of the theshold value CONVT and the margin VTMDB. In the same fashion an audio subcarrier threshold value CONAT is calculated. The calculation is made for the lowest subcarrier channel, since it is the most critical channel with respect to threshold. The audio subcarrier threshold margin ATMDB is added to the threshold value CONAT to give the carrier-to-noise ratio required for the audio channel. The larger of the two required carrier-to-noise ratios is chosen to simultaneously satisfy the threshold requirements of both the video and audio subcarrier channels. This selected value of $\frac{C}{N}$, based on the maximum allowable RF bandwidth, is generally not the final required value, since the quality of the demodulated carriers has not yet been considered.

The RF carrier-to-noise density COLN is then calculated from the RF bandwidth and the carrier-to-noise ratio and is used to calculate the individual component peak deviations X(I) of the NS signals that are required to provide the quality of each individual demodulated signal. The peak deviation DP1 of the RF carrier is a function of these calculated deviations. If the magnitude of the difference between DP1 and DP is less than DELPD, a value internal to the subroutine, the correct values of the parameters are assumed to have been computed unless the required RF bandwidth is higher than BMAX, the largest allowable value. If $|DP1 - DP|$ is $\geq$ DELPD, a new estimate of DP is made. If the last estimate DP of peak deviation is low, the calculated value

DP1 is high and vice-versa. Thus, a new and better estimate of DP is made by numerically averaging DP1 and the last estimate of DP. This new estimate of DP is used in the same way as the first estimate until the values of DP and DP1 are sufficiently close. If the number of iterations exceeds 50, a diagnostic message is printed and the program stops. Once convergence has occurred, the calculated value of required bandwidth is compared with the maximum allowable value BMAX. If BMAX is not exceeded, the final decibel values of carrier-to-noise ratio and carrier-to-noise temperature are computed. If BMAX is exceeded, the individual component peak deviations are all reduced by the same ratio, namely the ratio of the maximum allowable RF peak deviation to the peak deviation which was calculated on the basis of minimum required RF carrier power at the receiver. The RF bandwidth assumes the maximum allowable value and the peak deviation assumes that value consistent with the maximum allowable RF bandwidth. The RF carrier-to-noise density COLN and the RF carrier-to-noise ratio COCN are increased to compensate for the narrower RF bandwidth imposed. Finally, the decibel values of carrier-to-noise ratio and carrier-to-noise temperature are computed. Then the values of carrier-to-noise ratio at video threshold and the corresponding video threshold impulse rate are calculated on the basis of the final parameters.

The formulas on which the more significant calculations are based are presented in the following discussion. A modified form of Carson's rule is used to relate the RF bandwidth of a frequency-modulated signal to its peak deviation. This relation is

$$B = 2\left(f_m + \frac{D_p}{k}\right) \qquad (3\text{-}1)$$

where B is the RF spectral bandwidth of a frequency modulated carrier having a peak deviation D_p, and f_m is the maximum frequency of the modulating signal. The bandwidth of the FM subcarriers is calculated on the basis of Carson's rule (k=1), while the bandwidth of the frequency-modulated RF carrier is calculated for $k \geq 1$. The k factor has been added since laboratory experiments have indicated that the spectral bandwidths of various FM carriers is less than that predicted by Carson's rule. For example, in a CSC experiment, using a monochrome signal, a D_p of 10 MHz and a f_m of 4.2 MHz, a B of 15 MHz was employed without subjectively degrading the demodulated signal. This is equivalent to a K of about 3.

The picture (black-to-white) signal-to-weighted noise ratio $\left(\frac{S}{N}\right)_v$ is given by

$$\left(\frac{S}{N}\right)_v = 6\,\frac{\left(\Delta f_v\right)^2}{f_v^{\,3}}\left(\frac{C}{n}\right)K_v \qquad (3\text{-}2)$$

where Δf_v is one-half of sync-to-white frequency measured with preemphasis removed.

f_v is the maximum video frequency.

$\frac{C}{n}$ is the ratio of the received carrier power to the system noise power density at the input terminals of the receiver.

K_v is the video improvement factor to account for preemphasis and noise weighting.

Equation (3-2) can be solved for the peak deviation of the RF carrier by the video component of the modulating signal as follows:

$$\Delta f_v = \sqrt{\frac{\left(\frac{S}{N}\right)_v f_v^{\,3}}{6\left(\frac{C}{n}\right)K_v}} \qquad (3\text{-}3)$$

This is the equation used in the subroutine to calculate the video component of peak deviation of the RF carrier after the RF carrier-to-noise ratio is determined on the basis of the FM threshold and margin. Thus, the video component of the peak deviation of the RF carrier is that required to satisfy the quality defined by $\left(\frac{S}{N}\right)_v$.

The basis for the calculation of the audio subcarrier components of peak deviation is presented for clarification. Let X be the peak deviation of the RF carrier resulting from modulation by a single subcarrier. The demodulated output subcarrier power S_s can be calculated as

$$S_s = \frac{(2\pi X)^2}{2} = 2\pi^2 X^2 \tag{3-4}$$

If the subcarrier falls in a band with edges at frequencies f_1 and f_2 such that $f_1 < f_2$, the fluctuation noise power is given by

$$N_s = \frac{4\pi^2}{3\left(\frac{C}{N}\right)B}\left(f_2^{\,3} - f_1^{\,3}\right) \tag{3-5}$$

as given in Equation (3-14) of Paragraph 3-3. Since the impulse noise is negligible at the subcarrier frequencies, the subcarrier-to-noise power ratio as given by the ratio of the expressions in Equations (3-4) and (3-5) is

$$\left(\frac{S}{N}\right)_s = \frac{3}{2}\, X^2 \,\frac{1}{f_2^{\,3} - f_1^{\,3}}\left(\frac{C}{n}\right) \tag{3-6}$$

where $\frac{C}{n}$ is substituted for $\left(\frac{C}{N}\right)$ B. The peak deviation due to each audio subcarrier is

$$X = \sqrt{\frac{2\left(\frac{S}{N}\right)_s\left(f_2^{\,3} - f_1^{\,3}\right)}{3\left(\frac{C}{n}\right)}} \tag{3-7}$$

When the subroutine converges to an optimum bandwidth larger than the maximum allowable value, the value of $\left(\frac{C}{n}\right)$ is increased in accordance with Equations (3-2) and (3-6). In other words, the carrier-to-noise power density ratio is increased by a factor which is the square of the ratio of the two bandwidths. The value of $\left(\frac{C}{N}\right)$ is then found by multiplying $\left(\frac{C}{n}\right)$ by B, the final RF bandwidth. A value of $\frac{C}{T}$, the ratio of the received carrier power to the receiving system noise temperature, is calculated by

$$\frac{C}{T} = \left(\frac{C}{N}\right) kB \tag{3-8}$$

where k is Boltzmann's constant and the other symbols are the same as those defined earlier.

Equations (3-1) through (3-8) form the theoretical basis for the calculations performed in the subroutine.

3.3 THRESHOLD CARRIER-TO-NOISE RATIO SUBROUTINE

Two subroutines, THRES and NTCON, are used to calculate threshold carrier-to-noise ratios. The subroutine NTCON is used to make a calculation required in subroutine THRES. The flow chart for subroutine THRES is shown in Figure 3-9 and the subroutine is shown in Figure 3-10. The flow chart for subroutine NTCON is shown in Figure 3-11 and the subroutine is shown in Figure 3-12. Also shown in Figure 3-12 is subroutine BESSL which is called by NTCON for solving Bessel functions. There are five input parameters and one output parameter for subroutine THRES. The input parameters required to calculate the output carrier-to-noise threshold P9 (see Figure 3-8) in decibels are as follows:

1. A value T as previously defined.

2. A value F1 in Hz, defining the lower end of the output pass band of the demodulator for the channel of interest.

3. A value F2 in Hz, defining the upper end of the output pass band of the demodulator for the channel of interest.

4. A value B in Hz, which is the RF input pass band to the demodulator.

5. A value D in Hz, which is the peak deviation of the RF signal to be demodulated.

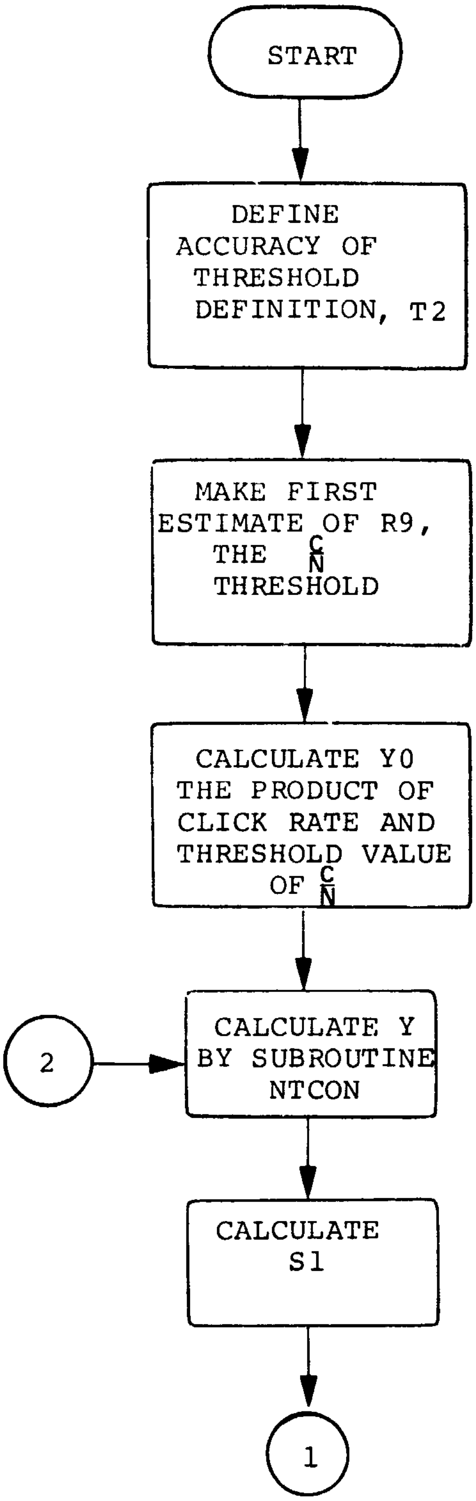


Figure 3-9. Flow Chart of Subroutine THRES

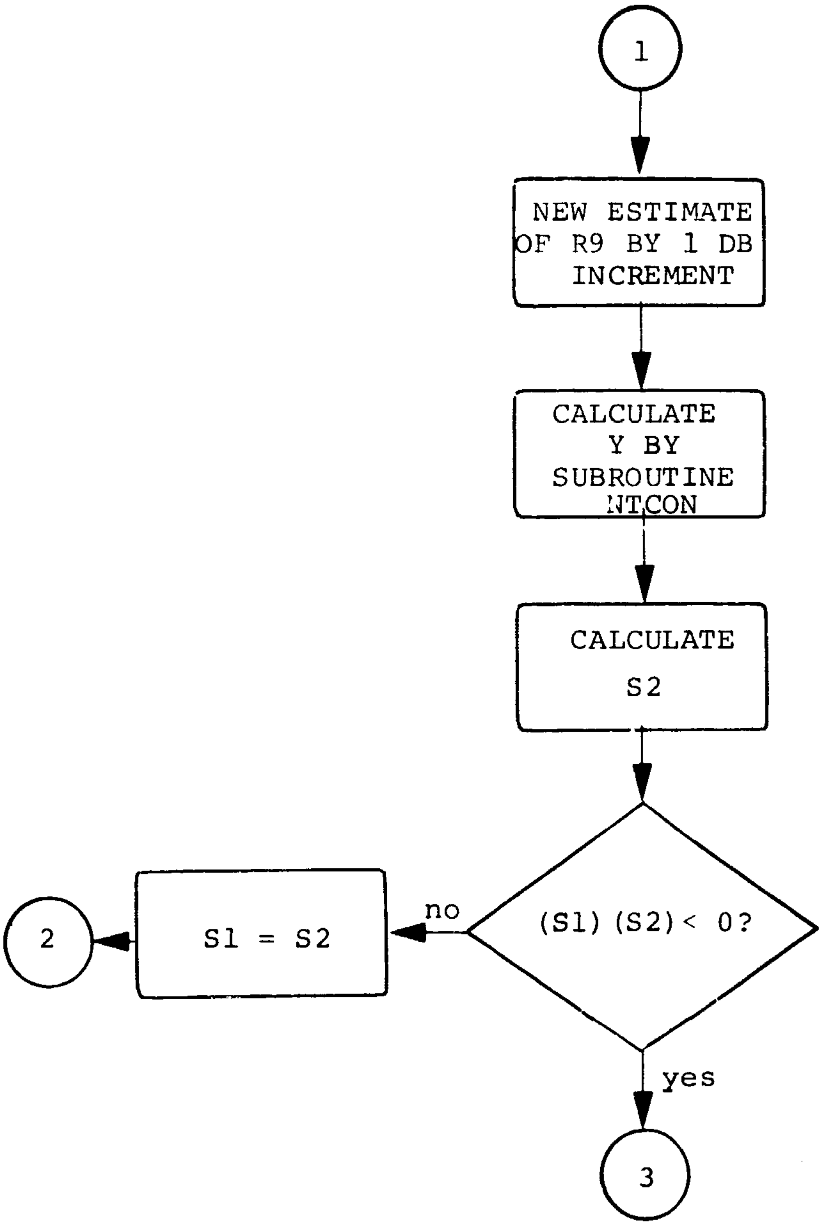


Figure 3-9. Continued

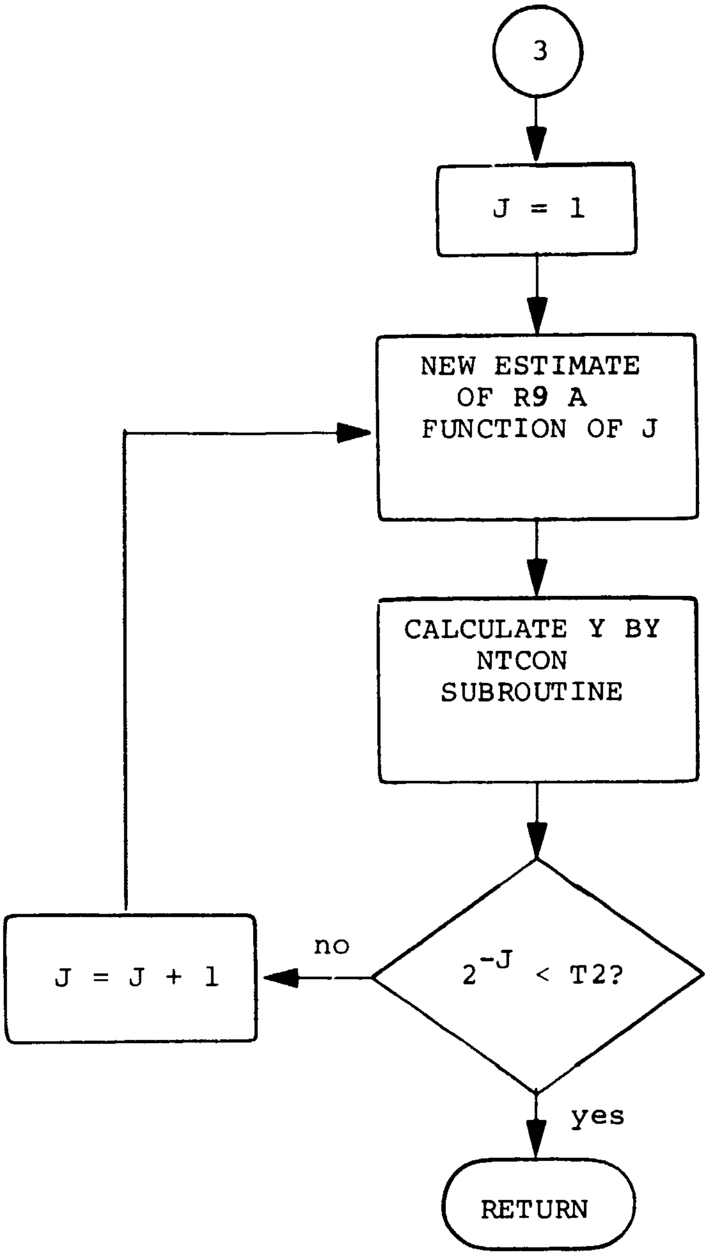


Figure 3-9. Continued

```
      SUBROUTINE THRES(T,F1,F2,B,D, R9)
C SUBROUTINE FOR C/N WITH THRESHOLD T IN DB. F1 AND F2 ARE
C THE ENDS OF THE DEMODULATED SIGNAL BAND IN HZ. B IS RF BW
C IN HZ AND D IS DEV IN HZ.
C R9=C/N THRESHOLD IN DB
      T2=.05
      P= 4*ATAN(1)
      R9= 10.0
      Y0=(F1**2+F2**2+F1*F2)/6.0/B*(10.0**(T/10.0)-1.0)
      R= 10.0**(R9/10.0)
  220 CALL NTCON(B,D,R, Y)
      S1=(Y-Y0)/ABS(Y-Y0)
      R9= R9+S1
      R= 10.0**(R9/10.0)
      CALL NTCON(B,D,R, Y)
      S2=(Y-Y0)/ABS(Y-Y0)
      IF (S1*S2) 290,270,270
  270 S1=S2
      GO TO 220
  290 J=1
  300 R9=R9+(Y-Y0)/ABS(Y-Y0)/2.0**J
      R= 10.0**(R9/10)
      CALL NTCON(B,D,R, Y)
      IF(2.0**(-J)-T2) 360,340,340
  340 J=J+1
      GO TO 300
  360 RETURN
      END
```

Figure 3-10. Subroutine THRES

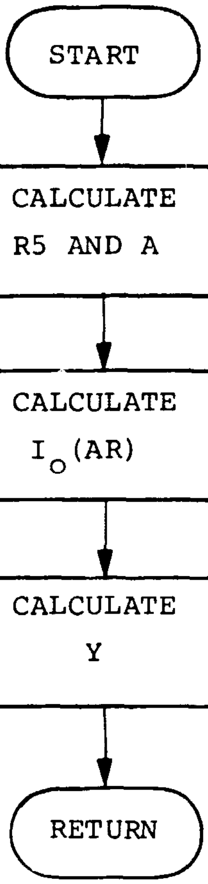


Figure 3-11. Flow Chart of Subroutine NTCON

```
      SUBROUTINE NTCON(B,D,R, Y)
C SUBROUTINE FOR (N TIMES C/N PWR RATIC)
      R5=B/3.464102
      A=.5*(D/R5)**2
      CALL BESSL(A*R,AIO)
      P=4*ATAN(1)
      Y=(D*EXP(-R)/P+R5*EXP(-R*(1.0+A))*AIO/SQRT(4.0*P*R))*2*R
      RETURN
      END

      SUBROUTINE BESSL(X,Y)
C SUBROUTINE FOR BESSEL FCN Y=IO(X) FOR X =-3.75
      IOUT=6
      T=X/3.75
      IF (X+3.75)730,610,610
  610 IF (X-3.75) 620,620,670
  620 Y=1.0+3.5156229*T**2+3.0899424*T**4+1.2067492*T**6
     1 +.2659732*T**8+.0360768*T**10+.0045813*T**12
      GO TO 750
  670 Y=EXP(X)/SQRT(X)*(.39894228+.01328592/T+.00225319/T**2
     1 -.00157565/T**3+.00916281/T**4-.02057706/T**5
     2 +.02635537/T**6-.01647633/T**7+.00392377/T**8)
      GO TO 750
  730 WRITE(IOUT,731)
  731 FORMAT(1X,'X -3.75 NCT ALLOWED')
      STOP
  750 RETURN
      END
```

Figure 3-12. Subroutines NTCON and BESSL

The method for calculating the threshold value of carrier-to-noise ratio is given in the following paragraphs. The technique is based on Rice's work (Reference 3-1) which assumes a sinusoidal modulating signal. This is not the case for the chosen model, however, little error is expected as a result of this assumption. (Reference 3-2)

The impulse noise spectral density is given by

$$n_1(f) = 8\pi^2 I \tag{3-9}$$

where I is the impulse rate in impulses per second, including both positive and negative going pulses. The fluctuation noise power spectral density is given by

$$n_2(f) = \frac{(2\pi f)^2 \omega(f_c + f)}{C} \tag{3-10}$$

where $\omega(f)$ is the one-sided RF noise power spectral density in a band symmetrical about the RF carrier frequency f_c, and C is the received carrier power. If $\omega(f_c + f)$ is a constant over the RF band of width B and if the total received noise is N, then

$$\omega(f_c + f) = \frac{N}{B} \quad \text{for} \quad |f| < \frac{B}{2} \tag{3-11}$$

and

$$n_2(f) = \frac{(2\pi f)^2 N}{BC} \tag{3-12}$$

If $n_1(f)$ and $n_2(f)$ are then integrated over the band of interest from f_1 to f_2 containing the demodulated signal, the impulse noise and fluctuation noise are given, respectively, by

$$N_1 = 8\pi^2 I (f_2 - f_1) \tag{3-13}$$

$$N_2 = \frac{4\pi^2}{3\left(\frac{C}{N}\right)B} \left(f_2^3 - f_1^3\right) \tag{3-14}$$

Since the threshold is caused by N_1's becoming a significant term in the total output noise as the input value of $\frac{C}{N}$ is decreased, an equation relating the threshold definition T (in dB) to the values N_1 and N_2 of output noise in the output band from f_1 to f_2 can be written as

$$10^{T/10} = \frac{N_1 + N_2}{N_2} = 1 + \frac{N_1}{N_2} \qquad (3\text{-}15)$$

This can be rearranged as follows:

$$\frac{1}{10^{T/10} - 1} = \frac{N_2}{N_1} \qquad (3\text{-}16)$$

By substituting values for N_1 and N_2 and solving for $\left(\frac{C}{N}\right)I$, the following equation is derived

$$\left(\frac{C}{N}\right)I = \frac{\left(10^{T/10} - 1\right)}{6B}\left(f_1^{\,2} + f_2^{\,2} + f_1 f_2\right) \qquad (3\text{-}17)$$

This condition must hold at threshold. Equation (3-17) is called Y0 in subroutine THRES of Figure 3-10. By using Rice's approximation for click rate given by Equation 83 in Reference 3-1, the following equation results:

$$\left(\frac{C}{N}\right)I = \left[\frac{D_p}{\pi}\exp\left(-\frac{C}{N}\right) + \frac{r}{\sqrt{4\pi\left(\frac{C}{N}\right)}}\exp\left|-\frac{C}{N}\left(1 + a\right)\right| I_o\left(a\,\frac{C}{N}\right)\right] 2\left(\frac{C}{N}\right) \qquad (3\text{-}18)$$

where D_p is the peak deviation of the carrier, r is $\frac{B}{\sqrt{12}}$ for a rectangularly shaped RF band, and A is $\left(\frac{D_p}{r}\right)^2$. Equation (3-18) must be solved for $\left(\frac{C}{N}\right)$, the threshold value of $\left(\frac{C}{N}\right)$.

Subroutine NTCON is used to calculate the expression on the right side of Equation (3-18). Subroutine THRES calculates the left side of Equation (3-18) by Equation (3-17). A converging sequence of estimates of $\left(\frac{C}{N}\right)$ is made in subroutine THRES until an estimate of $\left(\frac{C}{N}\right)$ is within the tolerance T2 = 0.05 dB of the exact value of the threshold carrier-to-noise ratio $\left(\frac{C}{N}\right)$. The output carrier-to-noise ratio from subroutine THRES is given in decibels as R9.

3.4 FM CARRIER PEAK DEVIATION SUBROUTINE PDEV

Consider a composite signal made up of a television video signal and several audio-frequency modulated, constant-amplitude subcarriers at frequencies above the video band, where the composite signal frequency modulates a carrier. In this case, where the various signals are added rogether linearly, the instantaneous deviations of the carrier are the same as the sum of instantaneous deviations due to each modulating signal.

If a sinusoid modulates a carrier the carrier reaches peak deviation twice on each cycle for 0.0% of the time, since the peak deviation occurs at only two points of zero duration. If two independent sinusoids are added together to modulate a carrier, the peak deviation is twice the individual peak deviations, but the peak may not occur for many cycles, depending on the phase relationship between the modulating sinusoids. If more sinusoids are added together linearly, there is less probability that the sum of their amplitudes will occur simultaneously to yield peak deviation.

Now consider another definition of peak deviation. Let the peak deviation be that deviation which is exceeded for some given percentage of time, say 1.0%. A single sinusoid exceeds 0.99988 times its amplitude during 1.0% of the time. If two independent sinusoids are added, a smaller fraction of the sum of the individual amplitude will be exceeded 1.0% of the time. As the number of independent sinusoids is increased, the fraction of the maximum possible amplitude that is exceeded 1.0% of the time decreases. As the percentage of time is decreased, the instantaneous value that is exceeded for that percentage of time approaches the sum of the individual amplitudes. If 0.1% or 0.01% is used and six or seven signals are used, little error is expected from assuming that the peak deviation is the sum of the individual peak deviations. The error resulting from this assumption increases with the number of signals.

The flow chart for the PDEV subroutine is shown in Figure 3-13, and the subroutine is shown in Figure 3-14. The subroutine adds together the peak deviations of the carrier resulting from the application of each separate modulating signal to approximate the peak deviation of the composite signal.

The input parameters are a vector X of dimension NS. The components of the vector are X(1), X(2),..., X(NS). X(1) represents the peak deviation of the video signal, X(2) represents the peak deviation of the carrier resulting from the first audio subcarrier, etc., and finally, X(NS) represents the peak deviation of the carrier resulting from the (NS-1)th, or highest, audio subcarrier. The output parameter DP is the calculated peak deviation of the carrier.

3.5 MAXIMUM ALLOWABLE EIRP SUBROUTINE ERPM

Subroutine ERPM, listed in Figure 3-15, calculates the maximum EIRP in watts allowable from a synchronous broadcasting satellite as a result of maximum power flux densities allowable on the earth's surface. The maximum allowable power densities on the earth's surface are based on the recommendations of the World Administrative Radio Conference (WARC). The input variables to the subroutine are F, the carrier frequency in Hz, and SABWD, SLAD, SLOD, PLAD, PLOD, and SPECF as defined in Section 3.1.

The WARC in June 1971 recommended maximum power densities allowable on the earth's surface as a function of the elevation of the satellite above the horizon at each point. These recommendations are shown in Table 3-1.

The spectral density is not considered in the lowest band, but it is in middle band. Subroutine ERPM uses these specifications in the two lower frequency bands and assumes that the restrictions on the 11.7-12.2 GHz band are the same as on the 2.50-2.69 GHz band.

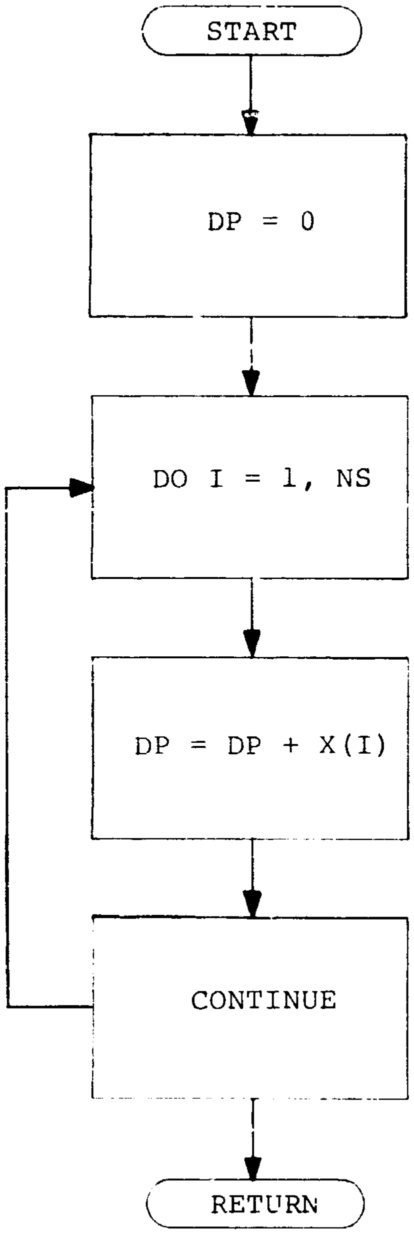


Figure 3-13. Flow Chart of the PDEV Subroutine

```
      SUBROUTINE PDEV(X,NS, DP)
C PEAK DEV. IS CALCULATED FROM THE NS COMPONENT DEVIAIONS X(I)
      DIMENSION X(1)
      DP=0
      DO 10 I=1,NS
      DP=DP+X(I)
   10 CONTINUE
      RETURN
```

Figure 3-14. Subroutine PDEV

```
ERPM,ERPM
            CSCX FORTRAN V
         SUBROUTINE ERPM(F,SABWD,SLAD,SLOD,PLAD,PLOD,SPECF, ERPMX)
    C F=CARRIER FREQ (HZ)
    C SLAD=SAT LAT IN DEG - SLOD=SAT LONG IN DEG
    C PLAD=POINTING LAT IN DEG - PLOD=POINTING LONG IN DEG
    C SPECF IS SPECTRUM FACTOR IN DB RELATING CARRIER POWER TO
    C    HIGHEST POWER IN ANY 4.0-KHZ BAND
    C ERPMX IS MAX ALLOWABLE EIRP OF SAT CHANNEL IN WATTS
         DELAD=1.0
    C DELAD=DEG INCREMENT ALONG A GREAT CIRCLE ON EARTH SURFACE TO
    C    DETERMINE MAX EIRP OF SAT
         P2=1.5707963
         R=6378388.0
         H=35793604.0
         RTOD=57.295779513
         F1=620.0E6
         F2=790.0E6
         F3=2.5E9
         F4=2.69E9
         F5=11.7E9
         F6=12.2E9
     110 IF(F-F1) 300,210,120
     120 IF(F-F2) 210,210,130
     130 IF(F-F3) 300,220,140
     140 IF(F-F4) 220,220,150
     150 IF(F-F5) 300,230,160
     160 IF(F-F6) 230,230,300
     210 M=1
         GO TO 320
     220 M=2
         GO TO 320
     230 M=3
         GO TO 320
     300 WRITE(6,310) F
     310 FORMAT(1X,'FREQUENCY=',1PE15.7,'NOT ACCEPTABLE TO ERPM SUB')
         STOP
     320 SLAR=SLAD/RTOD
         SLOR=SLOD/RTOD
         PLAR=PLAD/RTOD
         PLOR=PLOD/RTOD
         CALFA=SIN(SLAR)*SIN(PLAR)+COS(SLAR)*COS(PLAR)*COS(SLOR-PLOR)
         IF(CALFA) 390,395,390
     390 ALFAR=ATAN(SQRT(1.-CALFA**2)/CALFA)+(1.-CALFA/ABS(CALFA))*P2
         GO TO 397
     395 ALFAR=90./RTOD
```

Figure 3-15. Subroutine ERPM

```
 397 ALFAD=RTOD*ALFAR
     CAMXR=ATAN(SQRT(1.0-(R/(R+H))**2)*(R+H)/R)
     CAMXD=RTOD*CAMXR
     CAD=0.0
     ERPMX=1.0E37
 400 CALL GEOM(0.0,0.0,0.0,CAD,0.0,ALFAD, ELARD,ANPRD,DISTR)
     IF(M-2) 410,510,510
 410 IF(ELARD-20.0) 710,710,420
 420 IF(ELARD-60.0) 720,730,730
 510 IF(ELARD-5.0) 810,810,520
 520 IF(ELARD-25.0) 820,830,830
 710 P=10.**-12.9
     GO TO 1000
 720 P=10.**(-12.9+(ELARD-20.0)/25.0)
     GO TO 1000
 730 P=10.**-11.3
     GO TO 1000
 810 P=10.0**((-152.+SPECF)/10.)
     GO TO 1000
 820 P=10.**((-152.0+.75*(ELARD-5.0)+SPECF)/10.)
     GO TO 1000
 830 P=10.**((-137.+SPECF)/10.)
1000 GLODB=12.0412*(ANPRD/SABWD)**2
     IF(GLODB-20.) 1007,1005,1005
1005 GLODB=20.
1007 EIRPV=12.5663706*P*DISTR**2*10.**(GLODB/10.)
     IF(EIRPV-ERPMX) 1010,1020,1020
1010 ERPMX=EIRPV
1020 CAD=CAD+DELAD
     IF(CAD-CAMXD) 400,1030,1030
1025 FORMAT(1X,1P5E12.6)
1030 RETURN
     END
```

Figure 3-15. Continued

TABLE 3-1

WARC FLUX DENSITY RECOMMENDATIONS

FREQUENCY BAND	FLUX DENSITY LIMITS
620-790 MHz	$-129\ \mathrm{dBW/m^2},\ \theta \leq 20°$
	$-129 + \left(\frac{\theta-20}{2.5}\right)\mathrm{dBW/m^2},\ 20°<\theta<60°$
	$-113\ \mathrm{dBW/m^2},\ \theta \geq 60°$
2.50-2.69 GHz	$-152\ \mathrm{dBW/m^2/4\ kHz},\ \theta \leq 5°$
	$-152 + \frac{3(\theta-5)}{4}\ \mathrm{dBW/m^2/4\ kHz},\ 5°<\theta<25°$
	$-137\ \mathrm{dBW/m^2/4\ kHz},\ \theta \geq 25°$
11.7-12.2 GHz	No flux limits were given for broadcasting satellites.

Subroutine ERPM calculates the angle along a great circle on the earth between the satellite subpoint and the axis of the satellite antenna beam. Once this angle is known, it is possible to exercise the GEOM subroutine as if the great circle chosen were the equator. The angle along the great circle from the satellite subpoint at which a fictitious receiver is located is incremented from zero through the center of the satellite beam to a maximum value determined by the restriction that all points considered be within view of the satellite. Subroutine GEOM yields values of elevation angle of the fictitious receiver, the angle of the receiver off the satellite beam axis, and its distance from the satellite for each of the many locations determined by the increments. At each point the elevation angle of the receiver determines the power flux density allowable. The power flux density in the lowest frequency range can be multiplied by $4\pi R^2$ to find the maximum allowable EIRP of the satellite in that direction. The EIRP of the satellite along the beam is further increased by the difference in the off-axis gain of the antenna and its maximum gain. The smallest of the values of EIRP calculated in this fashion is taken as the maximum allowable EIRP of the satellite per television channel, the desired result.

For the two higher frequency bands a factor SPECF is used to relate the RF power of a TV channel to the power in the 4-kHz band of the spectrum having the maximum power. This is done because the maximum spectral density per unit area is defined rather than total power per unit area.

The satellite antenna is assumed to have a dB gain degradation that varies as the square of the angle off-axis and to have a maximum gain degradation of 20.0 dB.

The subroutine has the ability to stop execution if a frequency not falling in one of the three frequency bands is used in the call statement. A diagnostic printout is produced in such cases.

3.6 SCINTILLATION MODEL

On 19 November 1969 the ALSEP-1 (Apollo Lunar Surface Experiment Package) was placed on the surface of the moon. The package contains an S-band receiver (2119 MHz) and transmitter (2278.5 MHz). The station support of the ALSEP package functioned normally until February 1970 when the Ascension Island Station reported severe fluctuations of the downlink signal causing dropouts of telemetry data. In March several stations again were affected by signal fluctuations as large as 20 and 25 dB over a period of 15 days, causing numerous dropouts of telemetry data.

In the fall of 1969 several stations located in the Indian Ocean region noted rapid fluctuations of about ±4 dB on all signals received from an INTELSAT III geostationary communications satellite at 4 and 6 GHz. Further investigation showed that these variations were not originating in the equipment.

The aforementioned reports were surprising since the effect of ionospheric scintillation was generally considered to be negligible at these frequencies. Beginning in August 1970, 27 of the stations in the INTELSAT network cooperated in a more thorough investigation of these scintillations. The stations were located throughout the world, at high and low latitudes. The data were analyzed by Comsat and presented in Reference 3-3. Dr. E. J. Fremouw of Stanford Research Institute, under contract from NASA, is developing an observationally based model of electron-density irregularities in the F layer, appropriate for guiding designers of communication systems that encounter ionospheric scintillation. However, this model is mainly for VHF and thus its applicability for satellite broadcasting frequencies, particularly at S and X bands, is questionable.

Scintillation can be classified into three types. The first is a slow, relatively large (approximately 6 dB peak-to-peak amplitude) scintillation with time duration about 1 minute between peaks. This type of scintillation is probably produced in the troposphere and appears to affect only those stations at elevation angles below 10°. The second type of scintillation is fairly rapid and weak with a time scale of seconds and amplitude of fractions of a dB. The source of these variations is not well understood at present, but it may be due to the rain on the antennas. The last type is a strong and rapid scintillation, possibly due to weak scattering in the ionosphere, with a time duration of seconds between peaks and 6 to 8 dB peak-to-peak magnitude.

The results of Reference 3-3 are presented in Figures 3-16 to 3-19. It should be noted that these curves are based upon the data collected from August 1970 to January 1971 and thus they are heavily biased toward fall and winter seasons in the Northern

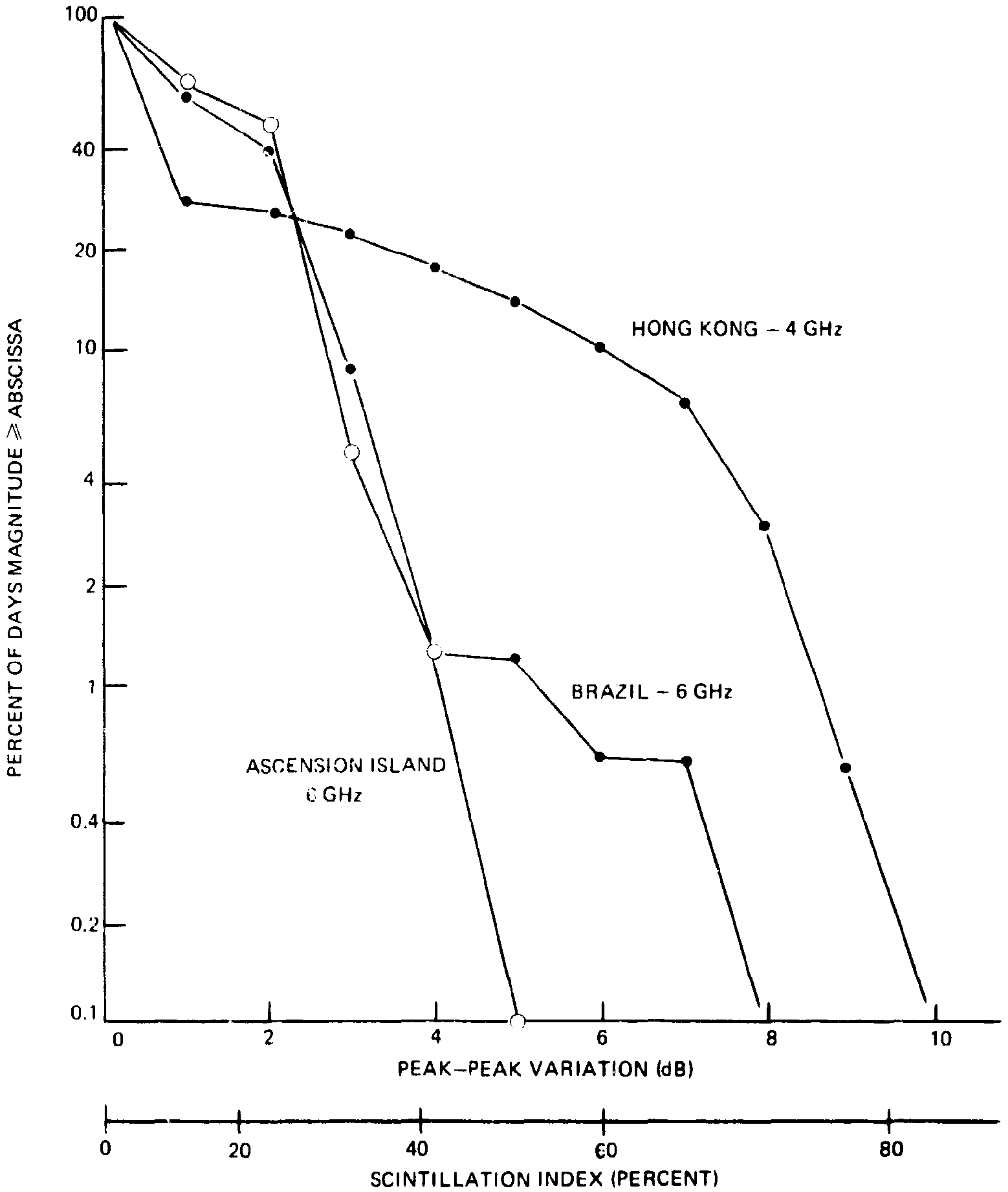


Figure 3-16. Signal Magnitude Variations Due to Scintillation (Reference 3-3)

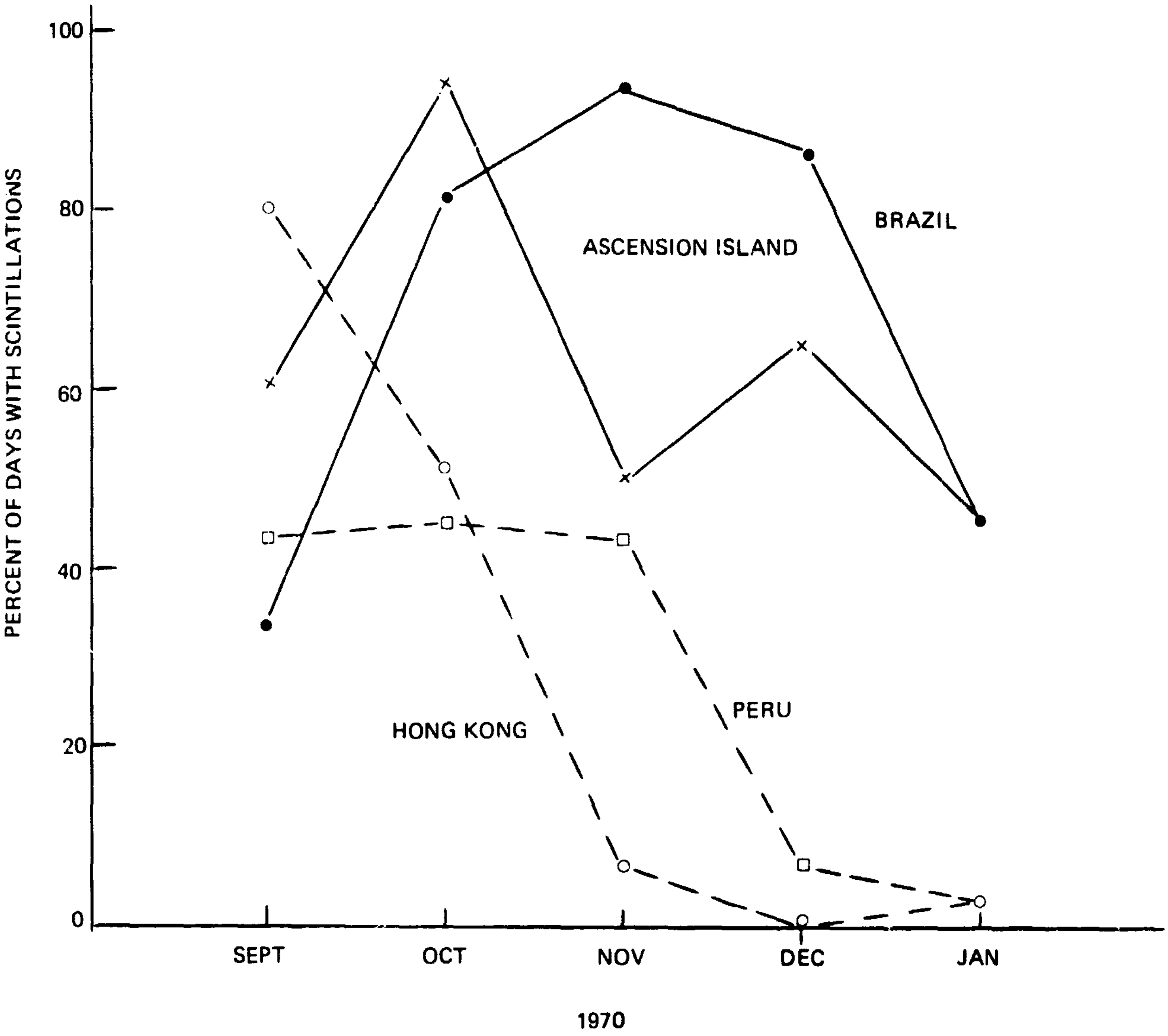


Figure 3-17. Scintillation vs. Month of Year (Reference 3-3)

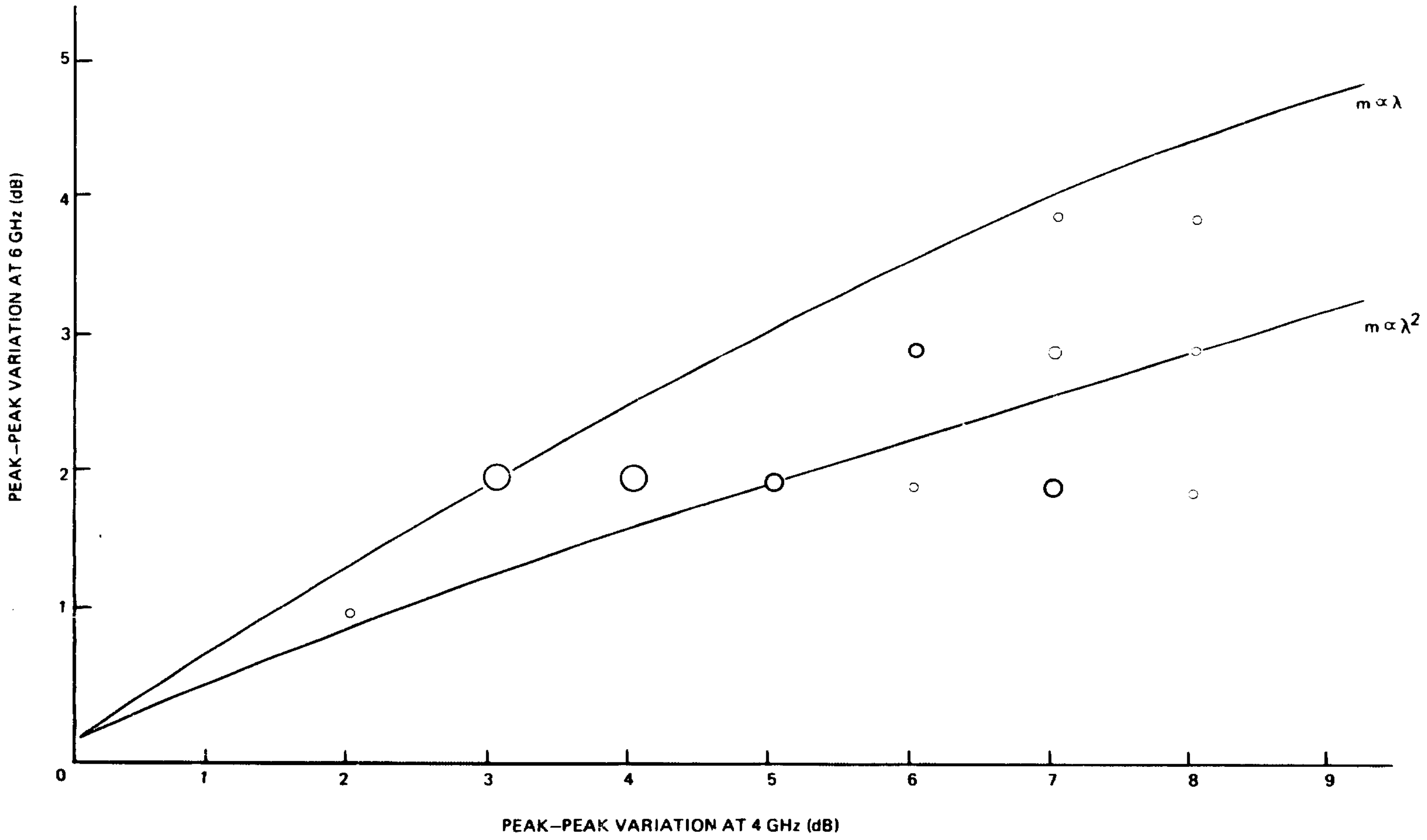


Figure 3-18. Frequency Dependence of Scintillation Magnitude
Hong Kong Data - Fall 1970
(Reference 3-3)

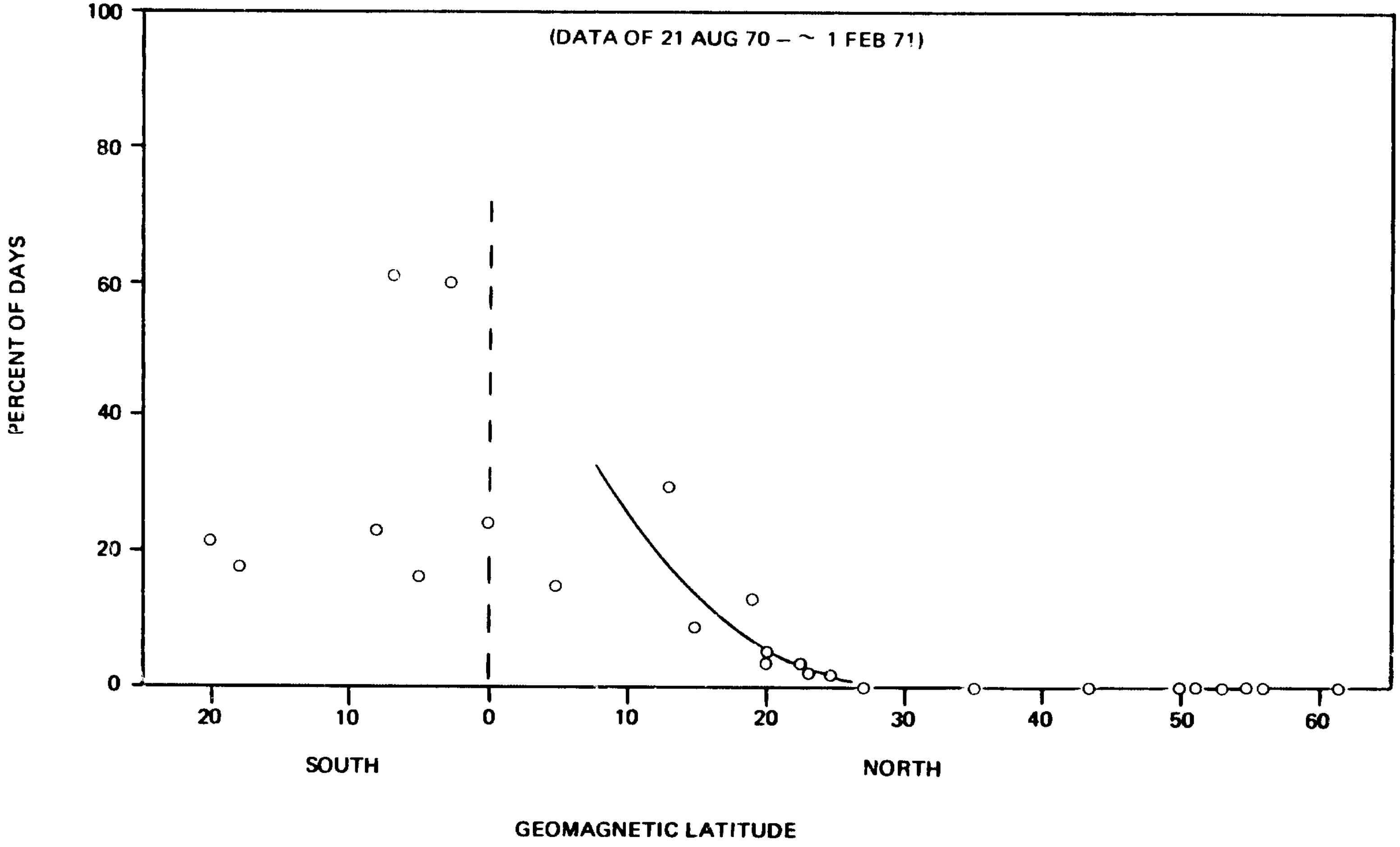


Figure 3-19. Percent of Days with Discernible Scintillation Activity (Reference 3-3)

Hemisphere. It is known that the ionospheric irregularities are more frequently observed during summer months; and if, as postulated, the ionospheric scintillation is due to those irregularities, then one would expect the scintillation occurrences to be even more frequent during the summer months. This effect can be clearly seen from the curve of Hong Kong data on Figure 3-17. Furthermore, it has been found that scintillation activity normally occurs at 40 to 90 minutes after local sunset on the ground and generally lasts for several hours, although scintillations may not be continuous during this period. Hence, if a more complete scintillation model is desired, seasonal and diurnal variations, as well as solar spot activity, should definitely be taken into consideration.

From Figure 3-19 scintillation activity is negligible at geomagnetic latitudes greater than 27°. However, since the data were taken during fall and winter seasons at the Northern Hemisphere, the terminating latitude is shifting to 30° north geomagnetic latitude such that the model can be used for a yearly average.

The chosen scintillation model is based on the Hong Kong curve shown in Figure 3-16, which gives the percent of days a particular scintillation index is exceeded at 4 GHz. The scintillation index is defined as

$$SI = \frac{P_{max} - P_{min}}{P_{max} + P_{min}} \tag{3-19}$$

where P_{max} and P_{min} are the maximum and minimum powers during scintillation respectively. SI can be directly related to the dB variation from the average power level which is the desired output. Latitudinal variations of the scintillation index is taken from Figure 3-19 and is modified for a yearly average by shifting the curve northward by 3° geomagnetic latitude as previously discussed.

Also, the index is varied as the square of the wavelength, as indicated in Figure 3-18. The computer subroutine requiring scintillation probability, geomagnetic latitude, and frequency as inputs is shown in Figure 3-20.

It should be noted that the 620 to 790 MHz band has not been included in the model, since the model is not recommended for frequencies below 2 GHz. It is believed that scintillations at 620 to 790 MHz and at S and X bands are due to different unknown sources. Hence the effects at one frequency region cannot be extrapolated based on the model of the other frequency region. For example, if one extrapolates according to a λ^2 variation, using the existing VHF model (Reference 3-4), the scintillation at 620 to 790 MHz is very small and none would be expected at X band, which is not true according to measurements. At present CSC believes the scintillations at 620 to 790 MHz are governed by the VHF model and hence are very small while scintillations at 2.50 to 2.69 and 11.7 to 12.2 GHZ can be much larger as dictated by the described model. As soon as the SRI model is available, results of the two models could be compared and modifications made if necessary.

3.7 GEOMETRY SUBROUTINE GEOM

Subroutine GEOM is used to calculate geometric parameters required for the ground segment model. The inputs are satellite subpoint location, receiver location and the location of the intersection of the satellite beam axis and the earth. The locations are all given in terms of latitude and longitude. The desired outputs are the elevation angle of the receiving antenna when it is pointed at the satellite, the angle of the receiver off the axis of the satellite transmitting antenna, and the distance of the receiver from the satellite. The subroutine is listed in Figure 3-21.

The cosine of the arc along a great circle between the satellite subpoint and the receiver location is first calculated. This, the distance of the satellite from the earth's surface, and the

```
        CSCX FORTRAN V
      SUBROUTINE SCINT (POR,GL,FCAR, SCNDB)
C POR=PERCENTAGE OF TIME SCINTILLATION SCNDB
C GL=GEOMAGNETIC LATITUDE
C FCAR=CARRIER FREQUENCY
C SCNDB=DB VARIATION FROM AVERAGE PWR LEVEL
      IF (POR-96.0) 1,1,2
    2 IF (POR-98.5) 11,11,12
   12 S=-86141862.0+2613170.0*POR-26424.3*POR**2+89.0689*POR**3
      SA=S*0.01
      GO TO 7
   11 SA=0.24*(POR-96.0)+7.7
      GO TO 7
    1 IF (POR-90.0) 3,3,4
    4 SA=1.7*(POR-90.0)/6.0+6.0
      GO TO 7
    3 IF (POR-80.0) 5,5,6
    5 SA=0.0
      GO TO 7
    6 SA=0.25*(POR-80.0)+3.5
    7 IF (GL-30.0) 8,8,9
    9 SCNDB=0.0
      GO TO 10
    8 F=FCAR/(10**9)
      B=(30.0-GL)*4/(17*F)
      SCNDB=SA*B**2
   10 RETURN
      END
```

Figure 3-20. Subroutine SCINT

```
GEOM,GEOM
             CSCX FORTRAN V
          SUBROUTINE GEOM(SLAD,SLOD,RLAD,RLOD,PLAD,PLOD, ELARD,ANPRD,
         1 DISTR)
    C INPUT SLAD,SLOD,RLAD,RLOD--OUTPUT ELARD,DISTR
    C SLAD IS SAT LAT IN DEG--SLOD IS SAT LONG IN DEG
    C RLAD IS EARTH REC LAT IN DEG--RLOD IS REC LONG IN DEG
    C PLAD IS POINTING LAT IN DEG--PLOD IN POINTING LONG IN DEG
    C ELARD IS ELEV ANGLE OF EARTH STATION ANTENNA IN DEG
    C ANPRD IS ANGLE (DEG) OF RECEIVER OFF SATELLITE BEAM CENTER
    C DISTR IS THE DISTRANCE BETWEEN SAT AND EARTH STA IN METERS
          RTOD=57.295779513
          R=6378388.0
          H=35793604.0
          RANDH=R+H
          SLAR=SLAD/RTOD
          SLOR=SLOD/RTOD
          RLAR=RLAD/RTOD
          RLOR=RLOD/RTOD
          PLAR=PLAD/RTOD
          PLOR=PLOD/RTOD
          COERS=SIN(SLAR)*SIN(RLAR)+COS(SLAR)*COS(RLAR)*COS(SLOR-RLOR)
          SINA=SQRT(1.0-COERS**2)
          IF (SINA) 20,10,20
       10 ELARD=90
          GO TO 30
       20 ELAR=ATAN(COERS/SINA-R/(RANDH*SINA))
          ELARD=ELAR*RTOD
       30 DSQR=R**2+RANDH**2-2.0*R*RANDH*COERS
          DISTR=SQRT(DSQR)
          COERP=SIN(PLAR)*SIN(RLAR)+COS(PLAR)*COS(RLAR)*COS(PLOR-RLOR)
          CHOSQ=R**2*(2.0*(1.0-COERP))
          COEPS=SIN(SLAR)*SIN(PLAR)+COS(SLAR)*COS(PLAR)*COS(SLOR-PLOR)
          DSQP=R**2+RANDH**2-2.0*R*RANDH*COEPS
          DISTP=SQRT(DSQP)
          COSPR=(DSQR+DSQP-CHOSQ)/2.0/DISTR/DISTP
          P2=1.5707963
          ANPRR=ATAN(SQRT(1.-COSPR**2)/COSPR)+(1.-COSPR/ABS(COSPR))*P2
          ANPRD=ANPRR*RTOD
          RETURN
          END
```

Figure 3-21. Subroutine GEOM

radius of the earth are used to calculate the elevation angle of the satellite above the horizon at the receiver. The distance of the receiver from the satellite is also computed using these same parameters and the law of cosines.

Similarly the program computes the cosine of the arc along the great circle between the receiver and the point on the surface of the earth at which the satellite beam is pointed. Then that value and the earth's radius are used to compute the square of the distance along a straight line between the same two points. The cosine of the arc along the great circle between the satellite subpoint and the point at which the satellite beam is pointed is computed and is used in the law of cosines to calculate the square of the distance from the satellite to the point on the earth's surface at which the satellite is pointed. The law of cosines is then used with the square of the three sides of the triangle defined by the locations of the receiver, the satellite, and the point at which the satellite beam is pointing to compute the cosine of the angle at the satellite between the ground receiver and the point at which the satellite beam is pointing. This is the off-axis angle of the receiver from the center of the satellite beam.

3.8 ANTENNA GAIN MODEL

An antenna model is described which is used to calculate the radiation (gain) pattern and beamwidth of a parabolic antenna. The model and its associated program are used for the ground receiving antenna.

For a circular parabolic dish antenna, the radiation pattern depends mainly upon the size of the dish, the operating frequency, and the aperture distribution. For most antennas an optimum design requires an aperture distribution with an edge illumination which is down 8 to 12 dB with respect to the center. The mathematical expression of the aperture distribution is

$$f(r) = b + \left[1 - \left(\frac{r}{a}\right)^2\right]^n \qquad (3\text{-}20)$$

where r is the arbitrary radius, and a is the dish radius.

When the edge taper is 10 dB, the equivalent value of b is 0.462. The radiation pattern at far-field is

$$F(u) = k\int_0^{\pi} \left[b + \left(1 - \frac{p^2}{\pi^2}\right)^n\right] J_o(pu)\ p\,dp \qquad (3\text{-}21)$$

where $u = \frac{\pi r}{a}$

k = a constant depending upon the efficiency

$p = \frac{2a \sin \theta}{\lambda}$; θ is the angle off the axis

J_o = the Bessel function of zeroth order

From Reference 3-5, Equation (3-21) integrates to

$$F(u) = k\left[b\ \Lambda_1(\pi u) + \Lambda_{n+1}(\pi u)/(n + 1)\right] \qquad (3\text{-}22)$$

where $\Lambda_1(\pi u) = 2\ J_1(\pi u)/\pi u$

$\Lambda_{n+1}(\pi u) = (n + 1)!\ J_{n+1}(\pi u)/\left(\frac{\pi u}{2}\right)^{n+1}$

From Equation (3-22) it can be seen that the radiation pattern is a function of b and n; i.e., the edge taper and the "shape" of the aperture distribution. For example, n = 0 means uniform illumination; n = 1 implies the amplitude of the field on the dish decreases linearly with increasing radius; i.e., linear taper. When n increases, the main beam becomes wider and the side-lobe level decreases. For most antennas, the value of n is about 2.

When the aperture distribution function is set at n = 2 and b = 0.462 (10 dB taper), the 3-dB beamwidth is approximately equal to 1.16 $\lambda/2a$ radians. The radiation pattern is

$$F(u) = \left[b\ \Lambda_1(\pi u) + \Lambda_3(\pi u)/(n + 1)\right] \cdot k \qquad (3\text{-}23)$$

The efficiency of an antenna depends on many factors; i.e., blockage, spill-over, aperture illumination, etc. The aperture illumination, however, determines the radiation pattern. Therefore, in order to calculate the pattern with efficiency as an input parameter, it is necessary to assume that the aperture illumination remains unchanged, as the efficiency varies. From Equation (3-23) the maximum field of the radiation pattern is at u = 0, i.e.,

$$F(0) = \left(b + \frac{1}{n + 1}\right)k \qquad (3\text{-}24)$$

If the efficiency of the antenna is η, then the gain is

$$G = \eta \cdot \frac{4\pi^2\ a^2}{\lambda^2} \qquad (3\text{-}25)$$

The relation between η and k can be obtained by equating Equations (3-24) and (3-26) to give

$$\left(b + \frac{1}{n + 1}\right)k = \eta \cdot \frac{4\pi^2\ a^2}{\lambda^2}$$

if b = 0.462 and n = 2,

$$k = \frac{4\pi^2\ a^2\ \eta}{0.795\ \lambda^2} = 49.7\ \frac{a^2\ \eta}{\lambda^2} \qquad (3\text{-}26)$$

Equation (3-23) becomes

$$F(u) = \left[22.95\ \Lambda_1(\pi u) + 16.6\ \Lambda_3(\pi u)\right] \frac{a^2\ \eta}{\lambda^2} \qquad (3\text{-}27)$$

Equation (3-27) is used for calculating the antenna radiation pattern.

The input parameters to the model are operating frequency, antenna diameter, and efficiency (relative to a uniformly illuminated dish of the same size without other kind of losses; i.e., blockage, spill-over, phase error, etc.). The operating frequency is expressed in Hertz, and the diameter of the antenna is in meters.

The output of subroutine ANTGA, listed in Figure 3-22, is the antenna radiation pattern defined at 2-degree intervals, which can easily be modified into smaller increments. The 3-dB beamwidth is also given in degrees.

3.9 ANTENNA NOISE TEMPERATURE MODEL

The data flow diagram for the antenna noise temperature model is shown in Figure 3-23 and its subroutine ANTEP is listed in Figure 3-24. The inputs are keyed such that the user chooses the (1) stellar (or galactic) noise environment, (2) rain rate, (3) man-made noise environment, and (4) relative humidity. Other inputs include the antenna gain pattern, frequency and receiver to satellite elevation angle. The output is antenna noise temperature.

Mathematically, the antenna noise temperature is calculated by

$$T_a = \frac{1}{4\pi} \int G(\theta,\phi)\ T(\theta,\phi)\ d\Omega \qquad (3\text{-}28)$$

where T_a is antenna noise temperature.

$G(\theta,\phi)$ is fractional power radiated in (θ,ϕ) direction.

$T(\theta,\phi)$ is environmental noise temperature in (θ,ϕ) direction.

Ω is solid angle.

From Equation (3-28) antenna noise temperature is the sum of the products of the antenna fractional power and its corresponding environmental noise temperature divided by 4π. Thus in order to

```
ANTGA,ANTGA
              CSCX FORTRAN V
           SUBROUTINE ANTGA(FA,DIA,AEFF, G,B)
C AEFF  ANTENNA EFFICIENCY
C FA=RF FREQUENCY - DIA=DIA OF PARABOLIC DISH (METER)
C G(I) IS ANTENNA GAIN VECTOR (DB) WHERE I=1+(DEG OFF BEAM CENTER)
C B=ANTENNA BEAMWIDTH IN DEG
           DIMENSION G(1)
           AL=(1.1811*10**10)/FA
           D=DIA/0.0254
           B=1.16*57.295779513*AL/D
           R=D/2
           V0=AEFF*39.5*((R/AL)**2)
           V0=SQRT(V0)
           C1=V0*0.581
           C2=V0*0.419
           DO 1 I=1,91,2
           T1=(I-1)/57.3
           U=(D*3.1416/AL)*SIN(T1)
           IF (U) 2,2,3
         2 B1=1
           B3=1
           GO TO 4
         3 IF (U-3.0) 5,5,6
         5 A0=1.-2.25*(U/3)**2+1.26562*(U/3)**4-0.31639*(U/3)**6
          1+0.04444*(U/3)**8-0.00394*(U/3)**10+0.21094*(U/3)**12
           A1=U*(0.5-0.5625*(U/3)**2+0.21094*(U/3)**4
          1-0.03954*(U/3)**6+0.00443*(U/3)**8-0.00032*(U/3)**10)
           GO TO 7
```

Figure 3-22. Subroutine ANTGA

```
 6 F0=0.79788-0.00527*(3/U)**2-0.0001*(3/U)**3
  1+0.00137*(3/U)**4-0.00073*(3/U)**5+0.00015*(3/U)**6
   F1=0.79788+0.0166*(3/U)**2+0.00017*(3/U)**3
  10.00249*(3/U)**4+0.00114*(3/U)**5-0.0002*(3/U)**6
   T0=U-0.7854-0.04166*(3/U)-0.00004*(3/U)**2+0.00263*(3/U)**3
  1-0.00054*(3/U)**4-0.00029*(3/U)**5+0.00014*(3/U)**6
   T1=U-2.35619+0.125*(3/U)+0.000056*(3/U)**2-0.00638*(3/U)**3
  1+0.00074*(3/U)**4+0.000798*(3/U)**5-0.00029*(3/U)**6
   A0=F0*COS(T0)/SQRT(U)
   A1=F1*COS(T1)/SQRT(U)
 7 A2=2*A1/U-A0
   A3=4*A2/U-A1
   B1=A1*2/U
   B3=6*A3/((U/2)**3)
 4 V=C1*B1+C2*B3
   D8=8.686*ALOG(ABS(V))
 1 G(I)=D8
   DO 10 I=93,181,2
10 G(I)=-20.0
   RETURN
   END
```

Figure 3-22. Continued

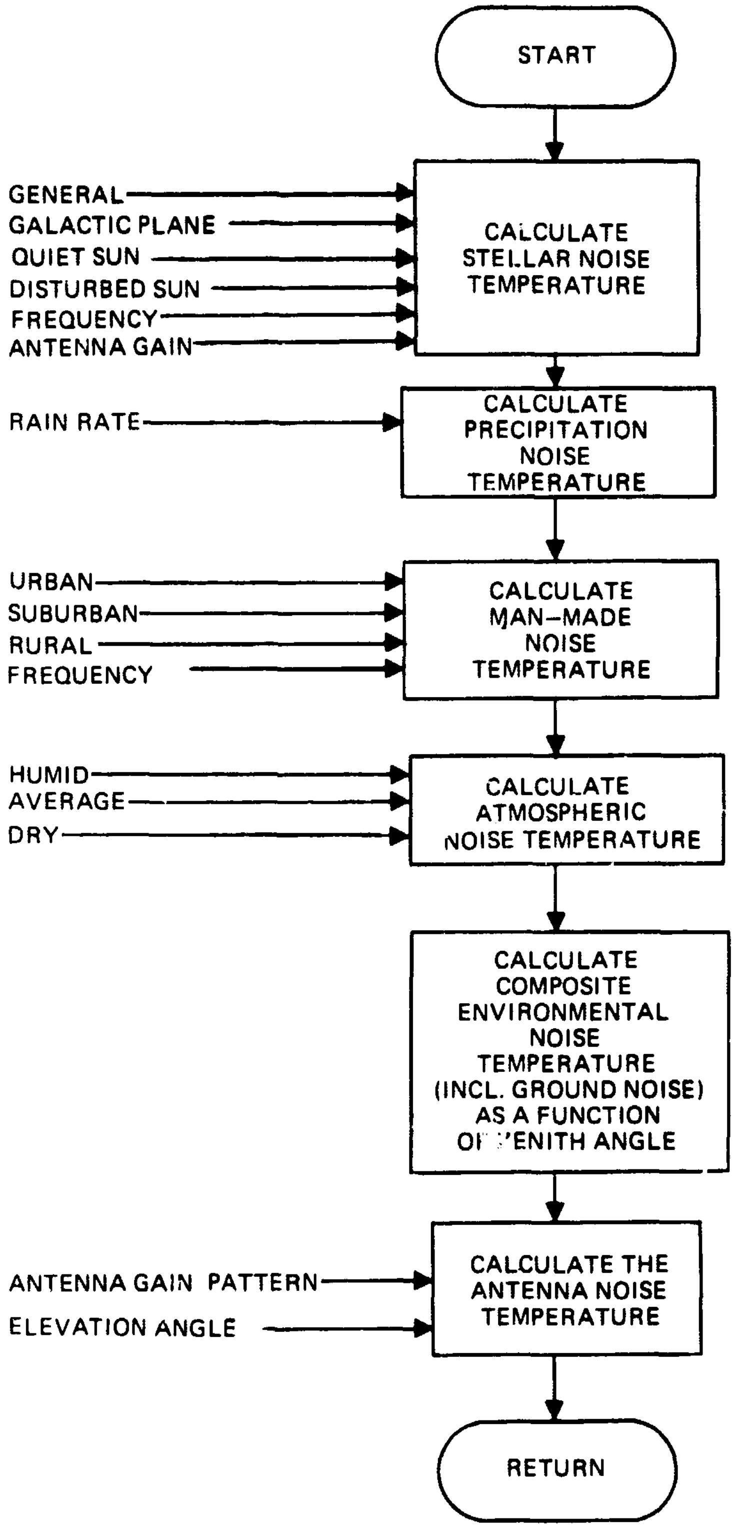


Figure 3-23. Antenna Noise Temperature Data Flow Diagram

```
ANTEP,ANTEP
             CSCX FORTRAN V
          SUBROUTINE ANTEP(FQ,RR,IENV,IHUMD,IG,ELAD,G, ATEMP)
    C FQ=RF FREQ - RR=RAIN RATE IN MM/HOUR
    C IENV=MAN-MADE NOISE ENVIRONMENT
    C IENV=0 NO MAN-MADE NOISE - IENV=1 RURAL
    C IENV=2 SUBURBAN - IENV=3 URBAN
    C IHUMD=HUMIDITY INDEX
    C IHUMD=1 DRY - IHUMD=2 AVERAGE - IHUMD=3 HUMID
    C IG=1 FOR CASSIOPEIA OR GENERAL GALACTIC NOISE LEVEL
    C IG=2 FOR GALACTIC PLANE
    C IG=3 FOR QUIET SUN - IG=4 FOR DISTURBED SUN
    C ELAD=ANTENNA ELEV (DEG) - G(I) IS THE ANTENNA GAIN VECTOR (DB)
    C WHERE I=1+(DEG OFF BEAM CENTER)
    C ATEMP=ANTENNA NOISE TEMP (DEG K)
          DIMENSION TS(100),T(200),DT(200),DF(200),D(200),AT(200)
          DIMENSION G(1),GA(200),B(200),B1(200)
          G0=G(1)-2.14
          DO 6 I=1,181,2
        6 GA(I)=10.0**(G(I)/10.0)
          FR=FQ*1.0E-6
          FG=FR/1000.
    C GALACTIC NOISE (FUNCTION OF FREQUENCY)=TG
          IF (IG-1)70,70,71
       70 AGA=-50.0-33.333*ALOG(FG)/ALOG(10.)+G0
          GO TO 72
       71 IF(IG-3)73,74,75
       73 AGA=-20.0-11.1111*ALOG(FG)/ALOG(10.)+G0
          GO TO 72
       74 AGA=-19.-23.3*ALOG(FG)/ALOG(10.)+G0
          GO TO 72
       75 AGA=-9.-23.3*ALOG(FG)/ALOG(10.)+G0
       72 TG=290.0*10.**(AGA/10.)
    C PRECIPITATION NOISE (FUNCTION OF FREQUENCY)=TP
          FK=FG/16.0
          AFG=-0.14*(RR**1.155)*(FK**3)
          TP=273.0*(1.0-10.0**(AFG/10.))
    C MAN-MADE NOISE=TM
          IF (IENV-2) 201,202,203
      201 IF (IENV) 204,204,205
      205 WMN=-155.4-25.*ALOG(FR/3.)/ALOG(10.)
          GO TO 200
      202 WMN=-142.2-24.*ALOG(FR/3.)/ALOG(10.)
          GO TO 200
      203 WMN=-132.2-22.5*ALOG(FR/3.)/ALOG(10.)
          GO TO 200
```

Figure 3-24. Subroutine ANTEP

```
  204 TM=0.0
      GO TO 206
  200 WMM=WMN/10.0+23.0
      TM=(10.0**WMM)/1.3804
  206 IF (IHUMD-2) 210,211,212
  212 DO 220 I=1,6
  220 TS(I)=290.-(290.-EXP(2.84+.163*FG-.00116*(FG**2)))*.2*(I-1)
      DO 221 I=7,11
  221 TS(I)=EXP(2.84+0.163*FG-0.00116*(FG**2.))-(1.0-(I-6)*0
     1.2)+EXP(2.258+0.102*FG+0.00037*(FG**2.))*(I-6)*0.2
      DO 222 I=12,31
  222 TS(I)=EXP(2.258+0.142*FG+0.00737*(FG*2.))*(1.-(I-11)/2
     10.)+EXP(1.245+0.139*FG+0.002*(FG**2.))*(I-11)/20
      DO 223 I=32,91
  223 TS(I)=EXP(1.245+0.139*FG+0.002*(FG**2.0))*(1.-(I-31)/6
     10.)+EXP(0.42+0.274*FG-0.00395*(FG**2.))*(I-31)/60
      GO TO 301
  211 DO 230 I=1,6
  230 TS(I)=290.0-(290.0-EXP(2.93+0.0284*FG+0.00442*(FG**2.)
     1))*(I-1)*0.2
      DO 231 I=7,11
  231 TS(I)=EXP(2.93+0.0284*FG+0.0442*(FG**2.))*(I-6)*0.2+EX
     1P(2.4+0.002*FG+0.00537*(FG**2.0))*(I-6)*0.2
      DO 232 I=12,31
  232 TS(I)=EXP(2.4+0.002*FG+0.00527*(FG**2.))*(1.-(I-11)/20
     1.)+EXP(1.36+0.027*FG+0.00442*(FG**2.0))*(I-1)/20.0
      DO 233 I=32,91
  233 TS(I)=EXP(1.36+0.027*FG+0.00442*(FG**2.))*(1.0-(I-31)/
     160.)+EXP(0.68+0.007*FG+0.00643*(FG**2.0))*(I-31)/160.0
      GO TO 301
  210 DO 240 I=1,6
  240 TS(I)=54.0*(6-I)+20
      DO 241 I=7,11
  241 TS(I)=2.*(11-I)+10
      DO 242 I=12,31
  242 TS(I)=0.3*(31-I)+4.0
      DO 243 I=32,91
  243 TS(I)=(91-I)/30.0+2.0
  301 CONTINUE
C ENVIRONMENTAL NOISE TEMPERATURE AS FUNCTION OF ELEV ANGLE
C DENOTED AS T(I), WHERE I IS IN DEGREE, I=181 AT ZENITH
      DO 302 I=1,90
  302 T(I)=290.0
      DO 303 I=91,100
  303 T(I)=TS(I-90)+TM+TP
C IN THE ABOVE CALCULATION THE MAN-MADE NOISE IS ASSUMED
```

Figure 3-24. Continued

```
C ONLY AT ELEVATION ANGLE FROM 0 TO 10 DEGREES.
      DO 304 I=101,181
  304 T(I)=TS(I-90)+TP
C THE FOLLOWING IS FOR CALCULATING THE ANTENNA NOISE TEMP
C OF THE PENCIL BEAM ANTENNA
C ELAD=ELEVATION ANGLE IN DEGREE
      DO 400 I=1,181,2
      DO 401 J=1,181,5
C I=PHI
C J=THETA
      P1=(SIN((I-1)/57.2))*COS((J-1)/57.2)
      P2=ATAN(P1/(SQRT(1.-P1**2.)))
      IF (I-91) 420,420,421
  420 P3=(P2*57.2+ELAD)
      K=P3+91
      GO TO 422
  421 P3=(P2*57.2-ELAD)
      K=P3+91
  422 IF (K-181) 412,412,431
  431 K=361-K
  412 DTH=5.0/57.2
C DTH=INCREMENT IN THETA DIRECTION IN RADIAN
  401 DT(J)=T(K)*DTH*2.0*GA(I)*SIN(I/57.3)
      DO 402 L=1,181,5
      DF(1)=0
  402 DF(L+5)=DT(L)+DF(L)
      D(I)=DF(186)*2.0/57.2
      AT(1)=0
  400 AT(I+2)=AT(I)+D(I)
      AT1=AT(183)
      DO 403 I=1,181,2
      B1(1)=0.0
      B(I)=GA(I)*2*3.1416*2*SIN(I/57.3)/57.3
  403 B1(I+2)=B1(I)+B(I)
      AGD=B1(183)
      ATEMP=AT1/AGD+TG
      RETURN
      END
```

Figure 3-24. Continued

obtain T_a, one must know $T(\theta,\phi)$ over the entire solid angle; i.e., the noise temperature surrounding the antenna. The environmental noise sources are described as follows.

3.9.1 Stellar (or Galactic) Noise

Stellar noise has been measured and presented in CCIR Report 322 (References 3-6 and 3-7). The galactic noise level depends mainly upon the direction in which the antenna is pointing. Generally there are four different levels when the antenna is looking at (1) Cassiopeia, (2) Galactic Plane, (3) Quiet Sun, and (4) Disturbed Sun. For each of these noise levels the corresponding mathematical expressions are

Cassiopeia $A_s = -50 - 33.3 \log f + G$ (3-29)

Galactic Plane $A_s = -20 - 11.1 \log f + G$ (3-30)

Quiet Sun $A_s = -19 - 23.3 \log f + G$ (3-31)

Disturbed Sun $A_s = -9 - 23.3 \log f + G$ (3-32)

where A_s is the stellar noise level in dB above kT_oB, (T_o = 240°K).

f is frequency in GHz.

G is the antenna gain over that of a half-wave dipole

The stellar noise temperature can be found from

$$T_s = (290)\ 10^{\left(\frac{A_s}{10}\right)} \qquad (3\text{-}33)$$

where T_s is the stellar noise temperature.

In order to avoid very complex geometric calculations, the user must choose the input key which corresponds to his particular antenna pointing geometry.

3.9.2 Precipitation Noise

It has been observed that at microwave frequencies, the antenna noise temperature increases when precipitation exists and in general increases as the rain rate increases. The noise level can change rapidly, sometimes by more than a factor of two, within a fraction of a minute. It also has been observed that a change in rainfall consistently lags a temperature change.

Theoretical analysis of the precipitation noise is somewhat difficult. It is known that condensed water is a strong absorber of electromagnetic waves, and thus will strongly affect the sky noise. If the rain rate, denoted as R, is known, then the calculation of α_p, i.e., the absorption coefficient of precipitation, is possible. According to Reference 3-8, under the assumption of spherical rain drops, the relationship between α_p and R is

$$\alpha_p = m\ R^n \tag{3-34}$$

where m and n are two real numbers. The value of m is approximately proportional to the inverse of the square of the wavelength and the value of n depends only slightly on frequency in the vicinity of 12 GHz (Reference 3-9).

$$\alpha_p = 0.035\ R^{1.15} \tag{3-35}$$

where R is in mm per hour.

If an average attenuation path of 4 km is assumed*, the total attenuation due to precipitation, denoted as A (in dB) is

$$\begin{aligned} A &= 4\alpha_p \\ &= 0.14\ R^{1.155} \end{aligned} \tag{3-36}$$

---

*The path length cannot be simply related to elevation angle, e.g., the path length through a heavy rainfall may be greater for an elevation angle of 90° than it is for an angle of 10°.

The corresponding precipitation noise temperature is calculated according to

$$T_p = \left(1 - 10^{-\frac{A}{10}}\right) T_o \tag{3-37}$$

where T_o is the physical temperature.

3.9.3 Man-Made Noise

Power lines, industrial and home electric machinery, automobile ignition systems, neon lamps, etc., generate so-called man-made noise. The noise varies greatly with geographic location and time, due to the nature of the sources. Thus, the available information, which has been taken at a limited number of locations, must be used with caution when applied to the general situation. The median values of man-made noise for "urban," "suburban," and "rural" areas, given in Reference 3-10, are used in the model. The relationships are

Urban $$N_m = -132.5 - 22.5 \log \left(\frac{f}{3}\right) \tag{3-38}$$

Suburban $$N_m = -142.2 - 24.0 \log \left(\frac{f}{3}\right) \tag{3-39}$$

Rural $$N_m = -155.4 - 25.0 \log \left(\frac{f}{3}\right) \tag{3-40}$$

where N_m = man-made noise power in decibels below 1 watt in a 1 Hz bandwidth

f = frequency in MHz.

The corresponding noise temperature T_m is

$$T_m = \frac{10^{\left(\frac{N_m}{10}\right)}}{k} \tag{3-41}$$

where k is Boltzmann's constant.

It should be noted that although the measurements in Reference 3-10 were taken below 500 MHz, extrapolations of these data into higher frequency are in good agreement with the measurement given in References 3-11 and 3-12.

Very little is known about "arrival angle" of man-made noise. It is expected that in rural areas the noise enters the antenna at lower angles while in urban areas it arrives at higher elevation angles due to high buildings, etc. In the model, man-made noise is assumed to arrive uniformly over the range of 0 to 10 degrees elevation angle.

3.9.4 Atmospheric Noise

The atmosphere contains mainly oxygen and water vapor, both of which absorb and therefore emit radio waves. These emissions represent a significant source of sky noise. The magnetic dipole resonance of the oxygen molecule is at frequencies near 60 GHz while that of water vapor is near 22.5 GHz, and depends on the humidity content of air. If the power absorption coefficients due to oxygen and water vapor are α_1 and α_2, respectively, then the atmospheric noise temperature, denoted as T_a, can be calculated as

$$T_a = \int_0^\infty (\alpha_1 + \alpha_2)\ T \exp\left[-\int_0^r (\alpha_1 + \alpha_2) dr\right] dr \qquad (3\text{-}42)$$

where T is the actual temperature at a given point in the atmosphere defined by the distance vector r. Since the atmosphere has a certain thickness, the value of T_a varies as a function of elevation angle. For lower elevation angle the temperature is higher, since the integration path is longer than at zenith.

The model is based on Reference 3-13 for three atmospheric conditions (1) dry (O_2 only), (2) average (O_2 and H_2O vapor of 10 gm/m^3), and (3) humid (O_2 and H_2O vapor of 20 gm/m^3). Equations were written to represent these conditions as a function of frequency and elevation angle. For example, for an elevation angle of 30° the relationship for humid and average conditions are

$$\text{Humid} \quad T_a = \exp\left[1.245 + 0.139\ f + 0.002\ f^2\right] \tag{3-43}$$

$$\text{Average} \quad T_a = \exp\left[1.36 + 0.027\ f + 0.00442\ f^2\right] \tag{3-44}$$

where f is the frequency in GHz. The "dry" condition curves are interpreted linearly from 1 to 20 GHz.

The atmospheric noise increases as the frequency becomes higher. At frequencies below about 1 GHz, atmospheric noise is low and does not vary with humidity.

To obtain atmospheric noise temperature as a function of elevation angle, linear interpolation is used between curves, given in Reference 3-13. This results in little error since curves are available for elevation angles of 5°, 10°, 30°, and 90°.

3.9.5 Ground Noise Temperature

According to Reference 3-8, ground noise temperature varies between two extremes. The low extreme is the noise due to sea water, which is about 130°K. The high extreme is the noise due to a perfect absorber, which is about 300°K. For our model the noise temperature is assumed to be 290°K, which is the value commonly used for noise calculations.

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SECTION 3

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SECTION 4

SPACE SEGMENT MODEL

A functional block diagram of the space segment model and its relationship to the Main Line program is shown in Figure 4-1. Each module or block represents a spacecraft subsystem or critical interface and is characterized by a set of parametric relationships. By defining the input and output interfaces of each module, a data flow may be established as shown in Figure 4-2.

The various satellite subsystems are synthesized by exercising the model(s) to define performance factors such as subsystem weight and prime power. The required calculations must be performed in a definite sequence, however, since certain parameters are inter-dependent on one another, for example the prime power subsystem cannot be defined without knowing the transponder prime communication power. Also, certain parameters require an iterative type calculation where the loop is initiated by a rough estimate and the estimate is then refined by repeated calculations and comparisons until the difference between the previous (stored) value and the working value is within an acceptable limit. Satellite weight, for example, requires an iterative calculation where the initial estimate is based on prime power. The models and subroutines required to define the satellite are discussed in the following paragraphs.

4.1 SPACE SEGMENT SUBROUTINE SPASEG

Subroutine SPASEG is used by the Main Line Control program to calculate the required satellite parameters. The flow chart for SPASEG is shown in Figure 4-3 and the subroutine is shown in Figure 4-4. SPASEG uses the inputs provided by the Main Line program, thirteen internally generated parameters and twelve output parameters. The required input parameters are:

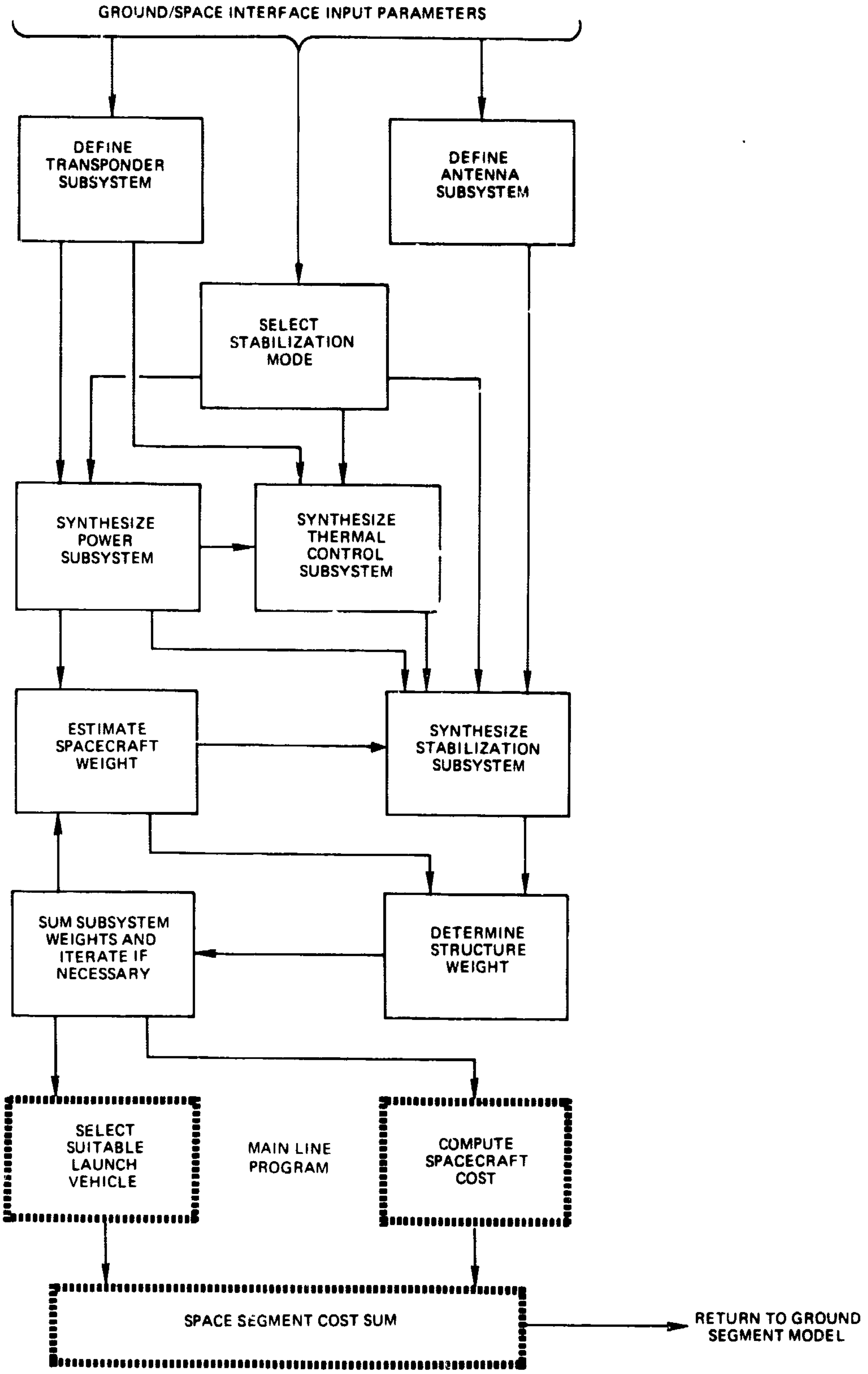

Figure 4-1. Space Segment Model Functional Block Diagram

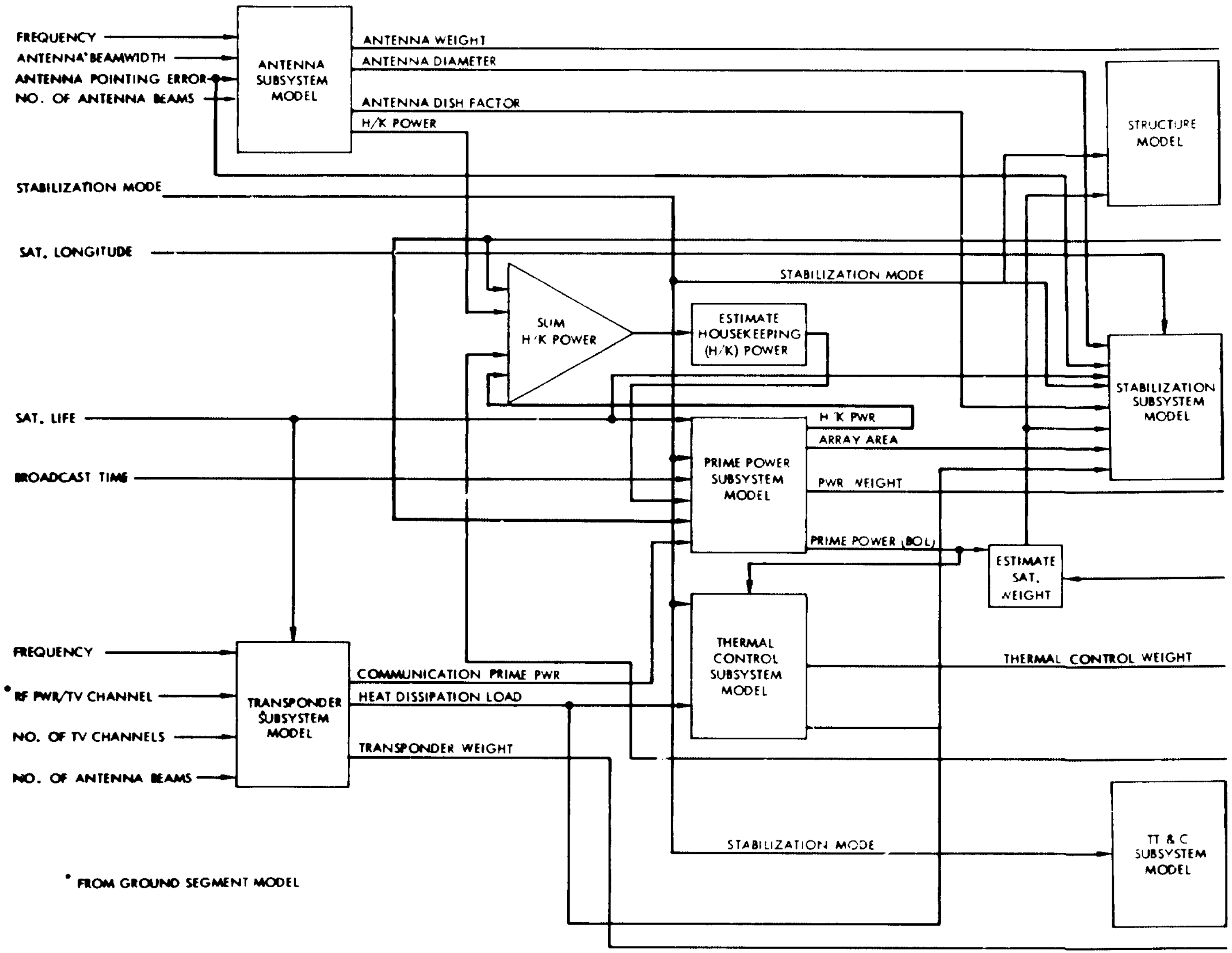

Figure 4-2. Space Segment Model Functional Data Flow Diagram

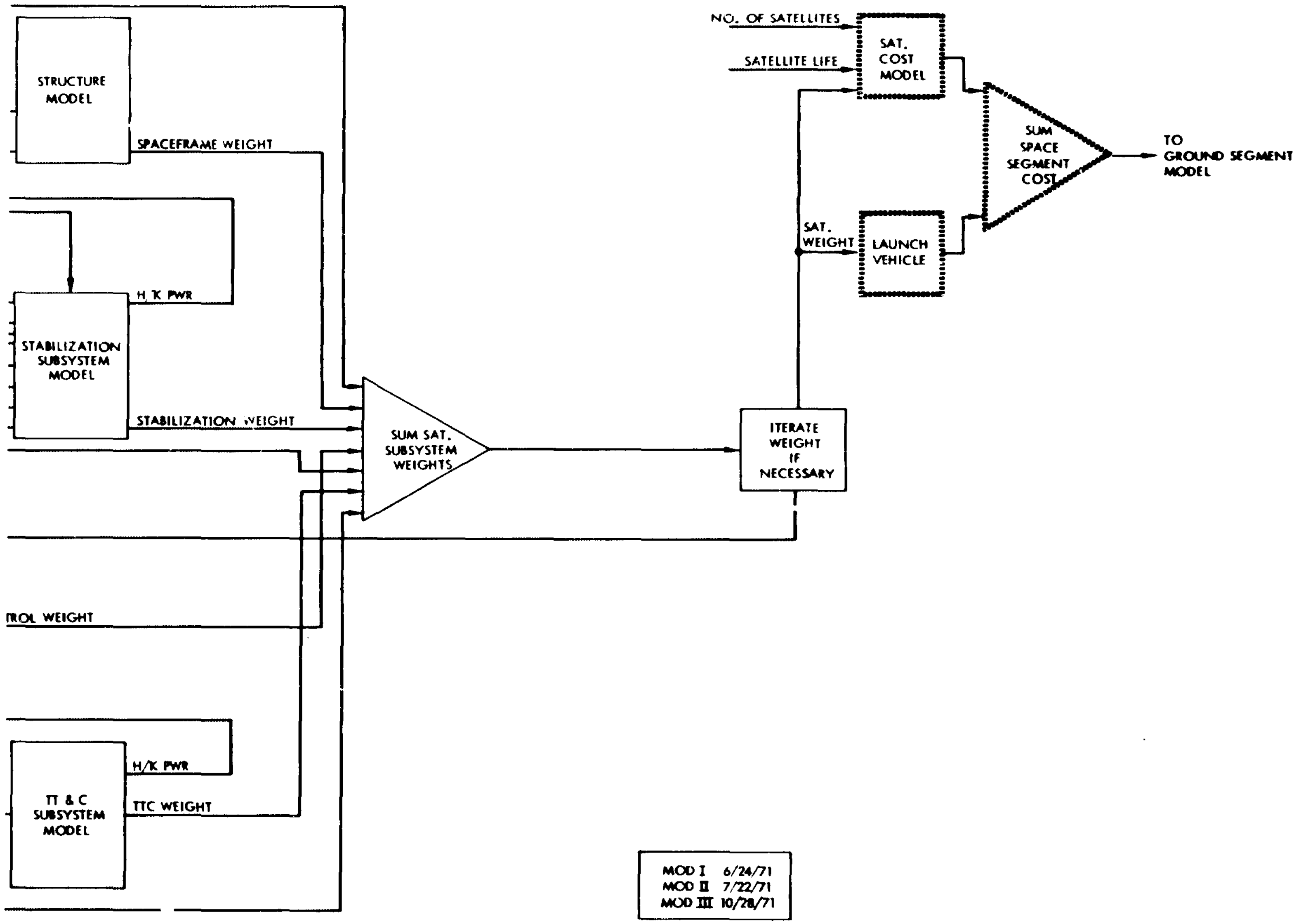

Figure 4-2. Continued

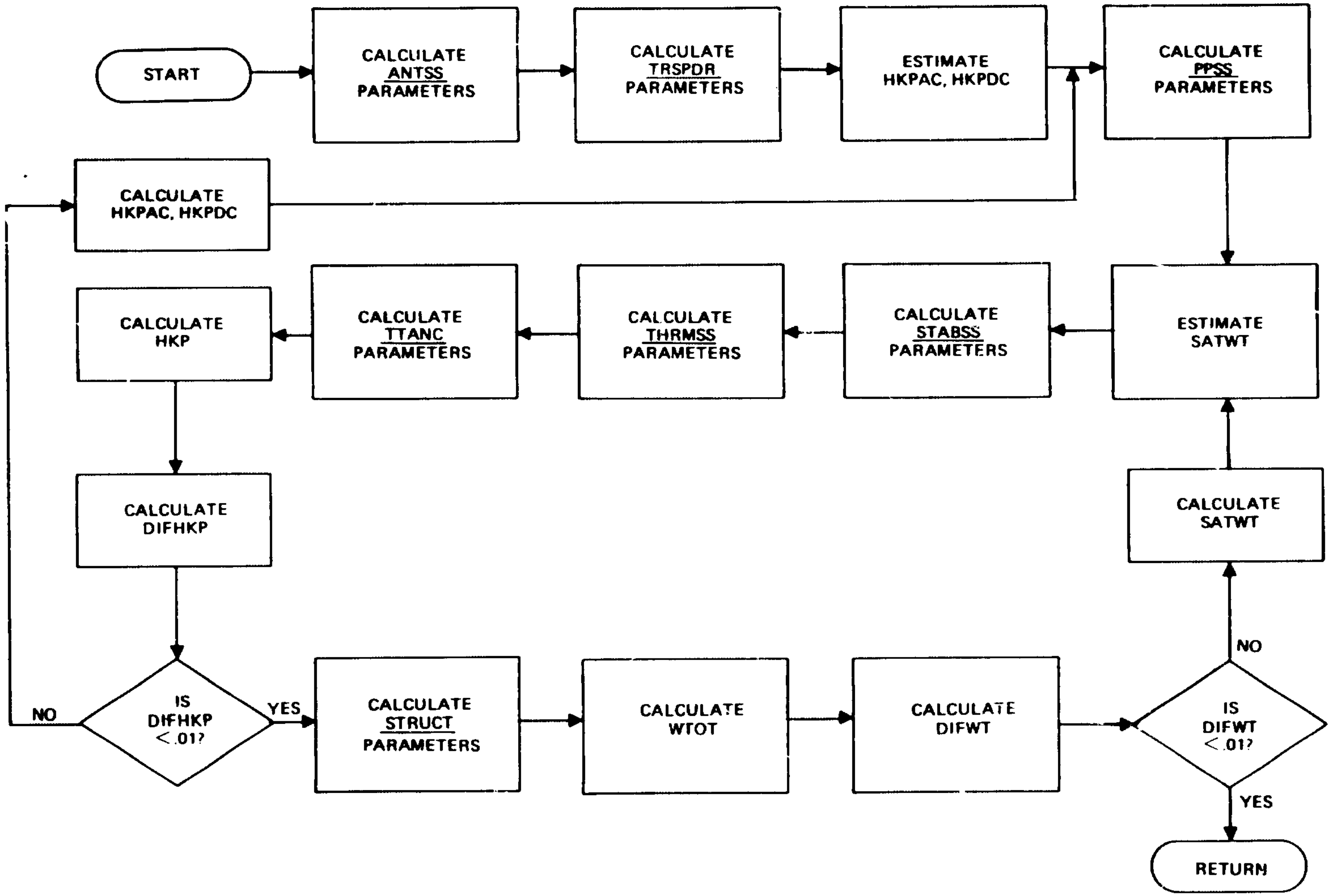

Figure 4-3. Flow Chart of the Subroutine SPASEG

```
    CSCX FORTRAN V
     SUBROUTINE SPASEG(FREQ,ANTBW,NCHNL,NBEAM,PTERR,RFPCHL,
    1MODES,SATLIF,ITIMBC,ANGLE,ANTWT,ANTDIA,PWRCOM,HTDL,PWRBOL,
    2TRNSWT,PPSSWT,SAAREA,STABWT,THRMWT,STRWT,SATWT)
     DIMENSION FREQ(1)
     DIMENSION RFPCHL(6)
     CALL ANTSS(FREQ,ANTBW,NBEAM,PTERR,ANTWT,ANTHKP,ANTDIA,ANTDF,
    1KFB)
     CALL TRSPDR(KFB,RFPCHL,NCHNL,NBEAM,SATLIF,PWRCOM,HTDL,TRNSWT)
     HKPDC=100.0
     HKPAC=45.0
10   CALL PPSS(HKPAC,HKPDC,SATLIF,ANTDIA,ITIMBC,PWRCOM,MODES,
    1PWRBOL,PPSSWT,PPSHKP,SAAREA)
     SATWT=8.05*(PWRBOL**0.69)
20   CALL STABSS(ANTDIA,PTERR,SATLIF,MODES,ANTDF,ANGLE,SATWT,HTDL,
    1SAAREA,STABWT,STABDC,STABAC)
     CALL THRMSS(HTDL,PWRBOL,MODES,THRMWT,THMHKP)
     CALL TTANC(MODES,TTCWT,TTCHKP)
     HKP1= ANTHKP + PPSHKP + THMHKP + STABDC +TTCHKP
     HKP2= STABAC
     HKP= HKP1 + HKP2
     DIFHKP= ABS(1.0 - HKP/(HKPAC + HKPDC))
     HKPDC= HKP1
     HKPAC= HKP2
     IF(DIFHKP-0.01)30,30,10
30   CALL STRUCT(SATWT,MODES,STRWT)
     WTOT=ANTWT + TRNSWT + PPSSWT + STABWT + THRMWT+STRWT+TTCWT
     DIFWT= ABS( 1.0 - WTOT/SATWT)
     SATWT=WTOT
     IF(DIFWT-0.01)40,40,20
40   CONTINUE
     RETURN
     END
```

Figure 4-4. Subroutine SPASEG

1. FREQ - RF Carrier Frequency of ith TV Channel in Hz.

2. ANTBW - Satellite Antenna Beamwidth in degrees.

3. NCHNL - Number of TV Channels.

4. NBEAM - Number of Satellite Antenna Beams.

5. PTERR - Satellite Antenna Pointing Error in degrees.

6. RFPCHL - RF Power in watts of ith TV Channel at the Satellite Antenna Input.

7. MODES - Mode of Stabilization (3-axis, spin, both).

8. SATLIF - Satellite Lifetime in years.

9. ITIMBC - Broadcast Hours Per Day.

10. ANGLE - Longitude of Satellite in degrees.

The internally generated parameters are:

1. ANTHKP - Antenna Subsystem Housekeeping Power.

2. PPSHKP - Prime Power Subsystem Housekeeping Power.

3. STABDC - Stabilization Subsystem Housekeeping Power - DC Component.

4. STABAC - Stabilization Subsystem Housekeeping Power - AC Component.

5. TTCHKP - TT&C Subsystem Housekeeping Power.

6. HKPAC - Total Housekeeping Power - AC Component.

7. HKPDC - Total Housekeeping Power - DC Component.

8. ANTDF - Antenna Dish Factor.

9. KFB - Carrier Frequency Band.

10. HKP - Sum of Calculated Housekeeping Powers of all Satellite Subsystem.

11. DIFHKP - Deviation of Calculated Housekeeping Power from Estimated Value.

12. WTOT - Sum of Subsystem Weights.

13. DIFWT - Deviation of Calculated Satellite Weight from Estimated Value.

The output parameters are:

1. ANTWT - Weight of Antenna Subsystem in Lbs.
2. ANTDIA - Antenna Diameter in Feet.
3. PWRCOM - Communication Power in Watts.
4. HTDL - Heat Dissipation Load in Watts.
5. PWRBOL - Beginning-of-Life Prime Power in Watts.
6. TRNSWT - Weight of Transponder Subsystem in Lbs.
7. PPSSWT - Weight of Prime Power Subsystem in Lbs.
8. SAAREA - Solar Array Area in Ft^2.
9. STABWT - Weight of Stabilization Subsystem in Lbs.
10. THRMWT - Weight of Thermal Control Subsystem in Lbs.
11. STRWT - Structural Weight in Lbs.
12. SATWT - Total Satellite Weight in Lbs.

The antenna and transponder parameters are calculated directly from the input parameters by the subroutines ANTSS and TRSPDR. The housekeeping AC and DC power requirements are then estimated and these values are used in the calculation of the Prime Power Subsystem PPSS parameters. The BOL prime power from the PPSS is used to initially estimate total satellite weight. Satellite weight is required as input to the Stabilization Subsystem STABSS, the Thermal Control Subsystem THRMSS, and the Telemetry, Tracking, and Command Subsystem TTANC subroutines. The housekeeping power requirements of the above subsystems are then summed and compared to the estimated value. If the summed value differs by more than 1% of the estimated value, the summed value is used to recalculate the parameters of the subroutine PPSS and subsequently STABSS, THRMSS, and TTANC. This loop iteration, on housekeeping power, continues until the difference is less than 1%. At this point the iteration stops and all parameters calculated on the last iteration are retained.

The Structural Subsystem STRUCT parameters are then calculated. The subsystem weights calculated by all the above subroutines are then summed to provide a value of total satellite weight. This weight value is compared to the estimated value and if the difference is greater than 1% the estimated value is reset and the iteration proceeds. When the satellite weight changes by no more than 1% of the previous iteration, the parameters calculated on the last iteration are retained and returned to the Main Line program.

4.2 ANTENNA SUBSYSTEM MODEL

4.2.1 Subsystem Configuration

The antenna subsystem consists of an earth coverage (EC) receiving antenna, a telemetry, tracking and command (TT&C) omni antenna and a directive antenna for broadcasting. The directive antenna consists of a parabolic reflector and a focal point feed cluster. The cluster contains one to six feeds, depending on the number of independent beams required.

A parabolic antenna is assumed since it is applicable to the three broadcasting frequency bands specified by the WARC and has certain advantages over other candidate configurations, if shaped beams are not required. For example, it (1) provides the best overall performance with the least complexity, (2) presently provides the highest gain per pound or per dollar, and (3) is state-of-the-art.

Two reflector configurations are considered for the directive antenna: (1) a space erectable structure and (2) a rigid structure.

The satellite configuration assumed for the space erectable antenna places the power amplifier(s) in a module on the earth viewing side of the antenna feed. This eliminates the need for lengthy waveguide (or coax) runs and results in a substantial weight and power (due to reduced RF attenuation) savings, particularly for the larger antennas. Therefore, the space erectable antenna system includes a reflector, deployment mechanism, feed(s) and associated supports. The antennas are fixed with respect to the spacecraft body, therefore gimbel motors are not required.

For the rigid reflector antennas, it is assumed that the antennas are mounted by supporting members to the spacecraft body and can be moved (or nodded) independent of the spacecraft. Therefore, the rigid antenna system includes a reflector, feed(s), waveguide, supports, hub, and gimbel motors.

4.2.2 Model Description

The data flow diagram for the antenna subsystem model is shown in Figure 4-5 and its subroutine ANTSS is listed in Figure 4-6. The model requires spacecraft antenna beamwidth and pointing error, frequency and number of beams as inputs. The outputs are spacecraft antenna diameter, weight, dish factor and power requirements.

The antenna beamwidth inputs are constrained as a function of frequency. Approximate beamwidth limitations are shown in Table 4-1 for the frequency bands of interest.

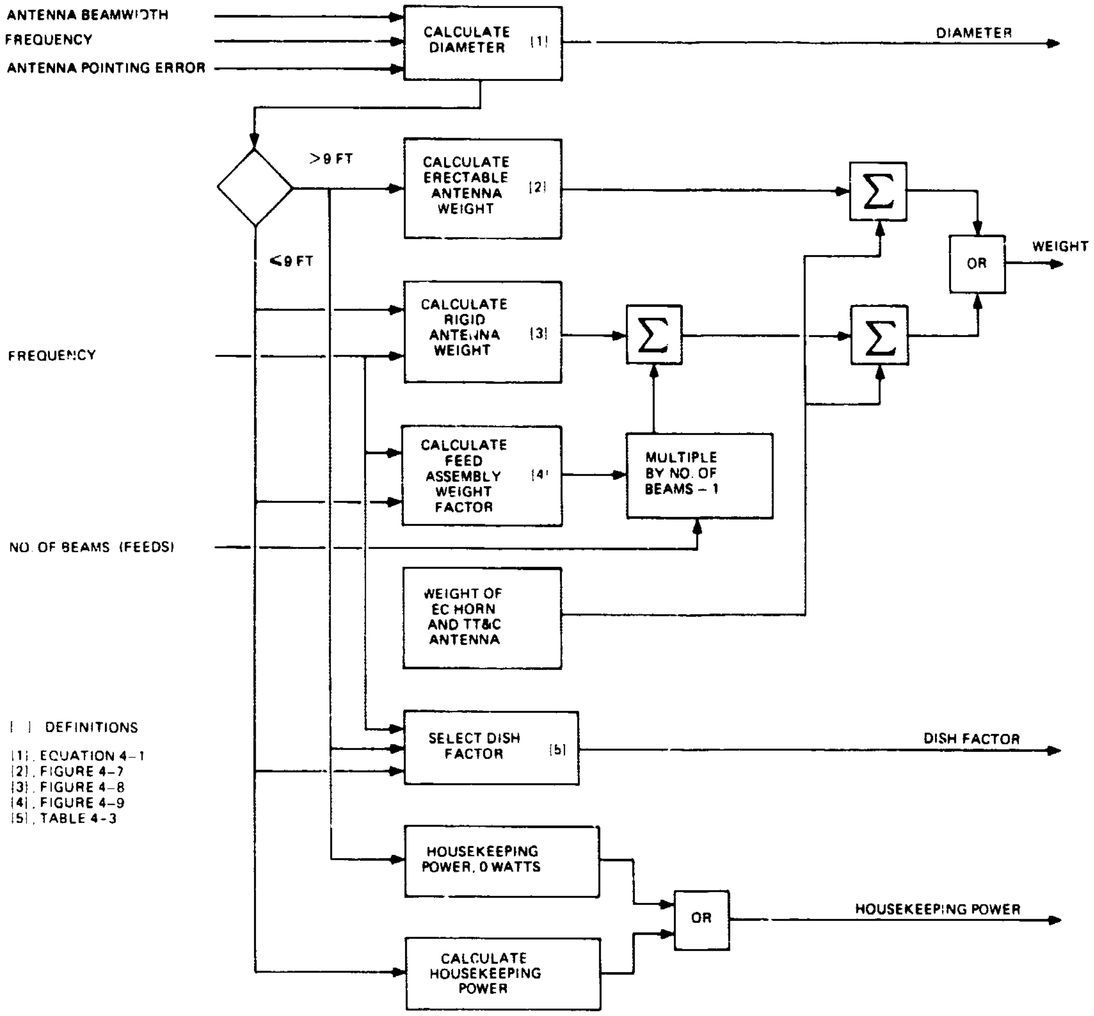

Figure 4-5. Antenna Subsystem Model Data Flow Diagram

```
         CSCX FORTRAN V
       SUBROUTINE ANTSS(FREQ,ANTBW,NBEAM,PTERR,ANTWT,ANTHKP,ANTDIA,
      1ANTDF,KFB)
       WAVEL=0.9843/FREQ
       ANTDIA=(66.5*WAVEL)/(ANTBW + 2.0*PTERR)
       IF(FREQ - 0.8)10,10,20
 10    KFB=1
       GO TO 50
 20    IF(FREQ - 2.7)30,30,40
 30    KFB=2
       GO TO 50
 40    KFB=3
 50    IF(ANTDIA-9.0)60,60,110
 60    IF(KFB-2)80,80,90
 80    ANTWW=10.0*10.0**(0.05*ANTDIA)
       FEEDWT=0.9*ANTDIA + 2.0
       GO TO 100
 90    ANTWW=14.0*10.0**(0.05*ANTDIA)
       FEEDWT=0.236*ANTDIA + 0.4
 100   TTCANT= 9.0
       ANTWT= ANTWW + (NBEAM-1.0)*FEEDWT + TTCANT
       ANTHKP= 2.0
       GO TO 160
 110   IF(KFB - 2.0)120,130,130
 120   ANTDF=0.88
       GO TO 150
 130   ANTDF=0.84
 150   TTCANT=9.0
       ANTWW=22.4*10.0**(0.025*ANTDIA)
       ANTWT= ANTWW + TTCANT
       ANTHKP=0.0
 160   CONTINUE
       RETURN
       END
```

Figure 4-6. Subroutine ANTSS

TABLE 4-1

BEAMWIDTH LIMITATIONS

	FREQUENCY, MHz					
	620 - 790		2500 - 2690		11,700 - 12,200	
Minimum Beamwidth, deg.	2.20	1.75	0.53	0.50	0.63	0.60
Maximum Beamwidth, deg.	8.00	8.00	8.00	8.00	8.00	8.00

The minimum beamwidth values shown result from assumed reflector diameter limitations. Space erectable antennas are used at the two lower frequency bands and are constrained to a maximum diameter of 50 feet. The rigid reflector antennas are used at the two upper frequency bands and are constrained to a nine foot maximum diameter. It should be noted that both antenna configurations are used at 2.50-2.69 GHz. The antenna pointing error is arbitrary but is usually taken to be about one-tenth the beamwidth.

The number of beams (feeds) that can be used in the model is dictated by the allowable blockage loss. For the large erectable antenna a blockage loss, due to the earth viewing module (EVM) and supports, of about 0.8 dB is considered acceptable. This implies that the dimension of the module facing the reflector should not exceed about 0.1-0.2 antenna diameters. A module of this size is sufficiently large that the maximum number of feeds, i.e., six, can be mounted on its face without increasing the blockage loss.

In the case of the rigid reflector antenna the situation is quite different since an EVM is not assumed. Hence, the blockage is only a function of the feed assembly; i.e., the feed, waveguide and associated supports. For this situation a maximum blockage loss of about 0.2 dB is assumed which limits the dimension of the feed cluster facing the reflector to about 0.08 antenna diameters. The number of circularly polarized feeds which can be accomodated under this constraint is shown in Table 4-2.

TABLE 4-2

MAXIMUM NUMBER OF FEEDS

	ANTENNA DIAMETER, FT.								
FREQUENCY GHz	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	>9
0.62-0.79	NA	NA	NA	NA	NA	NA	NA	NA	6
2.50-2.69	0	1	2	2	3	4	4	5	6
11.7-12.2	3	6	6	6	6	6	6	6	NA

4.2.2.1 Antenna Diameter

The antenna diameter is calculated using the relationship

$$D = \frac{66.5\lambda}{(BW + 2\varepsilon)},\ \text{ft.} \qquad (4\text{-}1)$$

where λ is wavelength, ft.

BW is 3 dB on-axis beamwidth, deg.

ε is rms pointing error, deg.

The beamwidth is that associated with a parabolic aperture distribution function having a 10-dB edge taper as defined in Section 3.8.

4.2.2.2 Antenna Weight

The diameter, along with frequency and the required number of beams, are used to calculate antenna weight. Antennas above nine feet and less than 50 feet in diameter are assumed to be space erectable while those equal to or less than nine feet are defined to be rigid reflector configurations. Nine feet represents that diameter which can be accomodated within the Titan III-C shroud without folding the reflector.

The weight of the space erectable antenna varies with frequency, as well as diameter, primarily because the reflector supporting structure weight increases with increasing frequency. The weight increase is not simply related to frequency, however since it depends on the individual design, tolerance requirements, etc. Nevertheless, it is possible to group the weights of space erectable reflectors into two rough divisions designated "high tolerance" and "low tolerance" as shown on Figure 4-7. The data points are weight estimates obtained directly from the manufacturers or from engineering type reports for the following reflector designs*, including the deployment mechanism:

1. General Dynamics/Convair PETA.
2. Goodyear Aircraft Graphite Fiber Reinforced Plastic (GFRP) Petaline.
3. Lockheed Flex-Rib.
4. RCA LEM Umbrella.
5. TRW UHF Umbrella.

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*Note: In the cases of TRW and RCA the reflector weights were estimated from total antenna weights.

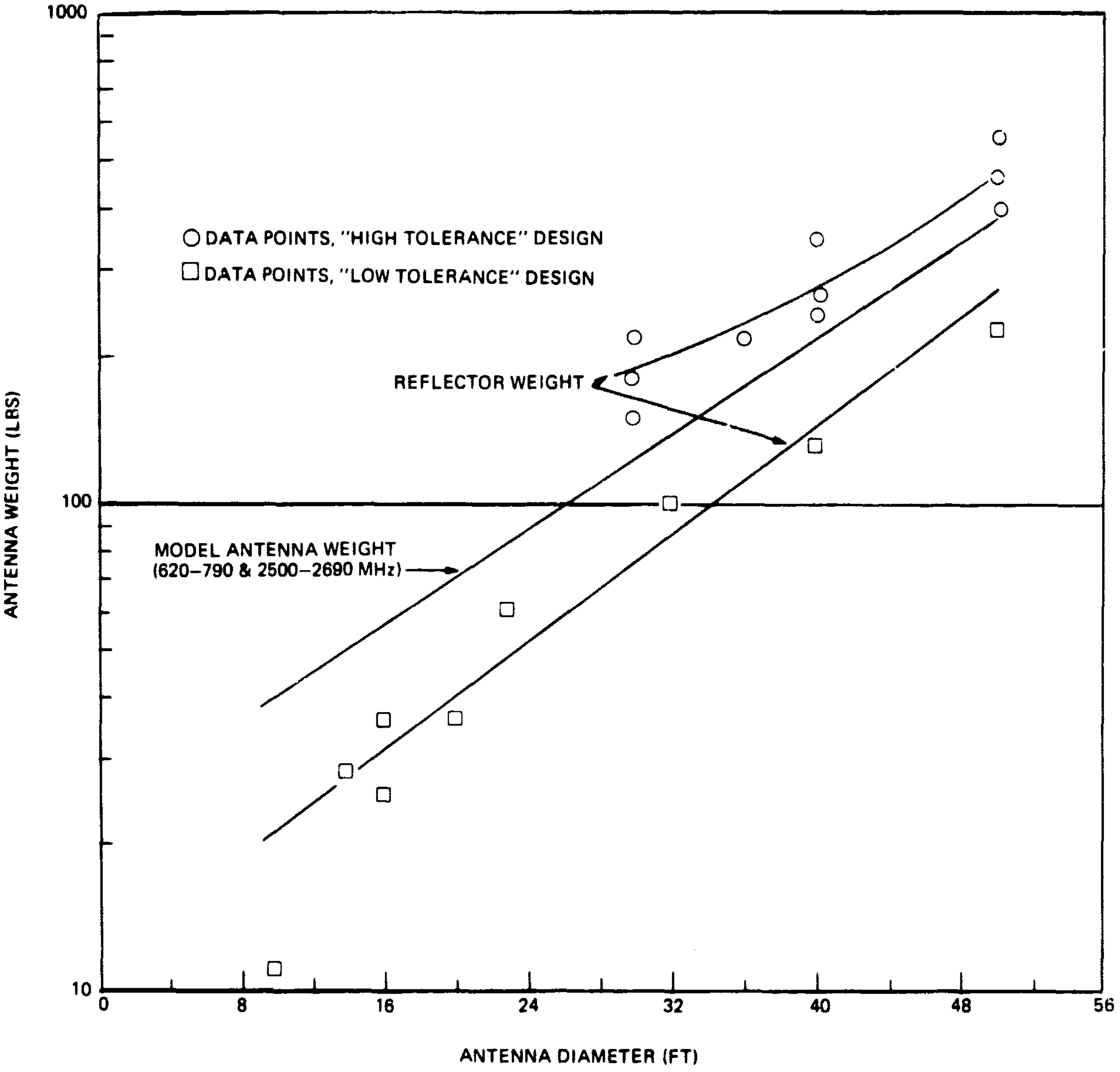


Figure 4-7. Space Erectable Antenna Weights

The "low tolerance" weight estimates are applicable to reflectors operating below approximately 3 GHz. The "high tolerance" estimates apply at frequencies up to about 13 or 14 GHz. The differences between the reflector designs are primarily in the number of supporting ribs, sections, etc. employed for a given diameter. For example, for a 40-foot diameter reflector the Lockheed Flex-Rib antenna employs 18 ribs in a "low tolerance" design and 96 ribs in a "high tolerance" design. The respective weights are 340 and 130 pounds. For comparison, the ATS-F Flex-Rib 8 GHz design employs 48 ribs and the estimated weight is 150 pounds. The "low tolerance" reflector weight curve, derived from the data points shown in Figure 4-7, is used in the model for weight calculations in the frequency ranges 620-790 MHz and 2.50-2.69 GHz. It should be noted that relatively good correlation existsbetween the data points, which include the weights of four separate designs. The "high tolerance" curve although not used in the model is included for reference.

The total antenna weight is given by the "model antenna weight" curve in Figure 4-7. This includes the weights of the feed(s) and supporting structure as well as the reflector. The weight of the supporting structure dominates over the feed weight and is primarily a function of the "top side" weight of the spacecraft, therefore it can be related to antenna diameter. The support weight is based on using a graphite fiber plastic such as that used on the ATS-F. The "model antenna weight" curve is applicable to the lower two frequency bands of interest, for one or multiple feeds. The weight added by multiple feeds is insignificant and within the estimated tolerances of the curve.

The rigid antenna system weight is shown in Figure 4-8. The weight relationships are assumed valid between one-half and nine feet. It should be noted that the antenna weights are dependent on frequency. This occurs for several reasons: (1) the transmitter is located behind the antenna (to avoid excessive

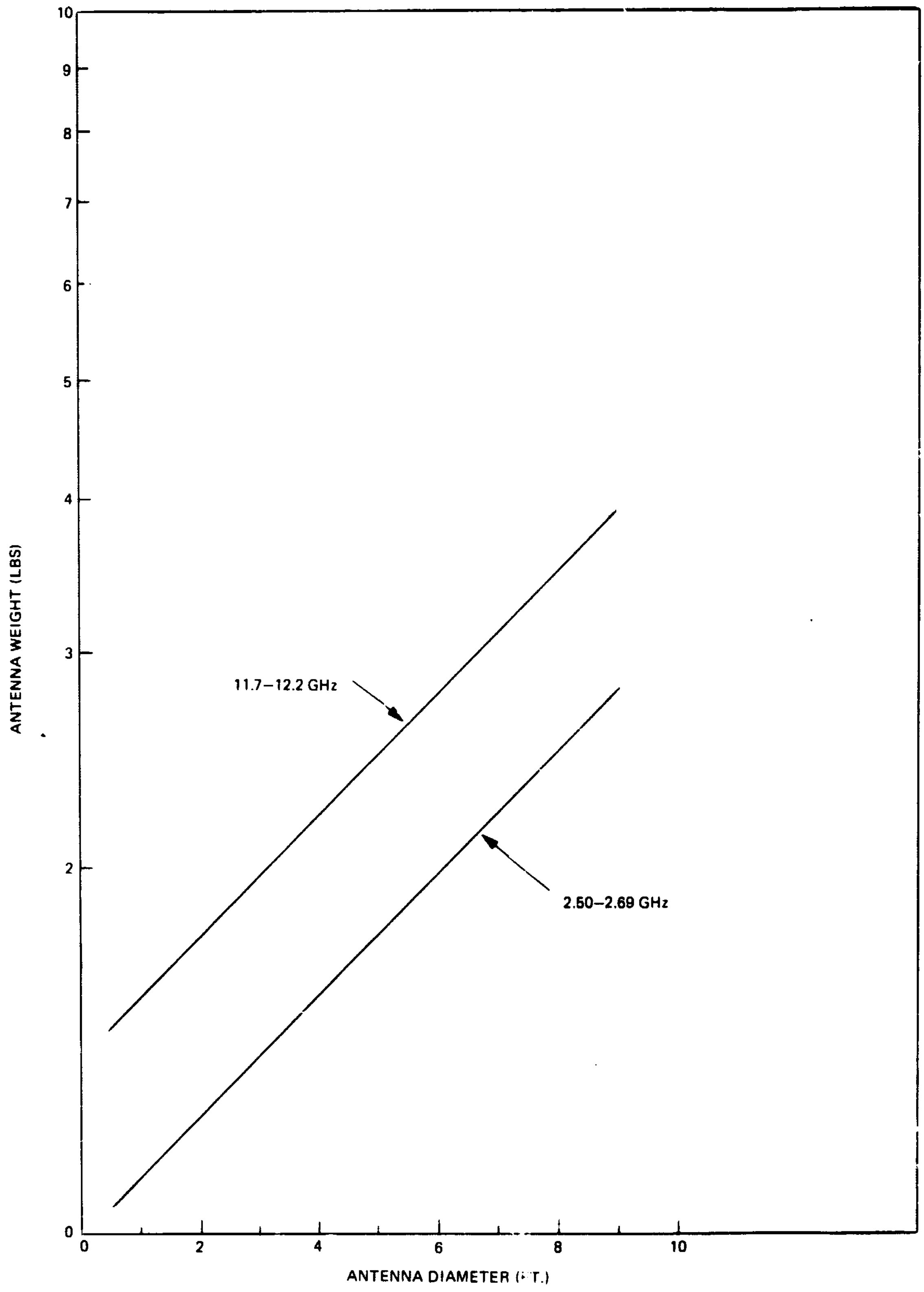


Figure 4-8. Rigid Antenna Weights

blockage), hence a relatively long waveguide run is required which together with the supports, feed, etc. comprise a significant percentage of the total antenna weight, (2) the weight of these components is frequency dependent, and (3) the reflector weight increases significantly with increasing frequency.

The two curves shown in Figure 4-8 were derived from data supplied by Hughes and TRW. One set of data is representative of Intelsat IV type antennas while the other data were based on the Phase II military design. The data were weighted somewhat in favor of the Hughes values since their design is more representative of a broadcasting type antenna.

The weights as shown in Figure 4-8 are representative of a single feed antenna system. As the number of feeds is increased to accommodate multiple beam operation an additional weight factor must be included to account for the increase in feed assembly weight. The feed assembly weight factor shown in Figure 4-9 includes the waveguide, feed, and a small percent for increased support weight, for one additional feed.

The weight factor was estimated for an f/D ratio of 0.35. Aluminum waveguide was assumed at 11.7-12.2 GHz while 1-5/8" aluminum jacketed air dielectric coax was used for estimates at the two lower frequency bands. This size coax will handle up to 2.3 kW at 2.69 GHz and 4.8 kW at 790 MHz.

The weight factor multiplied by the number of feeds (beams) minus one, when added to the weights in Figure 4-8 gives the rigid antenna system weight.

The model in Figure 4-5 also includes the weight, i.e., 9 lbs., of a horn E/C receiving antenna and a TT&C omni antenna, which are required to provide a total antenna system.

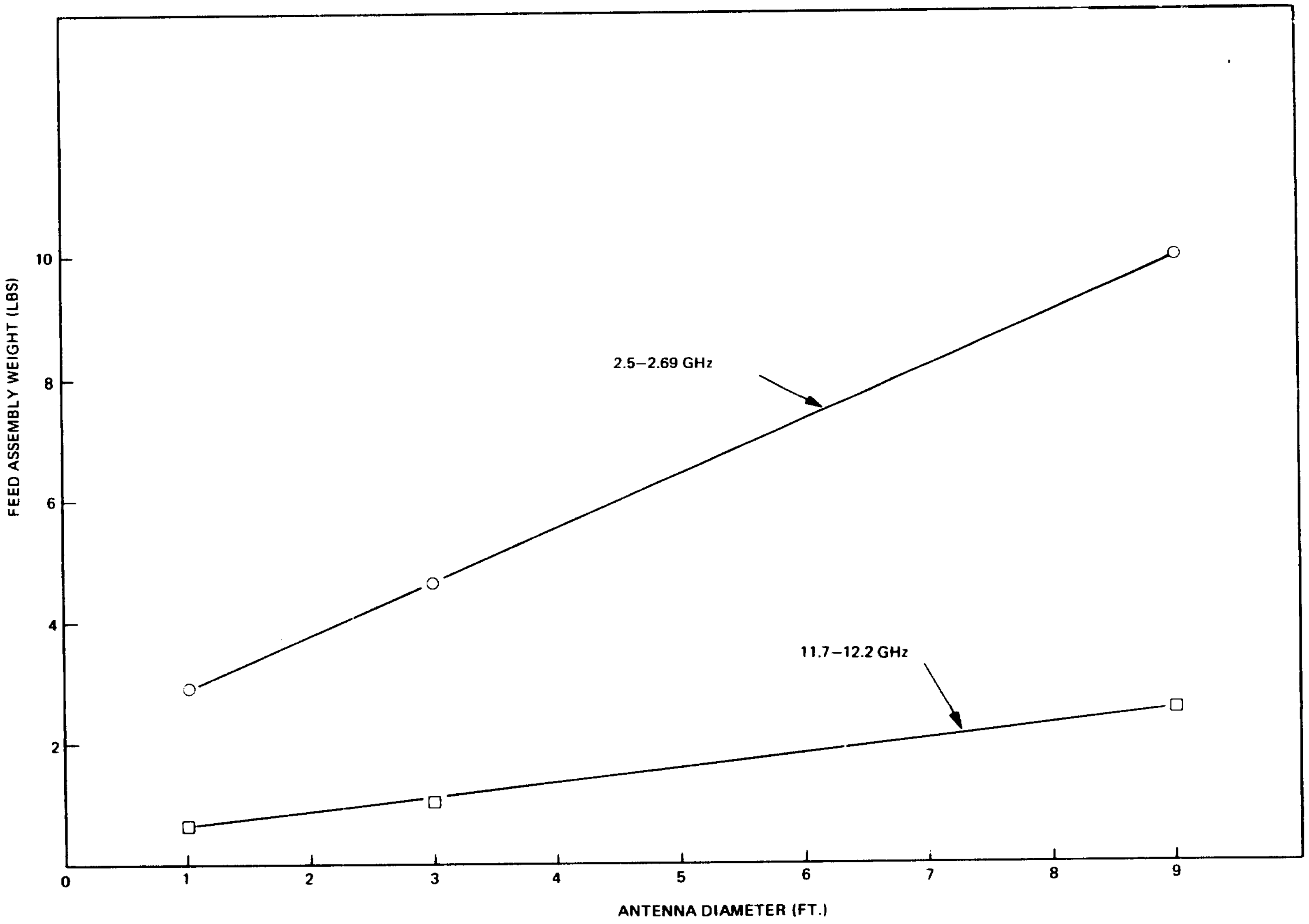


Figure 4-9. Feed Assembly Weight Factor

4.2.2.3 Dish Factor

The dish factor is a function of the reflector construction and is defined as the percent of the reflector's area which is open. For example, the dish factor of a solid reflector antenna is zero. This factor is important in determining solar pressure torques on the spacecraft. Table 4-3 gives the dish factors used in the model. For the erectable antennas the dish factors are equivalent to a reflector porosity loss of about 0.3 dB.

TABLE 4-3

DISH FACTOR

	DISH FACTOR %	
FREQUENCY, GHz	RIGID ANTENNA	ERECTABLE ANTENNA
0.62-0.79	NA	88%
2.50 - 2.69	0	84%
11.7-12.2	0	NA

4.2.2.4 Housekeeping Power

The housekeeping power required for antenna operation is assumed to be 2 watts and applies only to the one-half to nine foot rigid reflector antennas. These antennas can be positioned in two directions (azimuth and elevation) with respect to the spacecraft body by means of gimbel motors. For comparison the Intelsat IV gimbel motors require 900 ma of 28-Volt dc power per 46 inch diameter antenna.

4.3 TRANSPONDER SUBSYSTEM MODEL

4.3.1 Subsystem Configuration

Figure 4-10 is a block diagram of the basic transponder configuration used in the model. The transponder is channelized, with the exception of the preamplifier, and employs double conversion. The high power outputs from each repeater (channel) are combined in a high level multiplexer and the composite RF signal output drives the antenna feed. For multiple beam operation the composite signal is divided and drives multiple feeds.

The uplink frequency is taken to be 6 GHz, regardless of the downlink frequency, and a Tunnel Diode Amplifier (TDA) is assumed. The bandwidth of the preamplifier is sufficiently large so that only one is required, regardless of the number of channels employed.

The part of the transponder in which the signal is at a low level is designated the receiver. The receiver is conventional and consists of filters, mixers, an IF amplifier, a gain control device; i.e., FAGC or limiter, driver and interconnecting circuitry.

The type of power amplifier employed is a function of frequency and RF power requirement. The options used in the model are indicated below:

- At 620 to 790 MHz both solid state (≤ 150 watts) and Triode/Tetrodes (> 150 watts) are used.
- At 2.50 to 2.69 GHz both solid state (≤ 50 watts) and TWTs (≥ 50 watts) are used.
- At 11.7 to 12.2 GHz only TWTs are used.

The low level (LL) multiplexer uses the preamplifier output as input and provides a drive signal for each receiver channel. Stripline is assumed for this application.

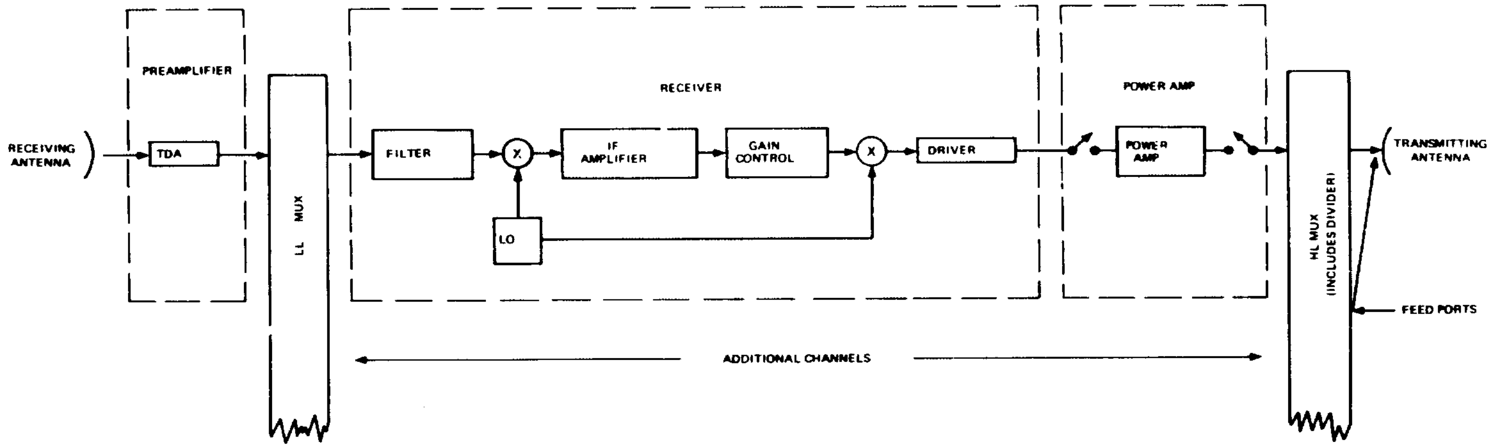


Figure 4-10. Basic Transponder Configuration

The high level (HL) multiplexer/divider is diagramed in Figure 4-11. The multiplexer accepts the high power RF outputs from the power amplifiers, from 1, 3 or 6 channels, and combines these into a single output which drives the antenna feed. For multiple beam operation a divider is used at the multiplexer output and provides the individual drive power for each feed. Waveguide is assumed for this application at 11.7 to 12.2 GHz while coax is assumed at 0.62 to 0.79 and 2.50 to 2.69 GHz.

4.3.2 Model Description

The data flow diagrams for the transponder subsystem model are shown in Figures 4-12 and 4-13 depicting performance parameters and weight values, respectively. The associated subroutine TRSPDR is listed in Figure 4-14. The model requires frequency, number of channels (1, 3 or 6), number of antenna beams (1-6), satellite life (2 or 5 years) and RF power/channel as inputs. The outputs are communication prime power, heat dissipation load, and transponder subsystem weight.

4.3.2.1 Communication Prime Power

The RF power/channel is the power required at the input to the spacecraft antenna. Therefore, the determination of prime power requires the calculation of transmission line loss, transmitter output power, and transmitter efficiency.

The transmitter line loss (L_L) is the insertion loss between a power amplifier and the antenna input. The loss is due to the HL multiplexer, the power divider and waveguide. Therefore, it is a function of the number of channels, the number of beams, and frequency. Loss factors have been assigned based on hardware performance estimates (References 4-20 to 4-28 and 4-30) and are shown in Table 4-4.

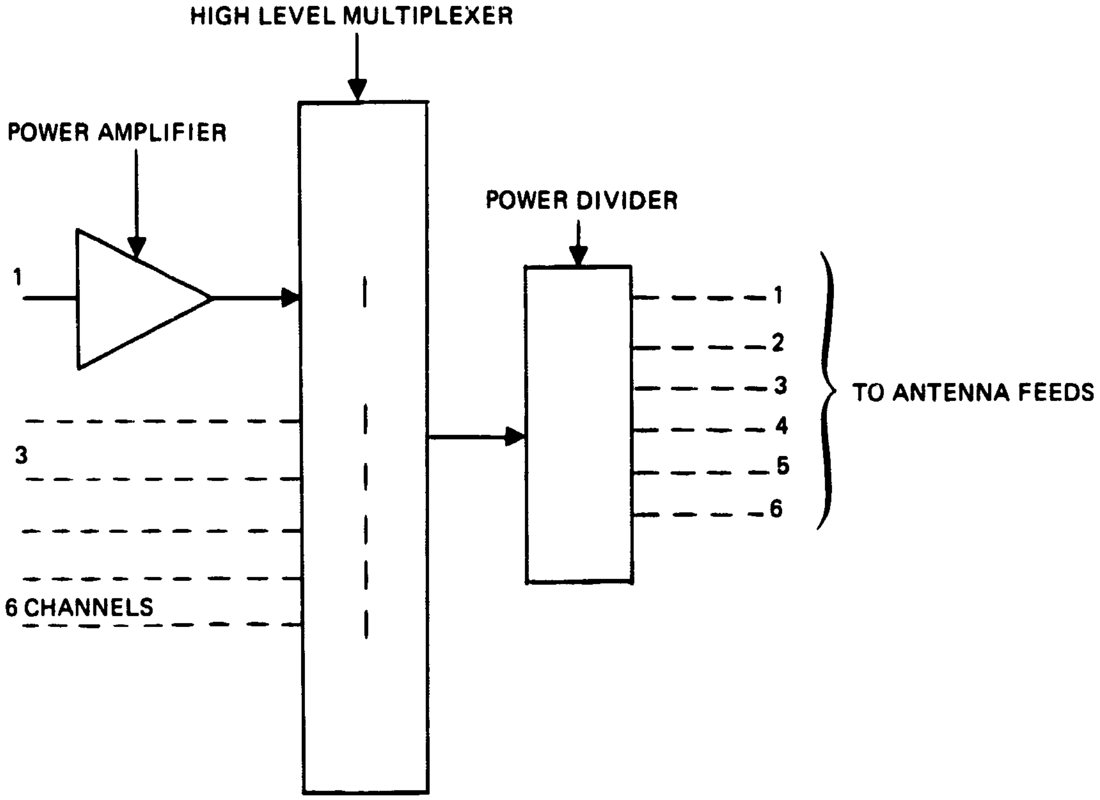


Figure 4-11. High-Level Multiplexer/Divider Configuration

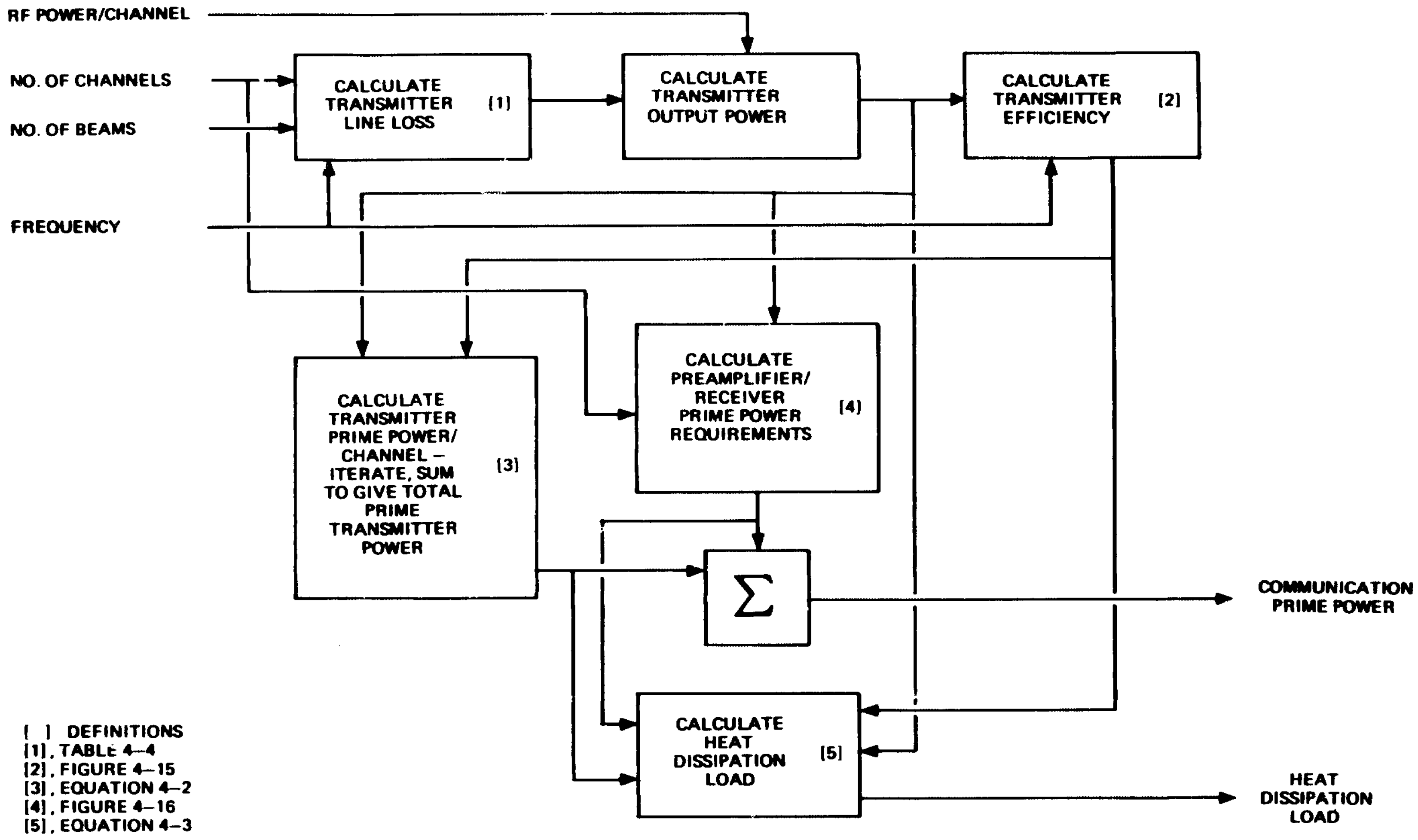


Figure 4-12. Transponder Subsystem Model Data Flow Diagram (Communication Prime Power and Heat Dissipation Load)

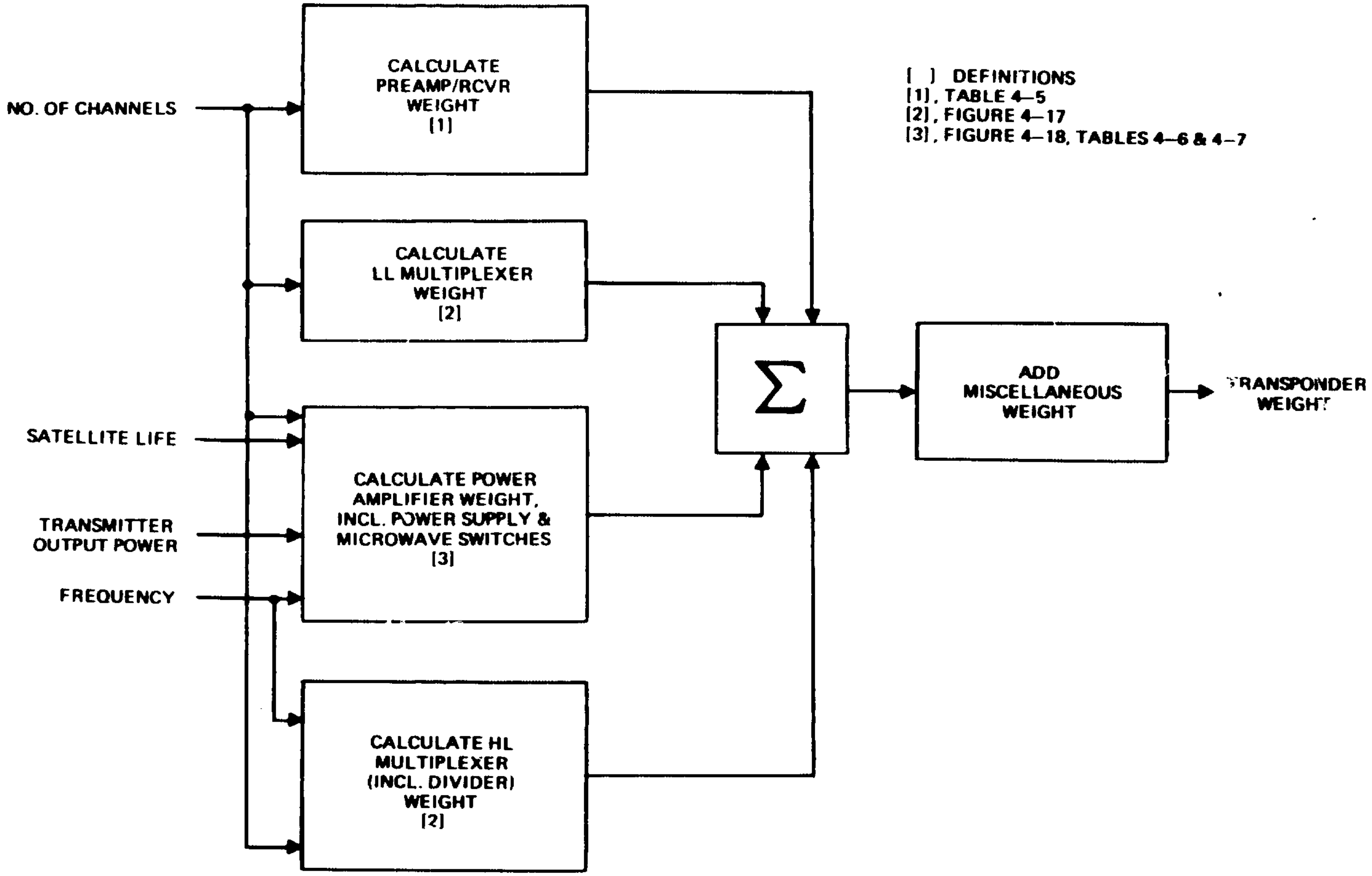


Figure 4-13. Transponder Subsystem Model Data Flow Diagram (Weight)

```
    CSCX FORTRAN V
 SUBROUTINE TRSPDR(KFB,RFPCHL,NCHNL,NBEAM,SATLIF,PWRCOM,
1HTDL,TRNSWT)
 DIMENSION WGL(10),PDL(10),PLEXL(10),WLLM(10),WHLM1(10),
1WHLM2(10),WHLM3(10),RFPCHL(6)
 DATA(WGL(II),II=1,3)/1.0715,1.0715,1.175/
 DATA(PDL(JJ),JJ=1,6)/1.0,1.047,1.047,1.097,1.148,1.148/
 DATA(PLEXL(KK),KK=1,6)/1.0,1.0,1.0966,1.0,1.0,1.122/
 DATA(WHLM1(KK),KK=1,6)/1.0,1.0,22.0,1.0,1.0,44.0/
 DATA(WHLM2(KK),KK=1,6)/1.0,1.0,14.0,1.0,1.0,28.0/
 DATA(WHLM3(KK),KK=1,6)/1.0,1.0,3.2,1.0,1.0,5.5/
 DATA(WLLM(KK),KK=1,6)/1.0,1.0,0.5,1.0,1.0,1.1/
 II=KFB
 JJ=NBEAM
 KK=NCHNL
 TTOP=0.0
 PPRW=0.0
 TTPP=0.0
 PAMWT=0.0
 TLL=WGL(II)+PDL(JJ)+PLEXL(KK)
 DO 110 J=1,NCHNL
 TOPI=RFPCHL(J)*TLL
 IF (TOPI-200.0)5,5,7
5    RCVRW=0.012*TOPI +6.6
 GO TO 8
7    RCVRW=14.0*(TOPI/1000.0)**0.275
8    IF (KFB-2)10,40,75
10   WHLM=WHLM1(KK)
 IF(TOPI-150.0)20,20,30
20   EFF=0.41/(10.0**(0.86*(TOPI/1000.0)))
 PAWT=66.0*(TOPI/1000.0)**0.69
 GO TO 100
30   EFF=0.24+0.216*(TOPI/1000.0)-0.0252*((TOPI/1000.0)**2.0)
 PAWT=56.0*(TOPI/1000.0)**0.415
 GO TO 100
40   WHLM=WHLM2(KK)
 IF(TOPI-50.0)45,45,50
45   EFF=0.422-1.75*(TOPI/1000.0)
 PAWT=66.0*(TOPI/1000.0)**0.724
 GO TO 100
50   IF(TOPI-200.0)55,55,60
55   PAWT=0.26*TOPI-2.5
 EFF=0.6*(TOPI/1000.0)**0.176
 GO TO 100
60   PAWT=72.0*(TOPI/1000.0)**0.22
```

Figure 4-14. Subroutine TRSPDR

```
      IF(TOPI-700.0)65,65,70
65    EFF=0.6*(TOPI/1000.0)**0.176
      GO TO 100
70    EFF=0.55+0.01*(TOPI/1000.0)
      GO TO 100
75    WHLM=WHLM3(KK)
      PAWT=30.0*(TOPI/1000.0)**0.37
      IF(TOPI-150.0)80,80,90
80    EFF=0.42*(TOPI/1000.0)**0.067
      GO TO 100
90    EFF=0.48*(TOPI/1000.0)**0.124
100   TPPI=TOPI/(0.85*EFF)
      TTOP=TTOP+TOPI
      PPRW=PPRW+RCVRW
      PAMWT=PAMWT+PAWT
110   TTPP=TTPP+TPPI
      IF(TOPI-200.0)120,120,130
120   R=2.0
      SWWT=3.0*NCHNL
      GO TO 160
130   IF(SATLIF-2.0)140,140,150
140   R=3.0
      SWWT=6.0*NCHNL
      GO TO 160
150   R=4.0
      SWWT=9.0*NCHNL
160   PAWTT=PAMWT*R + SWWT
      PPR=PPRW + 2.0
      PWRCOM=TTPP + PPR
      HTDL=TTPP*(1.0-EFF*0.85) + 0.9*PPR + TTOP*(1.0-1.0/TLL)
      WPR=20.0*NCHNL + 2.0
      TRNSWT=(WLLM(KK) + WHLM + WPR + PAWTT)*1.10
      RETURN
      END
```

Figure 4-14. Continued

TABLE 4-4

TRANSMITTER LINE LOSS FACTORS

(References 4-20 to 4-28 and 4-30)

HL MULTIPLEXER	
NO. CH.	LOSS, dB
1	NA
3	0.4
6	0.5

POWER DIVIDER	
NO. BEAMS	LOSS, dB
1	NA
2	0.2
3	0.2
4	0.4
5	0.6
6	0.6

WAVEGUIDE, ETC.	
FREQ, GHz	LOSS, dB
0.62-0.79	0.3
2.50-2.69	0.3
11.7-12.2	0.7

The transmitter output power for the ith channel P_{TOi} is calculated by multiplying the RF power/ith channel by L_L. The transmitter efficiency η_T is obtained from Figure 4-15 as a function of P_{TO} and frequency. The curves are based on data obtained from vendors (References 4-1 to 4-9, 4-22, 4-31 and 4-34). The data represents 1972-74 technology and includes losses due to hybrids etc. Hybrids are required for the solid state devices when it is not possible to obtain the indicated power with a single device. In general, the efficiencies associated with the higher power amplifiers are based on engineering estimates since little "hard" data is available. The transmitter prime power per channel is calculated using the relationship

$$P_{TPi} = \frac{P_{TOi}}{\eta_T \, \eta_C} \qquad (4-2)$$

where η_C is 0.85, the converter efficiency.

The above process is repeated for all channels since the RF power/channel generally varies as a function of the channel center frequency. The resultant prime powers are then summed to give the total transmitter prime power P_{TTP}.

The prime power required by the receiver, per channel, is shown in Figure 4-16. The required receiver power increases, with increasing transmitter power, since a higher drive level is required. The total preamp/receiver prime power P_{PRP} required is determined by multiplying the power from Figure 4-16 by the number of channels and adding 2 watts for the preamplifier. The prime communication power is $P_{TTP} + P_{PRP}$.

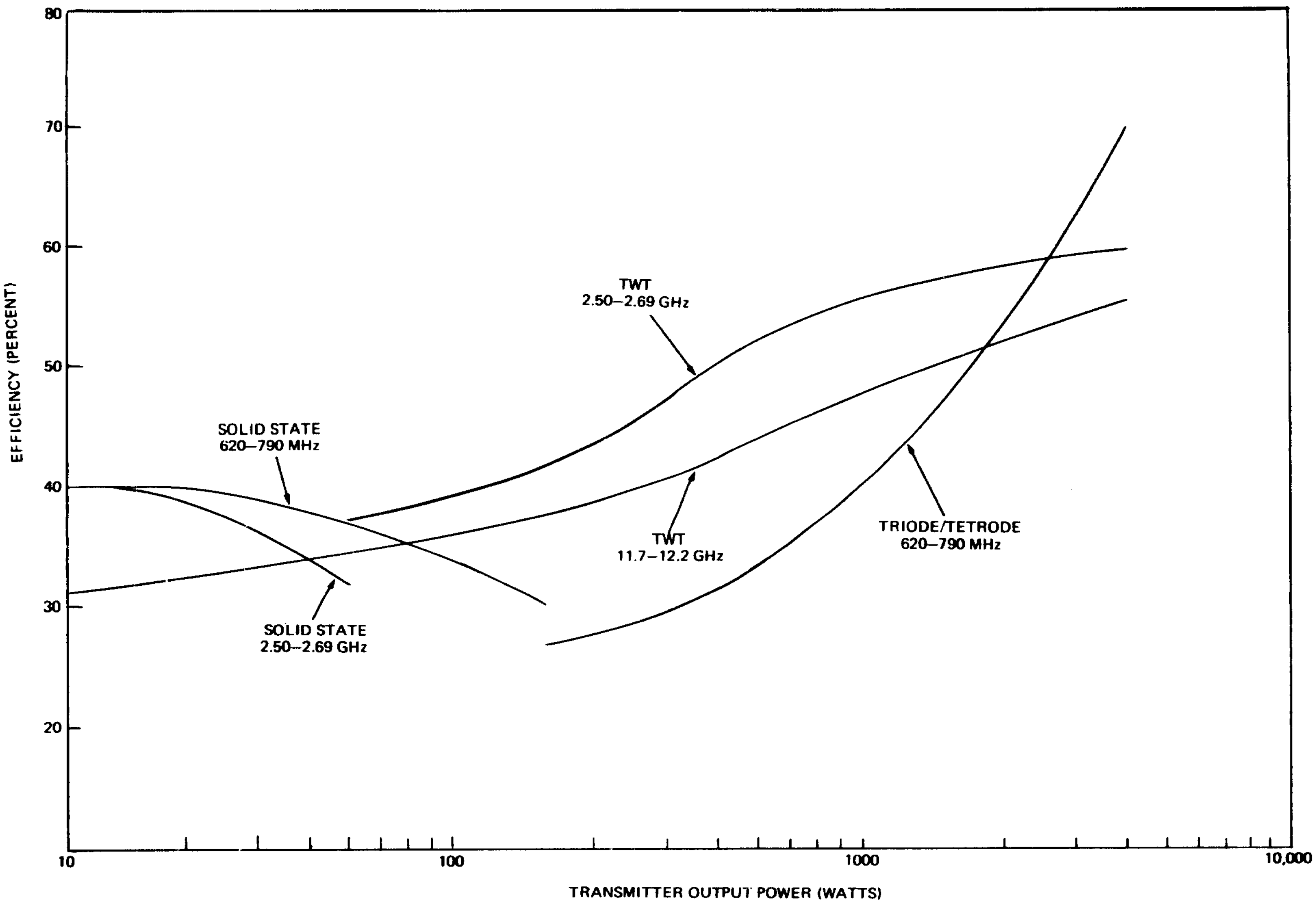


Figure 4-15. DC to RF Transmitter Efficiency
(References 4-1, 4-9, 4-22, 4-31 and 4-34)

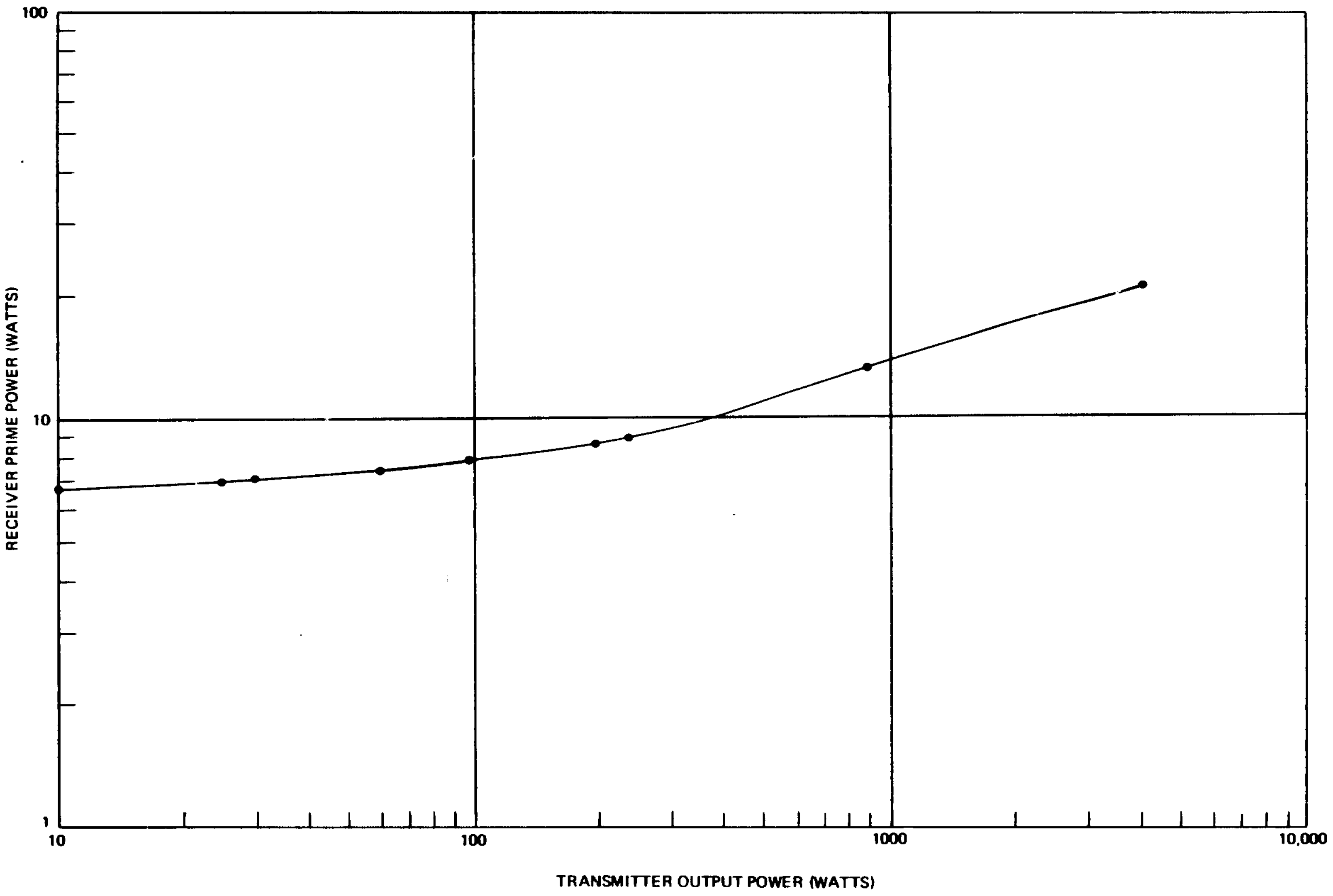


Figure 4-16. Receiver Prime Power/Channel

4.3.2.2 Heat Dissipation Load

Heating in the transponder, due to losses, occurs primarily in the power conditioner(s), the high power amplifier(s) and the HL multiplexer/divider.

The heat dissipation load is given by

$$H_{DL} = P_{TTP} \left(1 - \eta_T \; \eta_C\right) + 0.9 \; P_{PRP} + \sum_{i=1}^{n} P_{TOi} \left(1 - \frac{1}{L_L}\right) \qquad (4-3)$$

where n is the number of channels.

4.3.2.3 Weight

Figure 4-13 illustrates the flow diagram for transponder subsystem weight calculations. The inputs to the model are frequency, number of channels, satellite life and transmitter output power. The output is transponder subsystem weight. For purposes of discussion, the weight is divided into several categories: the preamp/receiver, LL multiplexer, power amplifier assembly and the HL multiplexer divider.

The weight of the preamp/receiver including redundancy, is determined from Table 4-5, as a function of number of channels. One redundant unit is included per channel, which is sufficient for 2 or 5 year life.

TABLE 4-5

PREAMPLIFIER/RECEIVER WEIGHT
(References 4-10 to 4-19)

NUMBER OF CHANNELS	PREAMP WEIGHT (LBS)	RECEIVER WEIGHT (LBS)
1	2	20
3	2	60
6	2	120

The LL multiplexer operates at 6 GHz and is stripline. The weight is determined from Figure 4-17 for 3 or 6 channels (References 4-29 and 4-32 to 4-36).

The power amplifier assembly includes the power amplifier(s), microwave switches, and power supply. The weight of one power amplifier, including supply, is determined from Figure 4-18, as a function of frequency and the highest transmitter power output per channel (References 4-1, 4-9, 4-22, 4-31 and 4-34). This weight is then multiplied by the number of channels and the redundancy factor to give the power assembly weight (less switches). The redundancy factors are given in Table 4-6.

TABLE 4-6

POWER AMPLIFIER REDUNDANCY FACTORS
(References 4-1, 4-2, and 4-3)

SATELLITE LIFE (YRS)	TRANSMITTER OUTPUT POWER (WATTS)	REDUNDANCY FACTOR
2 or 5	≤200	2
2	>200	3
5	>200	4

The microwave switch weights required to provide the stated amplifier redundancy are given in Table 4-7, as a function of satellite life, transmitter output power and number of channels.

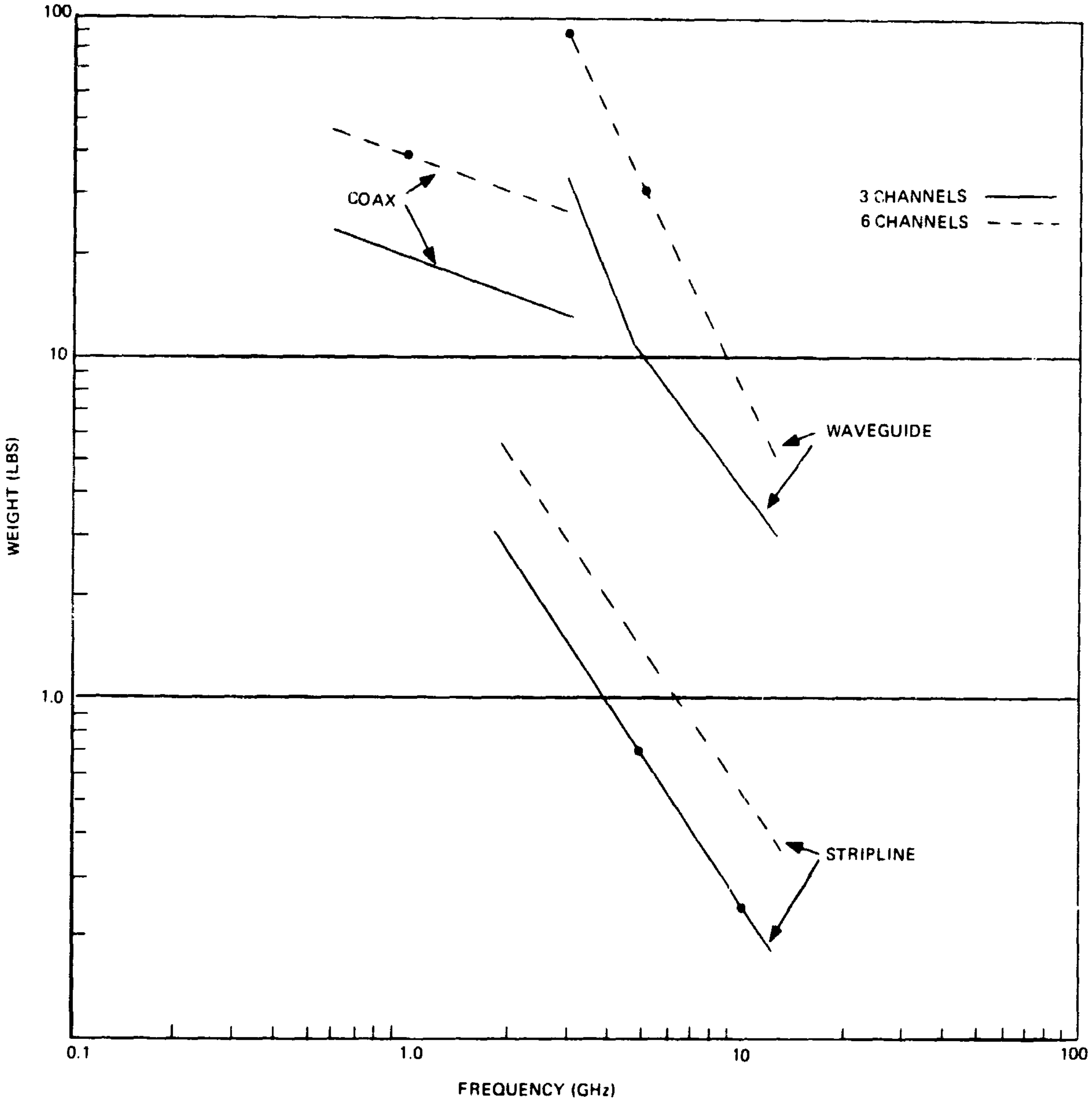


Figure 4-17. Multiplexer Weight
(References 4-29 and 4-32 - 4-36)

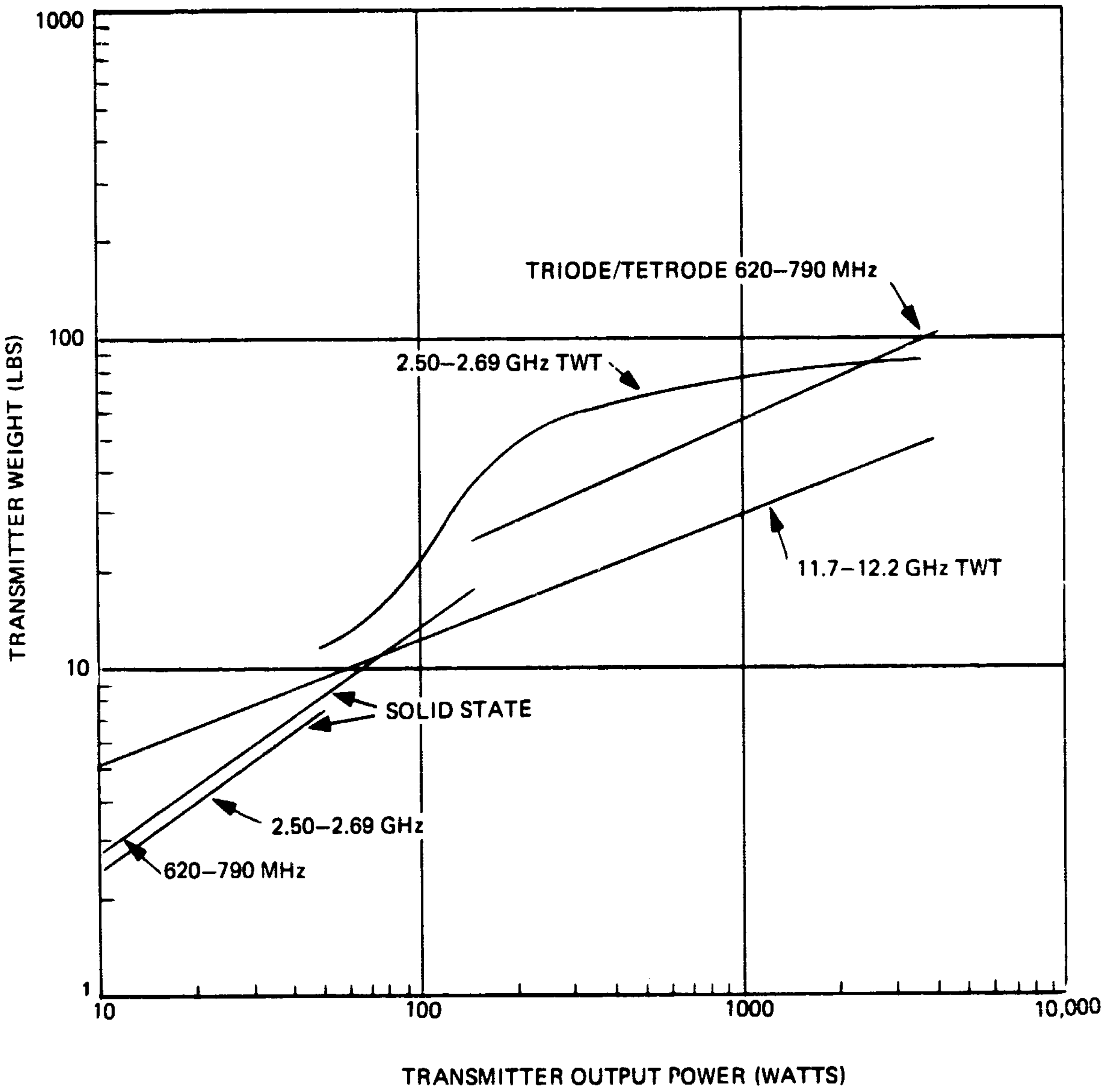


Figure 4-18. Transmitter (Power Amplifier and Supply) Weight (References 4-1 - 4-9, 4-22, 4-31 and 4-34)

TABLE 4-7

MICROWAVE SWITCH WEIGHTS
(References 4-21 - 4-25)

SATELLITE LIFE (YRS)	TRANSMITTER OUTPUT POWER (WATTS)	SWITCH WEIGHT (LBS) 1 CH.	3 CH.	6 CH.
2 or 5	≤200	3	9	12
2	>200	6	18	36
5	>200	9	27	54

Waveguide and coax are considered for the HL multiplexer at 11.7 to 12.2 GHz, and 0.62 to 0.79 and 2.50 to 2.69 GHz, respectively. The weights are derived from Figure 4-17 as a function of frequency and number of channels. The divider, when required for multi-beam operation, will not add significantly to the HL multiplexer weights.

The total transponder weight is obtained by summing the above weights and adding 10% of the sum to account for miscellaneous hardware items, including chassis weight.

4.4 PRIME POWER SUBSYSTEM MODEL

4.4.1 Subsystem Configuration

The prime power subsystem configuration is shown in Figure 4-19 with associated component efficiencies. The design is such that it satisfies the following requirements:

- Prime Power Source - Array of silicon photovoltaic cells, body-mounted on spin/despin spacecraft, sun-oriented on three-axis stabilized spacecraft.

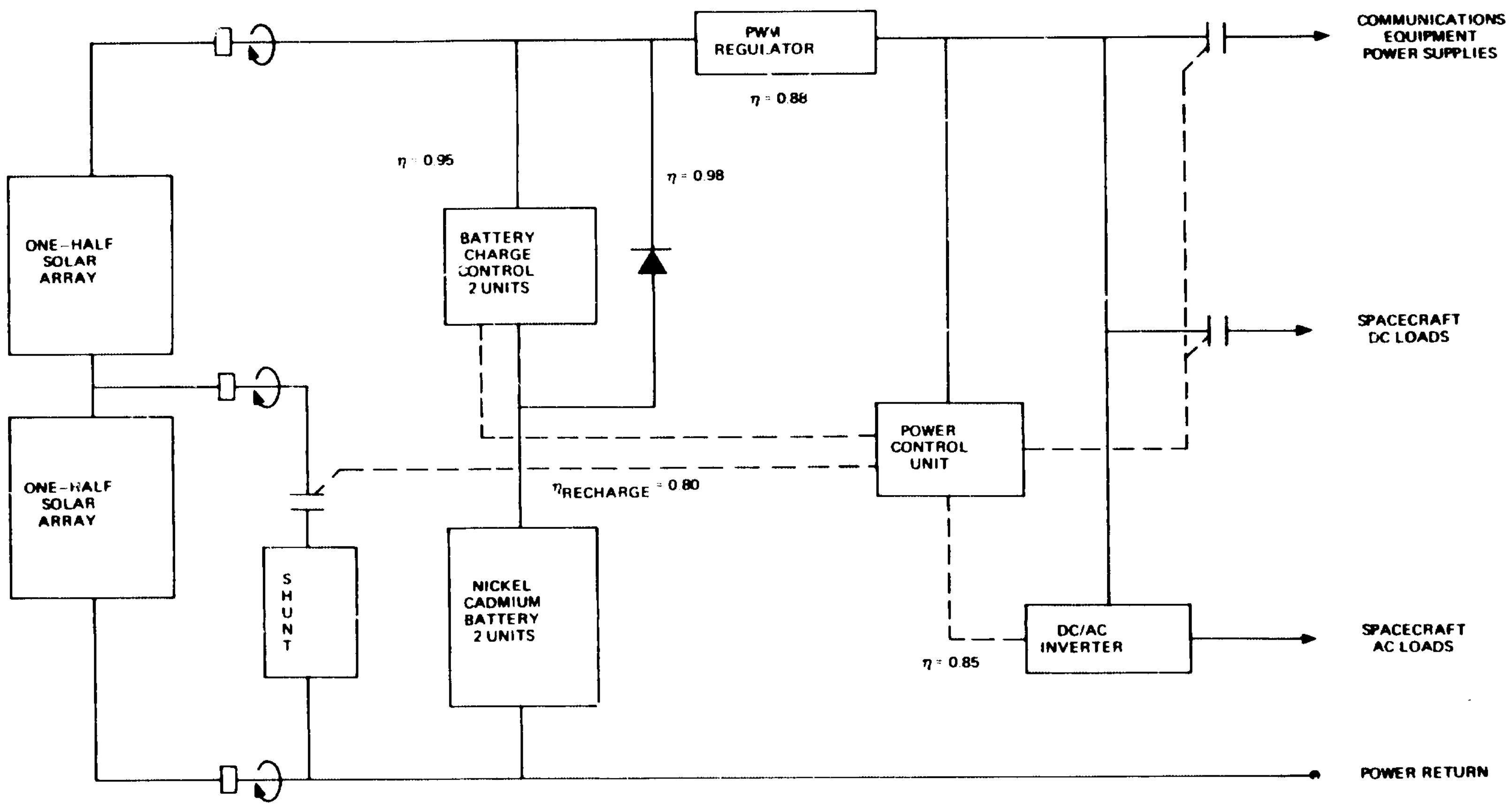


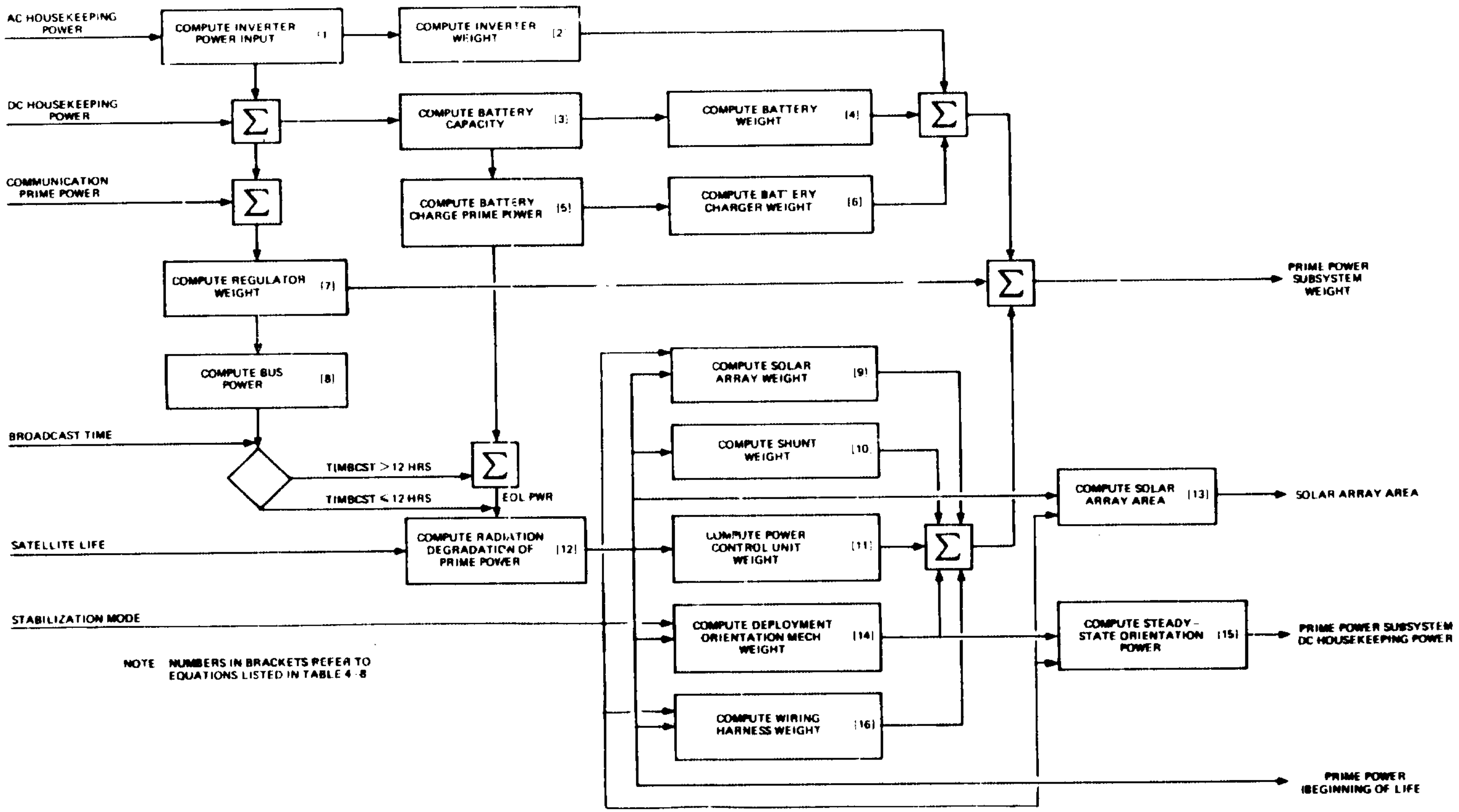
Figure 4-19. Prime Power Subsystem Configuration

- Energy Storage - Batteries of Nickel-Cadmium cells providing housekeeping powers during eclipse periods. Two batteries operating in parallel, sized such that should one fail the remaining battery can fulfill the mission function without experiencing a depth of discharge greater than 70 percent.
- Voltage Regulation - Major voltage fluctuations to be controlled by a shunt, operating on a portion of the solar array. Bus voltage to be regulated by PWM regulators. Selected bus voltage to be between 30 and 60 V.
- Power Conditioning - Dc/ac inverters will serve spacecraft housekeeping loads requiring ac power. All spacecraft dc loads supplied only with regulated dc power at bus voltage.
- Power Distribution - Power transfers through rotary joints by brush/slip ring assemblies. All other distribution via stranded copper cabling.
- Power Control - Switching and isolating functions controlled by an offline power control unit operated automatically and/or by ground command.

4.4.2 Model Description

The data flow diagram for the prime power subsystem model is shown in Figure 4-20 and its subroutine PPSS is listed in Figure 4-21. The model inputs are spacecraft ac and dc housekeeping power, communication prime power, broadcast time and satellite life. The outputs are BOL prime power, subsystem weight, solar array area and housekeeping power.

The equations used to compute the various parameters and outputs shown in the data flow diagram are given in Table 4-8. The equations were empirically derived, where possible, to ensure realistic representation of current technology. The symbols used in Table 4-8 are defined in Table 4-9.



NOTE NUMBERS IN BRACKETS REFER TO EQUATIONS LISTED IN TABLE 4-8

Figure 4-20. Prime Power Subsystem Model Data Flow Diagram

```
         CSCX FORTRAN V
      SUBROUTINE PPSS(HKPAC,HKPDC,SATLIF,ITIMBC,
     1PWRCOM,MODES,PWRBOL,PPSSWT,PPSHKP,SAAREA)
      PWRINV=HKPAC/0.85
      WTINV=(PWRINV*0.02)+4.0
 25   HKPTOT=PWRINV+HKPDC
      ENGREQ=(HKPTOT*1.2)/(0.88*0.98)
      ENGCAP=2*(ENGREQ/0.36)
      WTBAT=ENGCAP/9.3
      PWRCHG=ENGREQ/(0.94*4.0*0.80)
      WTCHG=2*(0.12*PWRCHG**0.675)
      PWRREG=PWRINV+HKPDC+PWRCOM
      PWRBUS=PWRREG/0.88
      WTREG=0.0724*(PWRREG)**0.915
      IF(ITIMBC-12)40,40,30
 30   PWREOL=PWRBUS+PWRCHG
      GOTO50
 40   PWREOL=PWRBUS
 50   DGRADE=0.05
      PWRBOL=PWREOL/((1.0-DGRADE)**SATLIF)
      IF(MODES-2) 70,60,60
 60   WTSOL=PWRBOL*0.253
      SAAREA=PWRBOL*0.321
      WTDOM=0.0
      WTHRNS=PWRBOL*0.052
      HKDOM=0.0
      GOTO110
 70   IF(PWRBOL-1500.0) 80,90,90
 80   WTSOL=PWRBOL*0.114
      WTHRNS=PWRBOL*0.052
      GOTO100
 90   WTSOL=PWRBOL*0.045
      WTHRNS=PWRBOL*0.026
100   SAAREA=PWRBOL/7.0
      WTDOM=25+0.0025*PWRBOL
      HKDOM=5.0
 110  WTPCU=25.0
      WTSHNT=20.0
      PPSSWT=WTINV+WTBAT+WTCHG+WTREG+WTSOL+WTSHNT+WTPCU
     1+WTHRNS+WTDOM
      PPSHKP=HKDOM
      RETURN
      END
```

Figure 4-21. Subroutine PPSS

TABLE 4-8

PARAMETRIC RELATIONSHIPS FOR MODEL

EQUATION NUMBER	PARAMETRIC RELATIONSHIP AND CONDITIONS
[1]	PWRINV = HKPAC/0.85
[2]	WTINV = PWRINV x 0.2
[3]	ENGREQ = (HKPTOT x 1.2)(0.88 x 0.98)
[3]	ENGCAP = 2 x (ENGREQ/0.70)
[4]	WTBAT = ENGCAP/9.3
[5]	PWRCHG = ENGREQ/(0.95 x 4.0 x 0.8)
[6]	$\text{WTCHG} = 2(0.12 \times (\text{PWRCHG})^{.675})$
[7]	$\text{WTREG} = 0.0724 \times (\text{PWRREG})^{.915}$
[8]	PWRBUS = PWRREG/0.88
[12]	$\text{PWRBOL} = \text{PWREOL}/(1 - \text{DGNRAT})^{\text{SATLIF}}$
[9]	WTSOL = PWRBOL x 0.253 (PWRBOL 200-1200 W, spin-despin)
[9]	WTSOL = PWRBOL x 0.114 (PWRBOL < 1500 W, 3-axis)
[9]	WTSOL = PWRBOL x 0.045 (PWRBOL > 1500 W, 3-axis)
[10]*	See Note
[11]*	See Note
[14]	WTDOM = 25.0 + (PWRBOL x .0025)
[16]	WTHRNS = PWRBOL x 0.052 (PWRBOL ≤ 1500 W)
[16]	WTHRNS = PWRBOL x 0.026 (PWRBOL > 1500 W)
[13]	SAAREA = PWRBOL x 0.321 (spin-despin stabilized)
[13]	SAAREA = PWRBOL x 0.143 (3-axis stabilized)
[15]*	See Note

*NOTE: Insufficient data to compute parametric relationship for these components; therefore, the following values are used.

Shunt Weight = 20 pounds
Power Control Unit Weight = 25 pounds
Orientation Power = 5 watts

TABLE 4-9

SYMBOL DEFINITION

HKPAC = Housekeeping power, ac
HKPDC = Housekeeping power, dc
PWRINV = Power at inverter input
WTINV = Weight of inverter
HKPTOT = Total housekeeping power
ENGREQ = Energy required for housekeeping load (watt-hours)
ENGCAP = Energy capacity of batteries
WTBAT = Weight of batteries
PWRCHG = Charge power required at battery charger input
WTCHG = Weight of chargers
PWRCOM = Power required at input to TWT power supplies
PWRREG = Power output of regulator
PWRBUS = Power input to regulator
WTREG = Weight of regulator
ITIMBC = Broadcast period (hours)
PWREOL = Array output power, end of life
DGRADE = Rate of power degradation due to radiation, percent per year
SATLIF = Satellite design life, years
PWRBOL = Array output power, beginning of life
MODES = Spacecraft stabilization mode indicator
WTSOL = Weight of solar array and deployment
SAAREA = Area of solar array, square feet
WTDOM = Weight of directive orientation mechanism
WTHRNS = Weight of power distribution harness
HKDOM = Housekeeping power required by orientation mechanism
WTPCU = Weight of power control unit
WTSHNT = Weight of shunt assembly
PPSHKP = Prime power subsystem housekeeping power

4.5 STABILIZATION SUBSYSTEM MODEL

4.5.1 Three-Axis Model

The three-axis stabilization subsystem consists of reaction wheels and their controls; sensors, and the associated electronics; a 3-axis gyro package for initial acquisition; and an auxiliary propulsion system (APS). The data flow diagram is shown in Figure 4-22. Subroutine STABSS, which is the subroutine for both the 3-axis and dual spin case, is listed in Figure 4-23. The input parameters are heat dissipation load, antenna diameter, solar array area, antenna dish factor, and antenna pointing error for the basic stabilization subsystem model, and spacecraft lifetime, spacecraft weight and longitude for the APS subsystem. The outputs are stabilization subsystem weight and ac and dc housekeeping power.

4.5.1.1 Weight

The subsystem weight is derived by summing the individual weights of the reaction wheels, sensors, electronics, and 3-axis gyro, and the APS subsystem.

$$W_{SS} = W_{RW} + W_S + W_E + W_G + W_{APS} \qquad (4-4)$$

The weight of the reaction wheels is determined by the required momentum capacity for offsetting disturbance torques. At synchronous orbit, the principal distrubance torque is due to solar pressure. The distrubing torque is the product of the net force and the center of pressure (cp) - center of gravity (cg) offset (δ). An accurate determination of δ is difficult without some knowledge of the satellite configuration and the reflectivities of the effective components. It is, therefore, advantageous to relate the momentum requirements to some relevant parameter as exhibited in existing spacecraft. Figure 4-24 gives the reaction

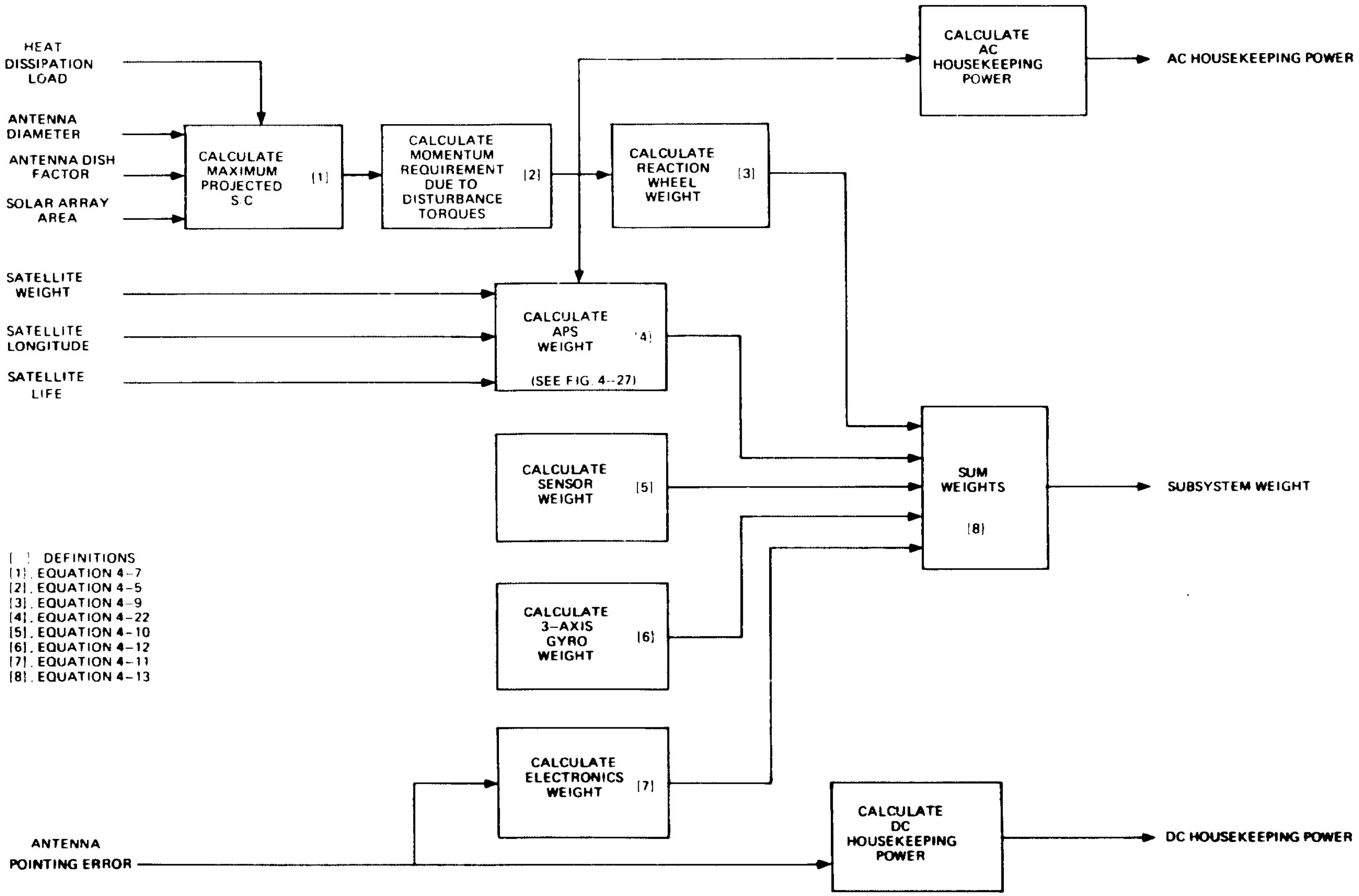


Figure 4-22. Three-Axis Stabilization Subsystem Model Data Flow Diagram

```
     CSCX FORTRAN V
      SUBROUTINE STABSS(ANTDIA,PTERR,SATLIF,MODES,ANTDF,ANGLE,
     1SATWT,HTDL,SAAREA,STABWT,STABDC,STABAC)
      TOTA=SAAREA+0.785*(1.0-ANTDF)*(ANTDIA**2.0)+0.035*HTDL
      H=(6.5E-5)*(TOTA**2.0)
      IF(H-2.1)10,10,20
10    F=1.0
20    F=5.0
30    DV1=64.4*H*SATLIF/(SATWT*5.0)
      DV2=5.79*SATLIF*SIN(2.0*((ANGLE+15.3)*0.0175))
      IF (MODES-2)40,50,50
40    DV3=200.0
      WRW=24.0*H**0.42
      WE=40.0-10.0*PTERR
      WS=32.0
      WG=15.0
      WTC=23.0
      WFW=WRW+WE+WS+WG
      STABDC=90.0
      STABAC=9.0*F
      GO TO 60
50    DV3=250.0
      WDMA=SATWT/50.0
      WS=20.0
      WE=54.0-10.0*PTERR
      WND=10.0
      WTC=15.0
      WFW=WDMA+WS+WE+WND
      STABDC=50.0-10.0*PTERR
      STABAC=0.0
60    DV=DV1+DV2+DV3
      WTACS=WTC+1.18*DV*SATWT/(DV+32.2*200.0)
      STABWT=WFW+WTACS
      RETURN
      END
```

Figure 4-23. Subroutine STABSS

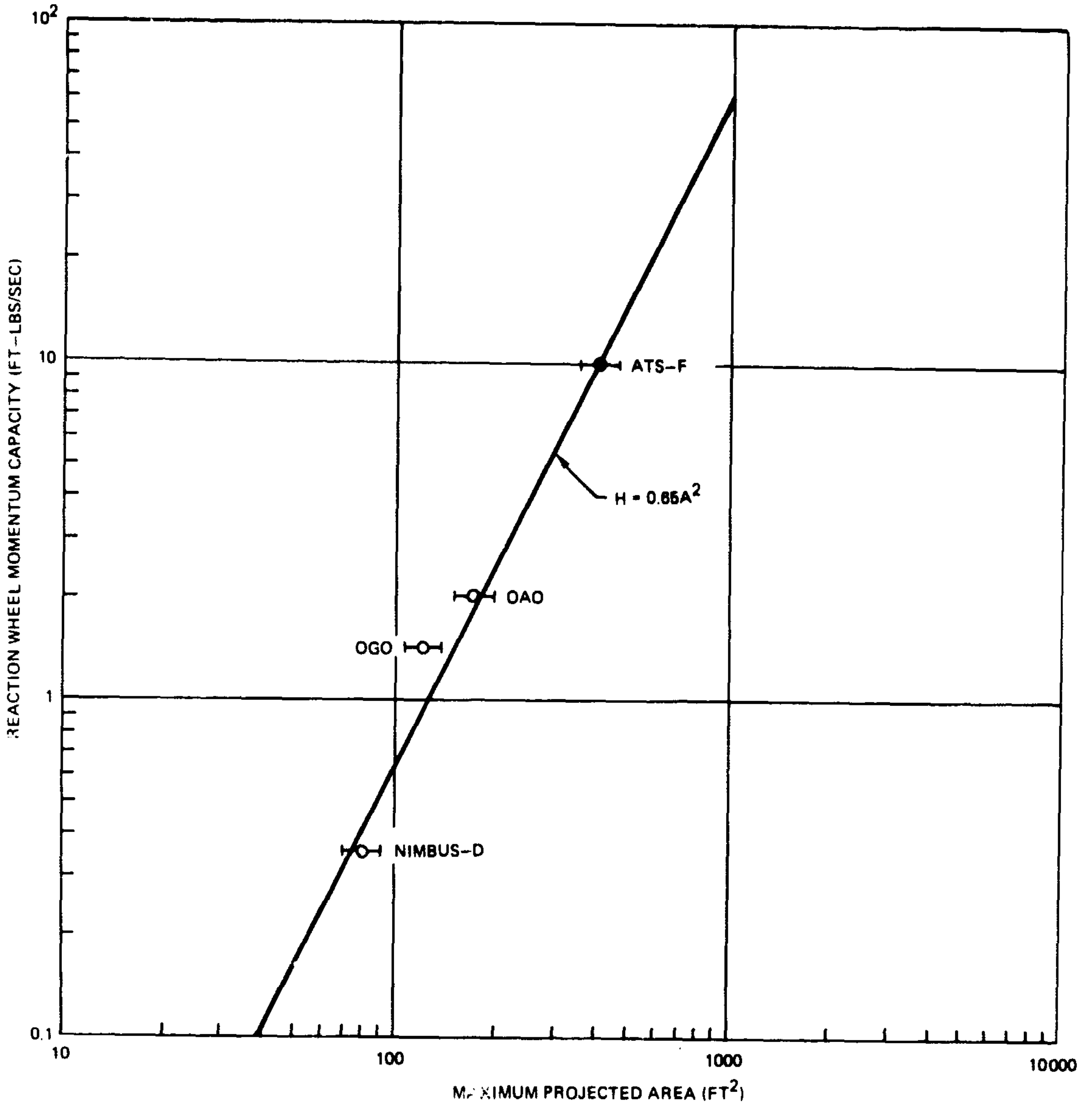


Figure 4-24. Reaction Wheel Momentum

wheel momentum capacity H as a function of the maximum projected spacecraft area A for four satellites (References 4-37 and 4-38). The resulting relationship is:

$$H = 6.5 \times 10^{-5} A^2 \qquad (4\text{-}5)$$

where A is defined to consist of the solar array area, the effective antenna area, and the area of the spacecraft main body. All of these areas are available as a result of calculations made in other subsystem models of the spacecraft. The solar array area is given directly by the prime power subsystem model. The effective antenna area may be calculated from the antenna diameter and dish factor given by the antenna subsystem model. The area of the spacecraft main body may be estimated from the area required for the louvres in the thermal control subsystem model. Hence, the maximum projected spacecraft area is:

$$A = A_S + 0.785\ \beta\ D^2 + 0.38\ A_L \qquad (4\text{-}6)$$

where A_S = solar array area
β = 1 - antenna dish factor
D = antenna diameter
A_L = louvre area

The louvre area may be further related to the heat dissipation load given by the transponder subsystem model to give

$$A = A_S + 0.785\ \beta\ D^2 + 0.35\ H_{DL} \qquad (4\text{-}7)$$

where H_{DL} is the heat dissipation load in watts.

The majority of 3-axis designs to date (NIMBUS, ADVENT, OAO, OGO, VELA, ATS-F) have used reaction wheels manufactured by the Bendix Corporation. Assume that the reaction wheel weights would therefore by typified by the weights exhibited by the Bendix wheels (Reference 4-39). These weights are given in Figure 4-25 as a function of the momentum capacity. The resultant relationship is:

$$W_{RW} = 24\ H^{0.42} \qquad (4\text{-}8)$$

for three axes. Equations 4-5, 4-7 and 4-8 are combined to give

$$W_{RW} = 0.42 \left[A_s + 0.785\ \beta\ D^2 + 0.035\ H_{DL} \right]^{0.84} \qquad (4\text{-}9)$$

The sensor package consists of a polaris sensor for control about the yaw axis and an earth sensor for control about the pitch axis. Sun sensors are used for initial acquisition. Typical weights for these sensors are 10 lbs, 4 lbs, and 0.5 lb, respectively (References 4-37, 4-38, 4-40 and 4-41). For satellite lifetimes greater than 1 year, double redundancy of the earth and polaris sensors is required. The total sun sensor package would typically weigh 4 lbs (References 4-37, 4-40 and 4-41). For the projected 2 to 5 year maximum lifetime, this level of redundancy is sufficient. The sensor package weight W_s would be

$$W_s = 32 \text{ lbs}. \qquad (4\text{-}10)$$

The sensor electronics are typically 1, 3, and 6 lbs. for the sun sensors, polaris tracker, and earth sensors, respectively, to give a total weight of 10 lbs., (References 4-37, 4-38, 4-40 and 4-41). For full redundancy, this value is doubled. The weight of the wheel controls is primarily a function of the required pointing accuracy. Weights of 10 lbs. and 20 lbs. are assumed, respectively, for pointing errors of 10° and 0.1°. This suggests a total electronics weight, with provisions for redundancy of:

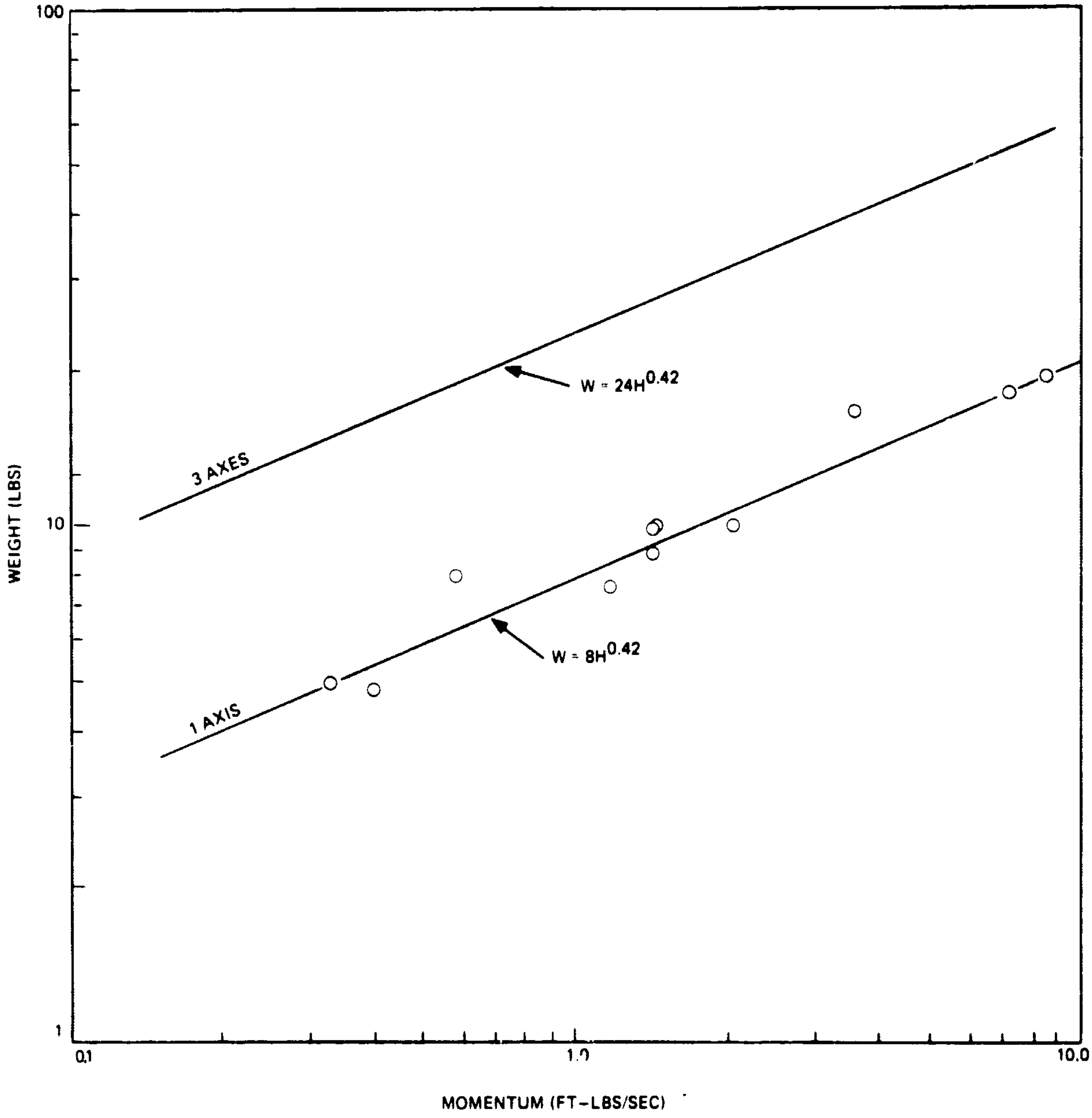


Figure 4-25. Reaction Wheel Weights
(Reference Bendix Corporation)

$$W_E = 40 - 10\ \varepsilon,\ \text{lbs} \qquad (4\text{-}11)$$

The 3-axis gyro package weight W_G has been assumed to be 15 lbs., (Reference 4-37 and 4-38).

$$W_G = 15,\ \text{lbs.} \qquad (4\text{-}12)$$

Combining Equations 4-9, 4-10, 4-11 and 4-12, and adding the weight of the auxiliary propulsion subsystem (see Paragraph 4.5.3) the total weight of the subsystem is:

$$W_{SS} = 0.42 \left[A_s + 0.785\ \beta\ D^2 + 0.035\ H_{DL} \right]^{0.84} - 10\ \varepsilon + 87 + W_{APS} \qquad (4\text{-}13)$$

4.5.1.2 Power

The only requirement for ac power is for the reaction wheels. For momentum capacities less than 2.5 ft.-lb./sec, the stall power is assumed to be 10 watts per wheel; for momentum capacities greater than 2.5 ft.-lb./sec, the stall power is assumed to be 55 watts per wheel, (Reference 4-39). However, the stall power requirement would be encountered infrequently, and in normal operation, the power requirement would be in the order of 20 percent to 30 percent of the stall power. Therefore, assume 3 watts per wheel and 15 watts per wheel for momentum capacities less than 2.5 and greater than 2.5 ft.-lb./sec, respectively, to give a total of 9 and 45 watts of ac power for the three-axis configuration.

The controls for the momentum wheels would consume 5 to 10 watts, depending on the pointing accuracy requirements. The earth and sun sensors would consume about 10 watts and the polaris tracker about 10 watts. The sensor electronics would consume approximately 20 watts. The 3-axis gyro would consume about

30 watts, but would be used only during acquisition, (References 4-37, 4-38, 4-40 and 4-41). Allowing for redundancy, the total dc housekeeping power is 90 watts. An additional 30 watts would be required for initial acquisition.

4.5.2 Spin-Despin Model

The spin-despin stabilization subsystem consists of a Despin Mechanism Assembly (DMA), sensors, electronics and the APS. The flow diagram for the spin-despin subsystem is given in Figure 4-26. The input parameters are total satellite weight, antenna pointing error, satellite lifetime, and longitude. The output parameters are subsystem weight and housekeeping power.

4.5.2.1 Weight

The subsystem weight is determined by summing the weights of the Despin Mechanism Assembly (DMA), the sensors, the electronics, and the auxiliary propulsion subsystem. The minimum weight of a DMA is about 10 lbs. and would be associated with very light spacecraft (in the 500-lb. range). An intermediate DMA weight of 27 lbs. is exhibited in the Phase II satellite, which weighs 1100 lbs. As the satellite weight increases (a 2000 lb. limit is assumed) above this value, the DMA approaches a limiting value of approximately 40 lbs. (Reference 4-42). In light of these observations, the weight of the DMA is estimated by

$$W_{DMA} = W_{SAT}/50 \tag{4-14}$$

The sensor package would consist most probably of earth sensors and sun sensors. Allowing for redundancy for satellite lifetimes of greater than 1 year, the sensor package weight is

$$W_s = 20, \text{ lbs.} \tag{4-15}$$

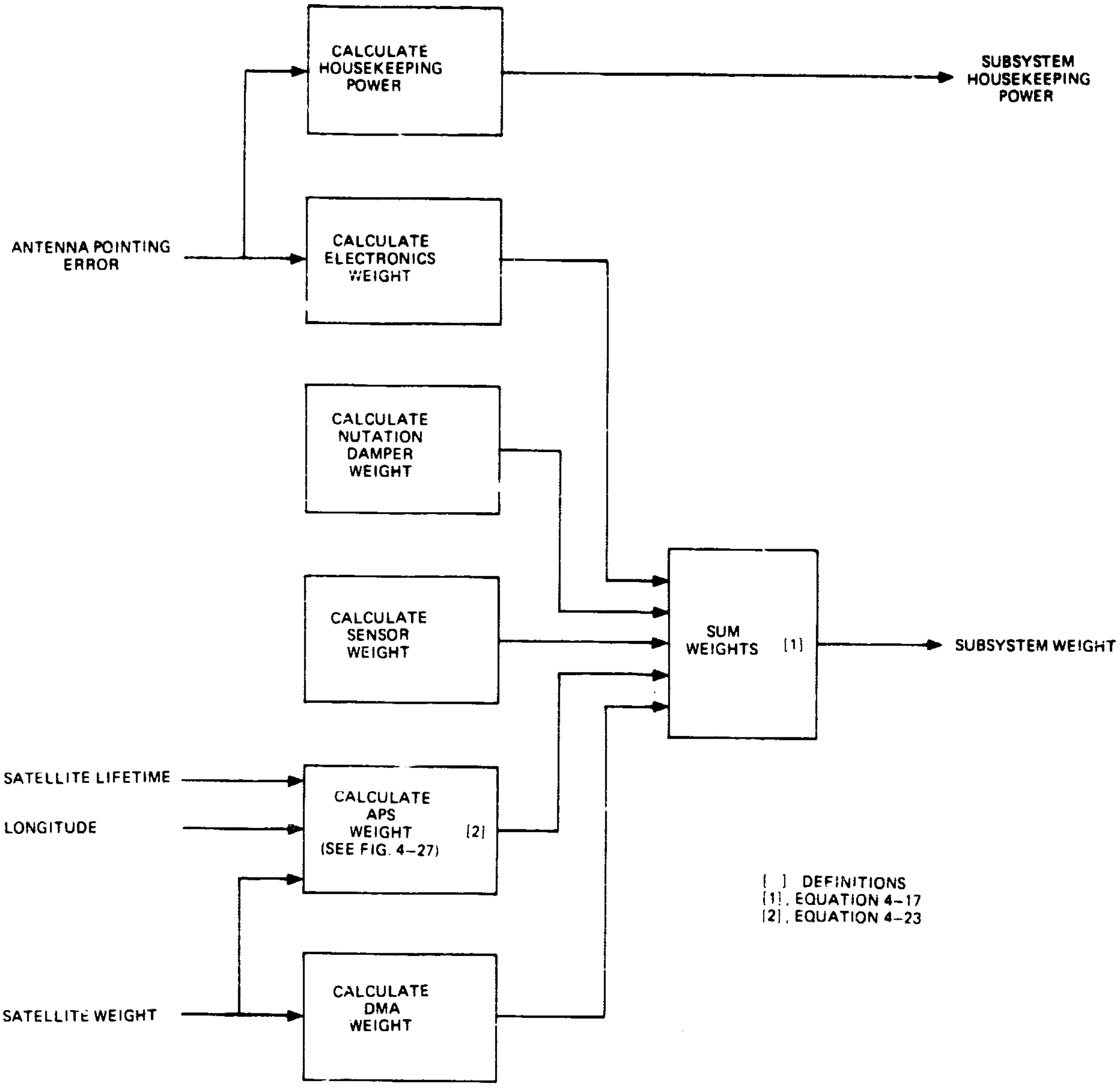


Figure 4-26. Spin-Despin Stabilization Model Data Flow Diagram

The sensor electronics associated with the above attitude sensors would weigh approximately 8 lbs., with another 6 lbs. for redundancy, (References 4-37, 4-41 and 4-42). The electronics associated with the DMA is primarily a function of the pointing accuracy requirements. A weight of approximately 20 lbs. would be associated with a pointing error ε of 0.15°, and a weight of 5 lbs. for a pointing error of 1°, (References 4-37, 4-38 and 4-42). Allowing for redundancy, the electronics package weight is:

$$W_E = 54 - 30\,\varepsilon, \text{ lbs.} \tag{4-16}$$

The weight of the nutation damper is assigned a value of 10 lbs., since several dampers in the 5-lb. range are available, and redundancy is required, (References 4-38, 4-42 and 4-43).

The total subsystem weight, therefore, is:

$$W_{SS} = W_{SAT}/50 - 30\,\varepsilon + 84 + W_{APS} \tag{4-17}$$

4.5.2.2 Power

The housekeeping power required for the DMA is taken to be 10 watts. Five watts is required for the sensors. Approximately 20 watts and 10 watts are required for the electronics for pointing accuracies of 0.15° and 1°, respectively, (References 4-42 and 4-43). Allowing for redundancy, the total housekeeping power is:

$$P = 50 - 10\,\varepsilon, \text{ watts} \tag{4-18}$$

4.5.3 Auxiliary Propulsion System

Two types of attitude control systems have been considered: three-axis stabilization and spin-despin. The propulsion requirements, in terms of ΔV, placed on each of these systems define the APS systems, and from this the weights can be determined. A data flow diagram for estimating the ΔV requirement and weight of the 3-axis and dual-spin auxiliary propulsion systems is shown in Figure 4-27. General References 4-44, 4-45, and 4-46 were used in generating the APS model.

4.5.3.1 ΔV Requirement

For a synchronous equatorial mission, the following requirements on the auxiliary propulsion system are considered:

a. Initial orbital positioning inaccuracies

b. Perturbations due to solar pressure torque

c. East-west station keeping

Initial orbital positioning inaccuracies are due to guidance and AKM performance variations which cause errors in the normal, tangential and radial directions. It is difficult to express the ΔV requirements for correcting insertion errors in terms of specific vehicle performance. Instead, a constant (conservative) value is assumed, as most vehicles currently employ similar guidance systems and have similar 3σ values for synchronous-equatorial launches. The subroutine of the computer program differentiates between missions employing direct insertion and those employing AKMs. AKMs are not used for modeling three-axis satellites. The assumed ΔV requirement for inplane and inclination corrections is 200 feet per second (fps) when no AKM is employed. When an AKM is employed for the spin-despin satellite, an additional error (usually on the order of ±1 percent) is incurred due to deviations from desired performance. This, in turn, produces a possible error of ±50 fps in the burn, necessary to obtain a perfect synchronous orbit. Therefore, considering the effects of booster and AKM as additive, a figure of 250 fps is used for the ΔV requirement when an AKM is employed.

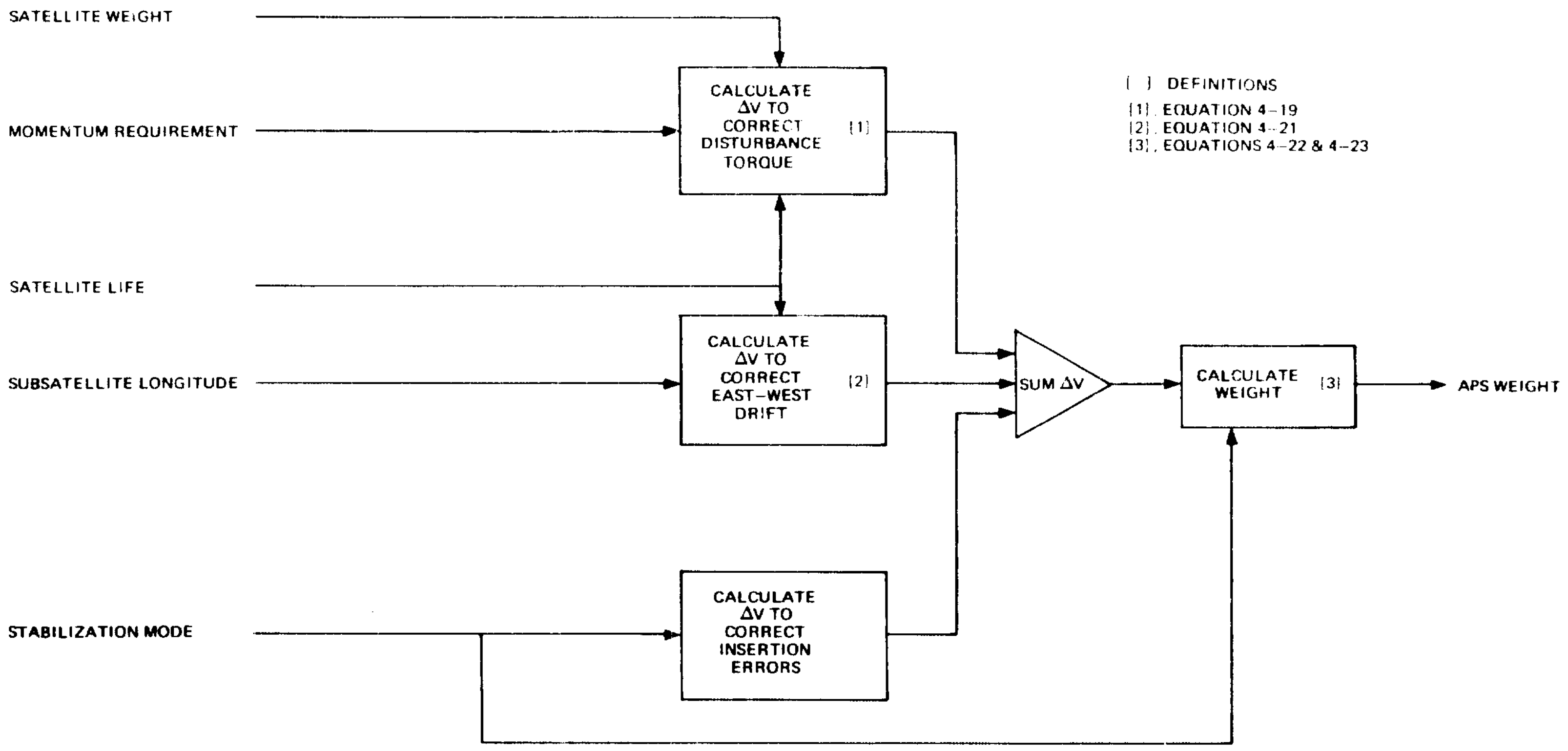


Figure 4-27. Flow Diagram for APS ΔV and Weight Estimations

The momentum requirements imposed on a three-axis stabilized spacecraft in synchronous-equatorial orbit, for offsetting disturbance torques, was given in Equation 4-5. The ΔV_{dt} expenditure to offset this momentum for the three-axis case is:

$$\Delta V_{dt} = \frac{2\ HLg}{ZS} \qquad (4\text{-}19)$$

where H = the momentum requirement
L = the satellite life
g = the gravitational constant
Z = the moment arm of the APS reaction jets
S = the satellite weight

It is assumed that pairs of jets fire simultaneously to create zero translational velocity when unloading the reaction wheels. The amount of propellant required to correct ΔV_{sp} for the three-axis satellite is very small when compared to other factors which comprise the total ΔV. Further, the spin-despin ΔV_{sp} is generally less than the three-axis ΔV_{sp}; therefore, it is considered negligible and is not used in the program.

The ΔV requirement for east-west station keeping is estimated as a function of the subsatellite point. The ΔV requirement is given as

$$\frac{\Delta V}{\text{year}} = 5.79 \sin 2\ (\lambda - \lambda_{22}) \qquad (4\text{-}20)$$

where λ is the subsatellite longitude given as + east and - west, and λ_{22} is the longitude of the earth's semi-major axis. This is currently estimated as -15.4° west. The total ΔV for station keeping is, thus,

$$\Delta V_{SK} = 5.79 \sin 2\ (\lambda + 15.4)\ L \qquad (4\text{-}21)$$

The total ΔV requirement is the sum of the ΔVs due to insertion errors, disturbance torques and station keeping. The primary difference in ΔV requirements between a three-axis and spin-despin system results from the difference in the insertion method, i.e., whether or not a AKM is employed.

4.5.3.2 Weight

The weight of the APS depends primarily on the fuel weight, the tankange and pressurization system, electronics, and thrusters. The fuel weight, in turn, is a function of the total ΔV, the specific impulse of the fuel, the gravitational constant, and the satellite weight. From surveys of existing satellite subsystems, APS tankage and regulated pressurization system weight was typically 18 percent of fuel weight. The electronics weighed about 5 pounds, while thrusters weighed typically 1.5 and 2 pounds each for 3-axis and dual-spin satellites respectively. The 3-axis satellite is assumed to employ 12 thrusters while 4 are assumed for the dual-spin version.

The weight relationship for the APS of a 3-axis satellite is:

$$W_{APS} = 18 + 5 + 1.18 \left(\frac{\Delta V_{total}}{I_{sp}\, g + \Delta V_{total}} \right) S \qquad (4\text{-}22)$$

For the dual-spin satellite:

$$W_{APS} = 8 + 5 + 1.18 \left(\frac{\Delta V_{total}}{I_{sp}\, g + \Delta V_{total}} \right) S \qquad (4\text{-}23)$$

where I_{sp} is 200 seconds, the specific impulse of the fuel. These equations have been integrated into the stabilization subsystem model in the computer program.

4.6 THERMAL CONTROL SUBSYSTEM MODEL

4.6.1 Three-Axis Stabilization Mode

4.6.1.1 Subsystem Configuration

The model is based on a thermal control configuration similar to that shown in Figure 4-28. This is the general configuration adopted for ATS-F, and the model description which follows relies heavily on the ATS-F thermal control design (Reference 4-47). The components of the system are the heat pipe assembly, the louvres, and insulation. In addition, there are miscellaneous items such as paint and thermal grease.

Heat pipes are attached to the radiating surface, e.g., the structure behind the louvres to provide an isothermal surface for maximum radiation efficiency. The most attractive heat pipe fluid for an inner satellite temperature environment of 0 to 200°F is ammonia. The higher temperatures allow for more efficient dissipation; however, one must also satisfy the temperature requirements of the various spacecraft components which generally are in the range of 20 to 120°F. Therefore, ammonia heat pipes are assumed with a satellite design temperature of 80°F. The heat pipes are arranged in the general pattern shown in Figure 4-28 to allow for load sharing between the north and south faces.

The validity of the model is independent of the particular spacecraft and thermal control configuration employed, except for the general layout of the heat pipes. The amount of heat that can be passively radiated, however, is dependent on the spacecraft configuration and antenna diameter because of shroud limitations. Three basic configurations were analyzed to determine the maximum amount of thermal energy that could be dissipated. Figures 4-29, 4-30, and 4-31 depict these configurations for rigid antennas with diameters less than 9 feet, for deployable antennas with diameters up to 50 feet where the main spacecraft body is located behind the antenna, and for deployable antennas with diameters up

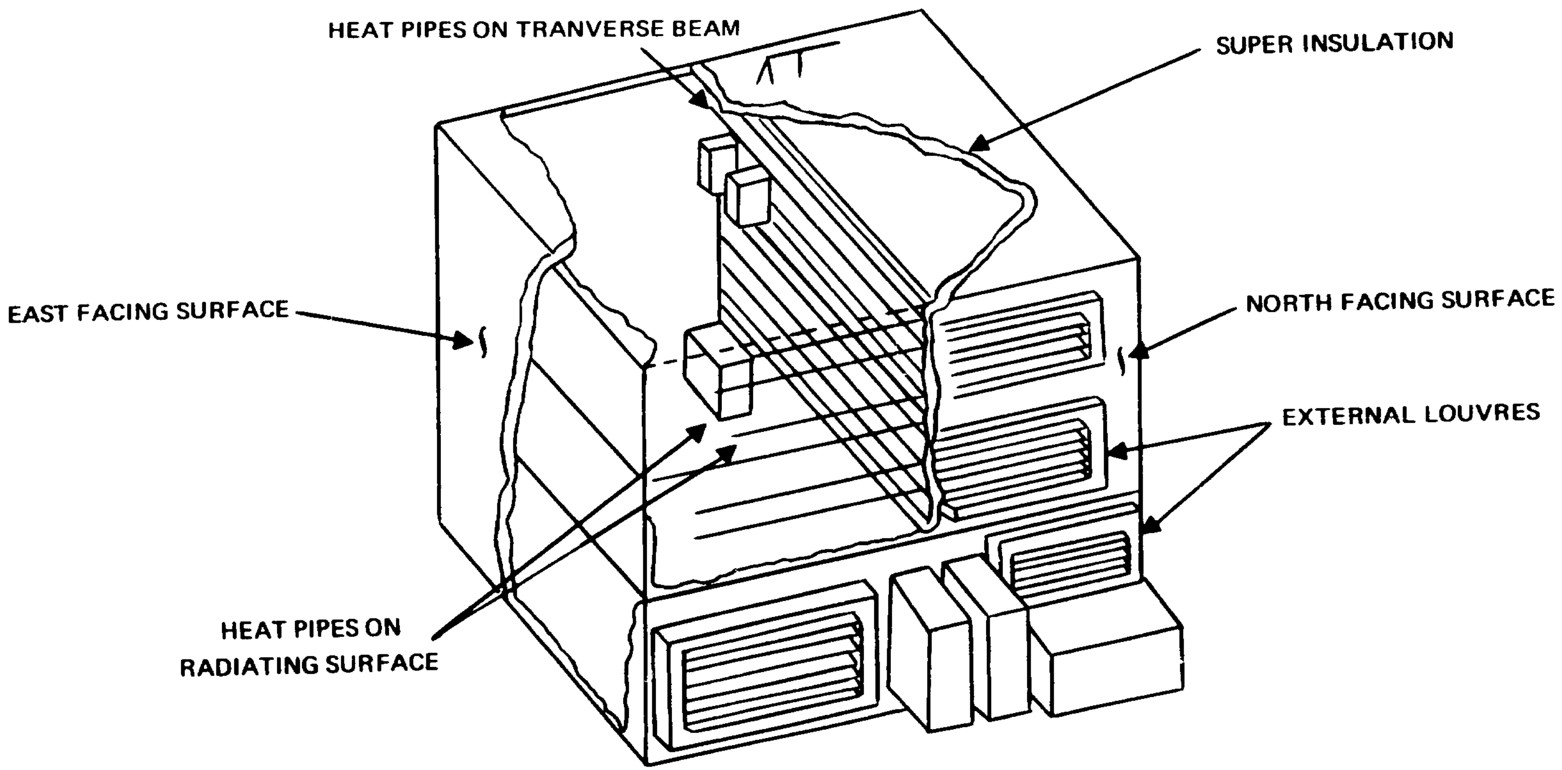


Figure 4-28. Thermal Control Subsystem
(Reference 4-47)

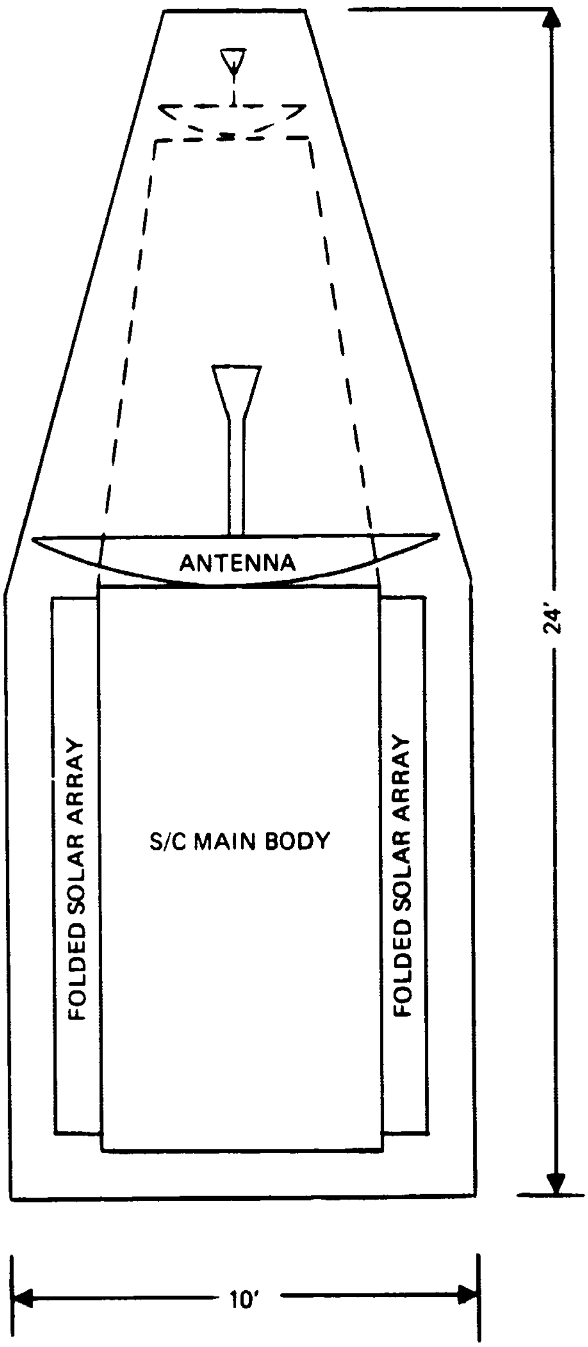


Figure 4-29. Configuration A - Rigid Antenna

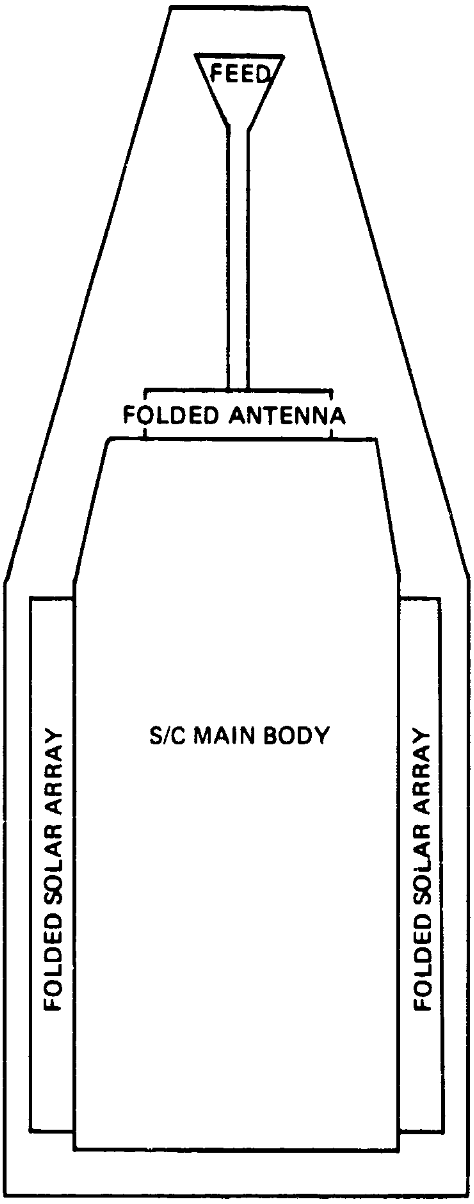


Figure 4-30. Configuration B - Deployable Antenna

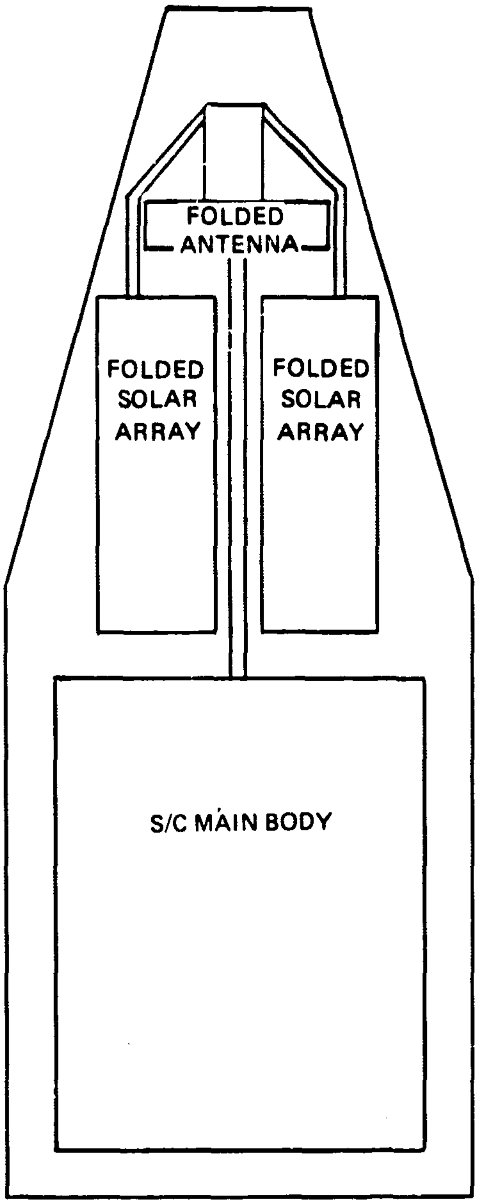


Figure 4-31. Configuration C - Deployable Antenna

to 50 feet where the main spacecraft body is located at the feed of the antenna. The shroud used in each case is the Titan III-C shroud. The results of the analysis are given in Figure 4-32. For Configuration C it was assumed that the maximum ratio of spacecraft body diameter to antenna diameter would be 0.165 to provide a minimum blocking efficiency of 0.90.

It is obvious that Configuration C, while efficient from a comuunications standpoint, is inefficient from a thermal standpoint. Therefore, Configurations A and B are preferred for heat dissipation requirements greater than 1 kilowatt. Configuration C, however, can be adjusted somewhat to provide higher dissipation capability by (1) dissipating on the east and west faces in addition to the north and south faces, thereby approximately doubling the dissipation capability; (2) using variable conductance heat pipes, which would increase the dissipation capability by approximately 40 percent since the louvre system would no longer be needed.

4.6.1.2 Model Description

The data flow diagram for the thermal control subsystem is shown in Figure 4-33 and subroutine THRMSS for the 3-axis and dual spin configurations is listed in Figure 4-34. The model input is heat dissipation load; the output is subsystem weight.

The subsystem weight is the sum of the weights of the heat pipe assembly, the louvres, and insulation. An additional 15 percent is added to cover such items as paint, thermal grease, etc., to give

$$W = 1.15 \, (W_L + W_{HP} + W_{INS}) \qquad (4\text{-}24)$$

A louvre system can dissipate from 20 to 38 watts per square foot (watts/ft^2) for a sun incidence angle of 67° to 90° (Reference 4-47), or alternatively, 23° to 0° above the plane of the louvre. Assuming that the louvre faces would be placed on the north and

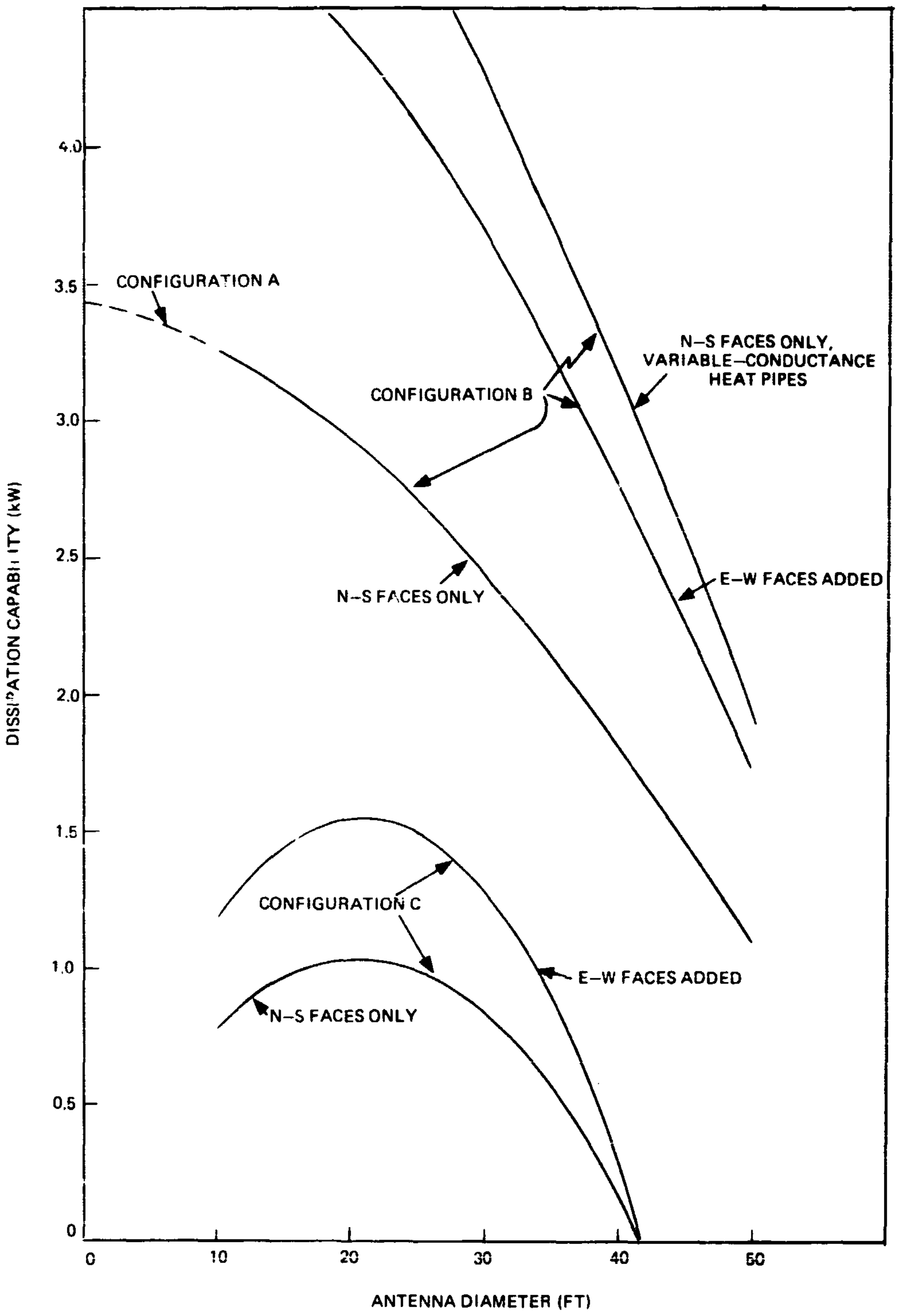


Figure 4-32. Dissipation Capability vs. Antenna Diameter

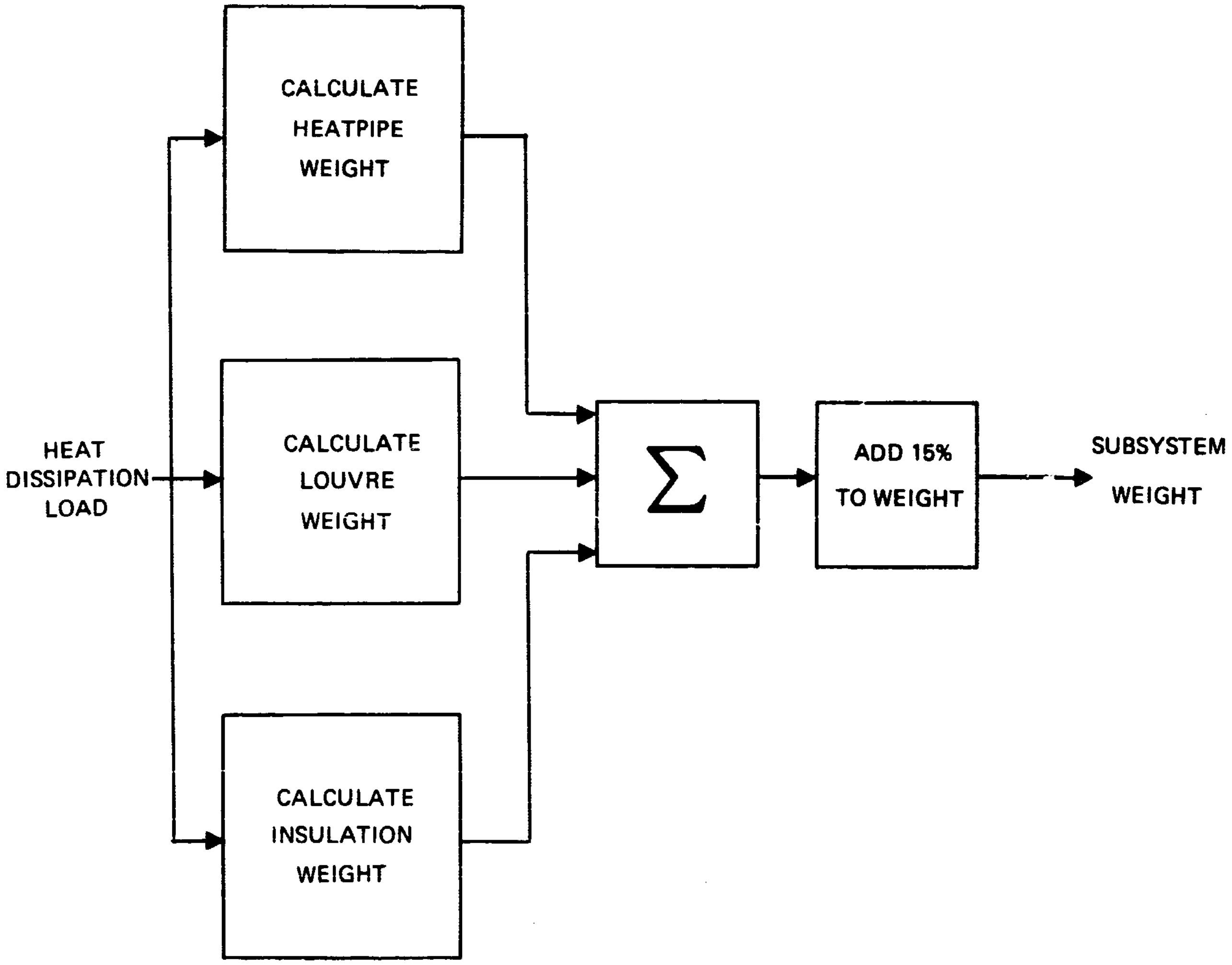


Figure 4-33. Thermal Control Subsystem Model Data Flow Diagram

```
         CSCX FORTRAN V
      SUBROUTINE THRMSS(HTDL,PWRBOL,MODES,THRMWT
      IF(MODES - 2)10,20,20
10    WLOUV=0.07*HTDL
      WHP=0.08*HTDL
      WINSUL=0.04*HTDL
      THRMWT=(WLOUV+WHP+WINSUL)*1.15
      GO TO 30
20    THRMWT=100.0*(PWRBOL/1000.0)**2.0
30    RETURN
      END
```

```
         CSCX FORTRAN V
      SUBROUTINE TTANC(MODES,TTCWT,TTCHKP)
      IF (MODES-2)10,20,20
10    TTCWT=50.0
      TTCHKP=20.0
      GO TO 30
20    TTCWT=40.0
      TTCHKP=15.0
30    RETURN
      END
```

```
         CSCX FORTRAN V
      SUBROUTINE STRUCT(SATWT,MODES,STRWT)
      IF(MODES-2)10,20,20
10    STRWT=0.15*SATWT-75.0
      GO TO 30
20    STRWT = 0.18* SATWT
30    RETURN
      END
```

Figure 4-34. Subroutines THRMSS, TTANC, and STRUCT south sides of the satellite, in the worst condition one face would be dissipating 38 watts/ft^2 while the other would be dissipating 20 watts/ft^2. To allow for the worst condition, assume that each face dissipates 20 watts/ft^2. The weight of the louvre system is estimated to weigh 1.4 lbs/ft^2 (Reference 4-48), therefore,

$$W_L = 70\ H_{DL} \tag{4-25}$$

where H_{DL} is the number of kilowatts of heat to be dissipated.

The heat pipes would be spaced 3 inches apart and would weigh 0.2 lb per linear foot, for the assumed configuration. This gives a weight density of 1.2 lbs/ft^2 of radiating surface (References 4-47 and 4-48). Assume as an engineering objective a louvre area utilization of 75 percent. For a louvre dissipation of 20 watts/ft^2, the weight of the heat pipe assembly is

$$W_{HP} = 80\ H_{DL} \tag{4-26}$$

The insulation required in the ATS-F EVM weighs approximately 20 lbs (Reference 4-48). Since there are no other designs near or above the ATS-F heat dissipation level it is assumed that the insulation weight increases linearly with dissipation requirements to give

$$W_{INS} = 40\ H_{DL} \tag{4-27}$$

4.6.1.3 Spin-Despin Stabilization Mode

Comparison of several spin-despin satellites, e.g., Phase II, Intelsat IV, etc., shows that it is difficult to estimate the weight of the thermal control subsystem on a component basis since these weights (e.g., insulation, etc.) can vary considerably with the satellite configuration. It is therefore useful to estimate this weight on some bulk satellite characteristic related to the thermal dissipation requirements. Data on the amount of thermal energy to be dissipated on existing satellite designs is difficult to find, but the related parameter, beginning of life prime power, is more readily available. Figure 4-35 gives the thermal control subsystem weight as a function of beginning of life prime power for Intelsat IV (Reference 4-49), Phase II (Reference 4-50), and Intelsat III (Reference 4-51). The correlation is very good; therefore, this approach for estimating the weight of the spin-despin thermal control subsystem is used in the model. The resultant thermal control subsystem weight is

$$W = 100\ P_p^2 \qquad (4\text{-}28)$$

where P_p is given in kilowatts of beginning of life prime power.

4.7 TT&C SUBSYSTEM MODEL

The requirements imposed on a TT&C subsystem cannot be accurately defined without a detailed spacecraft design. However, an estimate can be formulated by investigation of the range of weights and power levels of TT&C subsystems on existing and proposed spacecraft. CSC has evaluated five candidate TT&C subsystems (Table 4-10).

One would expect the broadcasting satellite's TT&C subsystem to weigh less than that of Phase II, which includes telemetry encryption and command decryption equipment. Similarly, one would expect the weight to be less than that of the ATS-F TT&C subsystem, which must provide for the monitoring of many experiments. The extensive monitoring present on Intelsat IV more closely parallels the type of monitoring required on the broadcasting satellite. This arises partially from the fact that a significant amount of monitoring would be required for the broadcasting satellite because of the projected use of large solar arrays and high-power dissipation in the three-axis stabilization mode. This is supported by the weight assigned to the TT&C subsystem by RCA in the study of a voice broadcast satellite. The weight figure cited by GE is low because of the lack of redundancy. With lower dissipation levels and body-mounted arrays projected for the spin-despin design, some reduction in TT&C weight would be expected.

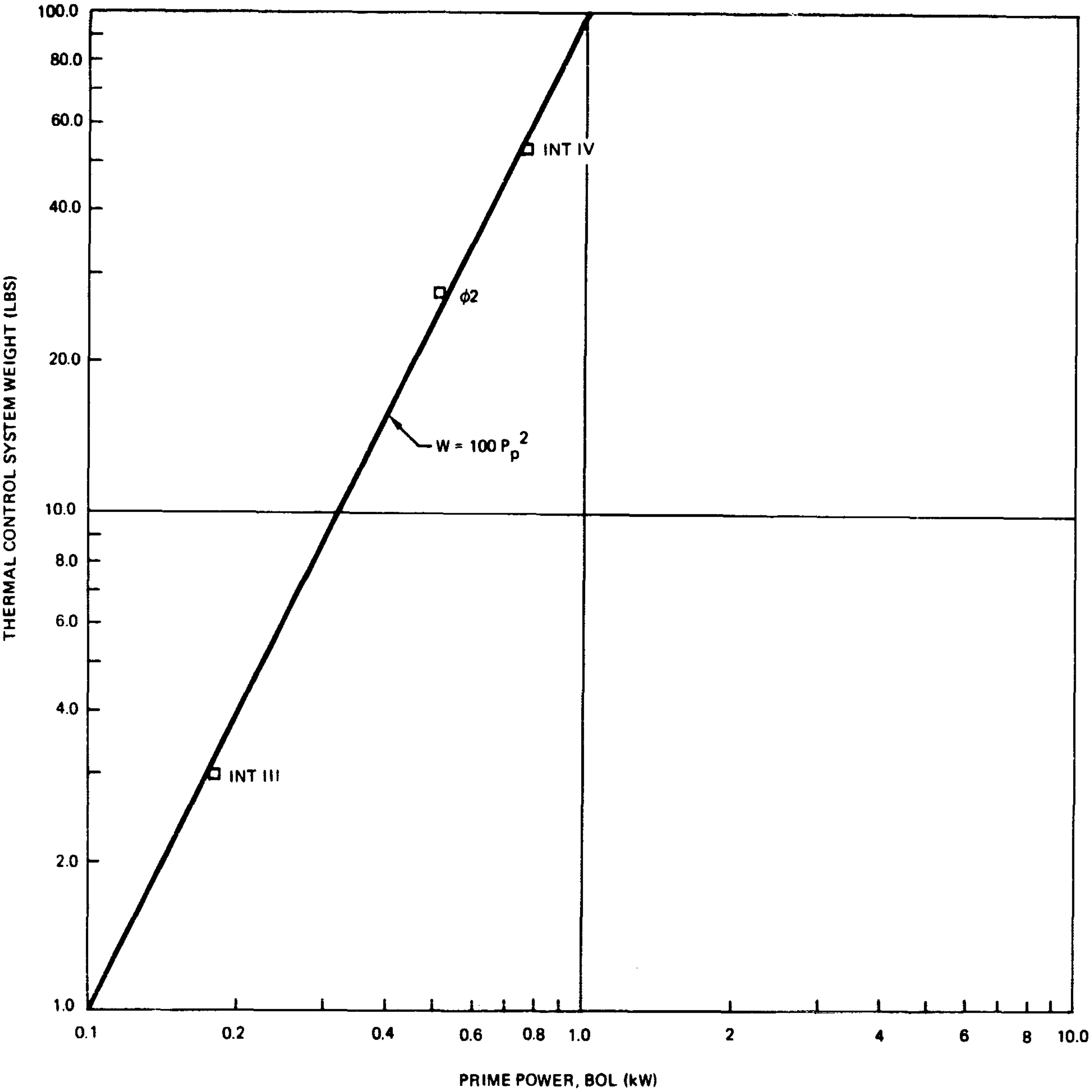


Figure 4-35. Thermal Control Subsystem Weight (Dual Spin)

In light of the above observations, it is reasonable to assume a TT&C weight of 50 pounds in the three-axis stabilization mode and 40 pounds in the spin-despin stabilization mode. Using the power requirements listed in Table 4-10 as a basis, the power requirements for these two modes would be 20 watts and 15 watts, respectively. The associated subroutine TTANC is listed in Figure 4-34.

TABLE 4-10

TT&C WEIGHT AND POWER LEVELS FOR TYPICAL SPACECRAFT

SPACECRAFT	WEIGHT (lbs)	POWER (Watts)
Phase II	73	50
ATS-F	64	37
Intelsat IV	49	20
RCA VBS Study	50	Unknown
GE TVBS	20	10

4.8 STRUCTURAL MODEL

A number of factors influence the size and shape of a communication satellite; the principal ones are:

1. Requirements imposed by desired antenna
2. Housing for equipment and propulsion system
3. Interface with launch vehicle and fairing
4. Mounting and deployment of solar cells

All of these, together with a host of details, must be considered in arriving at a satellite configuration.

To keep weight low, the basic structure of all satellites is usually made from alloys of magnesium, aluminum, or titanium. For a communications satellite the most practical structure, from the point of view of strength-to-weight as well as convenience in distributing and attaching equipment, is normally a shell, either relying on the skin of the shell alone for strength (monocoque) or utilizing some type of reinforcing member in the skin (semimonocoque). Typical 3-axis attitude-controlled satellites use rectangular structures for simplicity in thermal control and mounting of components.

Before the satellite is placed in orbit, it undergoes a variety of loads: assembly loads caused by its own weight, thermal differentials, residual stresses from manufacturing processes, transportation and handling loads, and launch accelerations. Once in orbit only thermal and residual stresses remain, along with mild g loads from whatever attitude and orbit control accelerations are required. Assuming a satisfactory temperature control system for the satellite, the fact that its structure is designed to withstand the pre-orbital stresses will more than adequately take care of the in-orbit stresses. The balance of weights in the satellite and careful location of the center of gravity are, however, essential for orbital operations, whether the satellite is spin-stabilized or maintained as a stable platform. If mass is ejected from the satellite, as in gas expulsion, the effects on the center of gravity must be anticipated or, as is usual, balanced so that the center of gravity does not change. If an antenna or a solar cell surface is reoriented in orbit, the shift in location of mass must be accomplished symmetrically.

It is often necessary to construct a prototype structure and thoroughly test its reaction under loads, before an accurate estimate can be made of structural weight. Thus, for the purposes of modeling it is necessary to determine a simplified approach to estimating structural weight. Therefore, previous structures of satellites are considered in order to estimate structural weight as a percentage of total spacecraft weight. Figures 4-36 and 4-37 show the results of the survey. Tables 4-11 and 4-12 define the points on the respective figures.

Examining Figure 4-36, the slope of the curve through the nine points, representing the nine satellites in Table 4-11, is approximately 18 percent. This is the value assumed to predict structure weight for spin-despin satellites in the parametric model.

Examining Figure 4-37, two curves have been constructed, the upper curve (dotted line) represents those satellites that have actually flown or are soon to fly, that are three-axis stabilized. The lower curve (solid line) is more representative of current design studies. The upper curve indicates that structure has been about 18 percent of total satellite weight less 150 pounds for flown version of three-axis satellites. The lower curve indicates that current design trends are about 12 percent structure. It is quite important to note that the data points on the upper curve are those of predominately "applications" type satellites (OAO, OGO, Nimbus) while those on the lower curve represent communication satellite designs. Therefore, the model curve is chosen to be 15 percent of total satellite weight less 75. The associated subroutine STRUCT is listed in Figure 4-34.

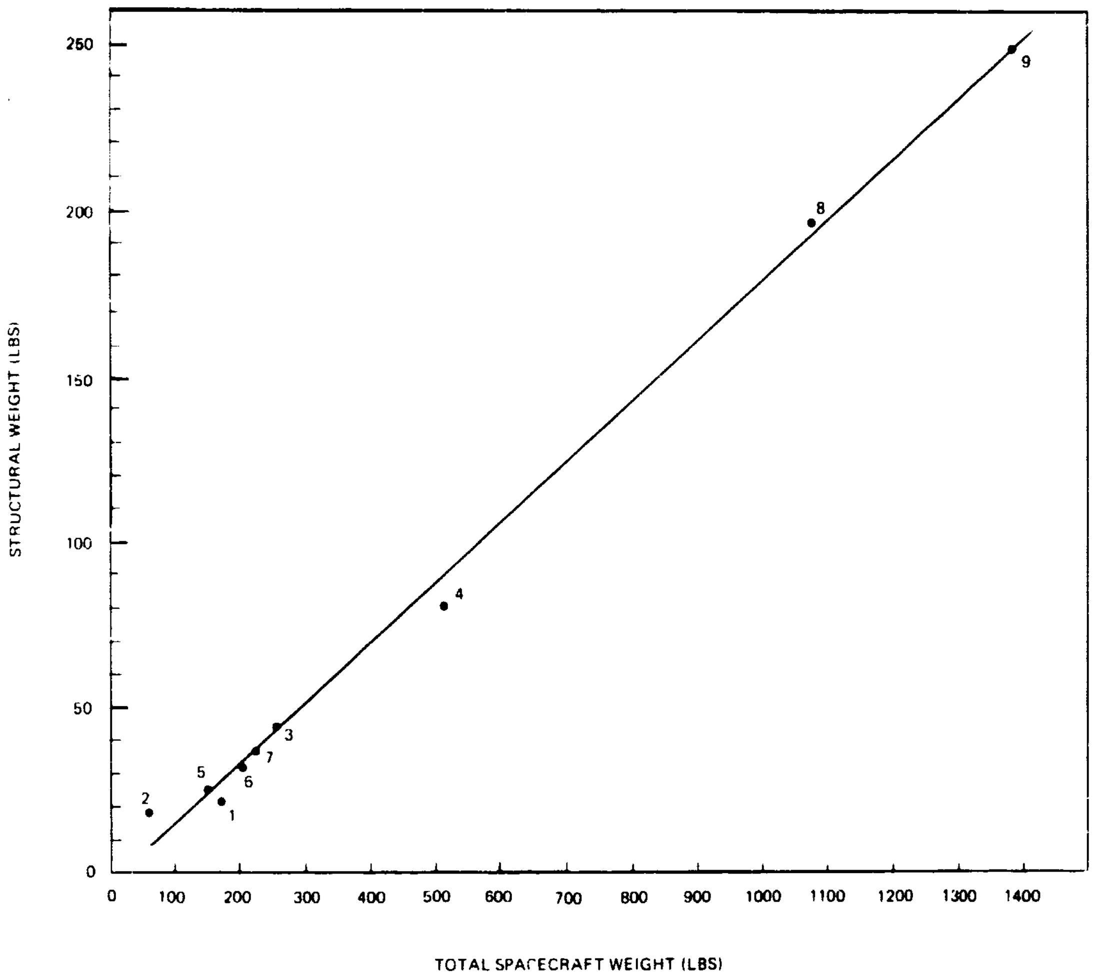


Figure 4-36. Structural Weight of Spin-Despin Satellites

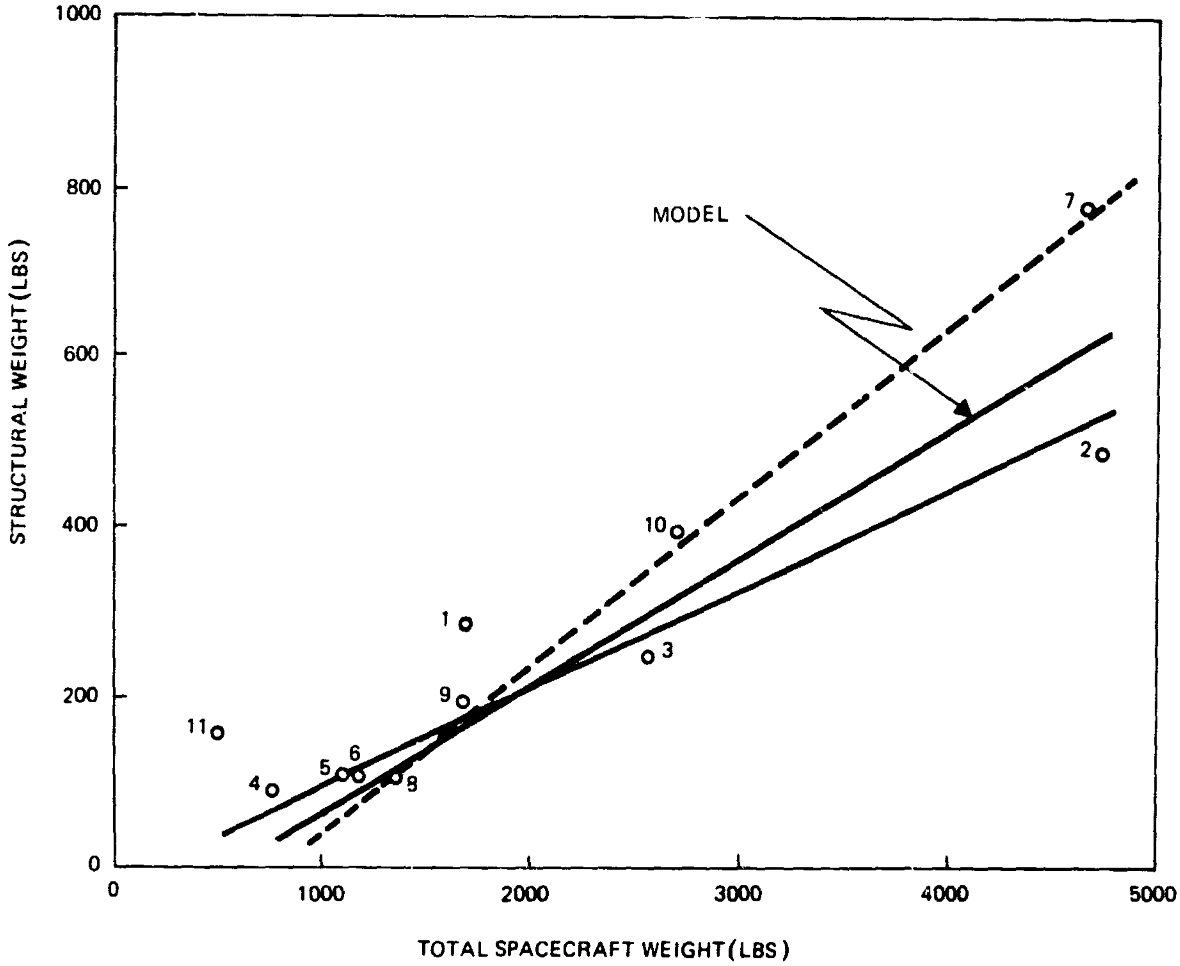


Figure 4-37. Structural Weight of Three-Axis Satellites

TABLE 4-11
STRUCTURAL DATA ON SPIN-DESPIN SATELLITES

Satellite	Stabilization	Structure	* Total	%	Status	Points
TELSTAR	Spin	22.0	175.0	12.6	Flown	1
RELAY	Spin	19.5	68.0	33.2	Flown	2
INTELSAT III	Spin	46.0	255.0	18.3	Flown	3
ADV. SYNCOM	Spin	82.6	511.1	16.2	Study	4
SYNCOM-D	Spin	26.5	150.5	17.7	Study	5
HUGHES PHASE II	Spin	32.0	204.0	15.7	Study	6
HUGHES PHASE II	Spin	39.0	222.9	17.5	Study	7
TRW PHASE II	Spin	197.0	1075.0	18.3	Design	8
CSC FLEETSAT	Spin	250.0	1395.0	17.9	Study	9

TABLE 4-12
STRUCTURAL DATA ON 3-AXIS SATELLITES

Satellite	Stabilization	Structure	* Total	%	Status	Points
GE ATS F&G	3-axis	296.5	1626.0	18.2	Study	1
GE TVBS (HF)	3-axis	480.0	4741.0	10.0	Study	2
GE TVBS (VHF1)	3-axis	250.0	2560.0	9.8	Study	3
GE TVBS (VHF2)	3-axis	80.0	771.0	10.4	Study	4
GE TVBS (UHF)	3-axis	120.0	1126.0	10.7	Study	5
CSC FLEETSAT	3-axis	120.0	1173.0	10.2	Study	6
OAO B	3-axis	785.0 (3)	4660.0	16.8	Flown	7
OGO 6	3-axis	116.3	1369.4	8.5	Flown	8
NIMBUS 5	3-axis	200.0 (1)	1700.0	11.7	Design	9
FH ATS F	3-axis	400.0	2750.0	14.5	Design	10
SYMPHONIE A	3-axis	156.0 (2)	490.0	31.8	Design	11

*Does not include weight of any AKMs.

1) Additional structure is provided by spacecraft attitude control system and experiment packages.
2) Includes both structure and thermal control.
3) Mechanical mechanisms, and forward baffle not included.

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4-26 Private communications with personnel at Peninsula Microwave, Mountain View, Calif.

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SECTION 5

COST MODELS AND LAUNCH VEHICLE SELECTION

This section includes a description of the costing models and launch vehicle selection matrix used by the Main Line program to calculate the costing data required to generate the final performance/cost tradeoff curve.

5.1 GROUND SEGMENT COST

The ground terminals considered in the model are "low cost" configurations, representative of community type installations. The ground segment cost is the sum of the costs of the antennas and the receiver. The receiver consists of a FM to AM converter and a preamplifier as an option.

5.1.1 Antenna Cost Model

The cost of a receiving antenna for community repection depends mainly upon the size of the dish, which governs its beamwidth and directive gain, and the construction which affects efficiency and hence power gain. Two types of antennas are considered for purposes of generating a cost data base. The first type has an aluminum reflector and is well constructed which results in a relatively high efficiency and cost. The second type has a less expensive reflector, e.g., one employing either mesh or aluminum-coated plastic cloth. The cost of this type is lower and if carefully designed, the gain will compare favorably to that of the solid reflector type. However, the reliability and lifetime will be degraded somewhat.

Figure 5-1 shows antenna cost for various quantities and diameters as quoted by antenna manufacturers, CCIR and NASA. The source and type of the data used in Figure 5-1 is defined in Table 5-1. It is known that when dealing with a very large

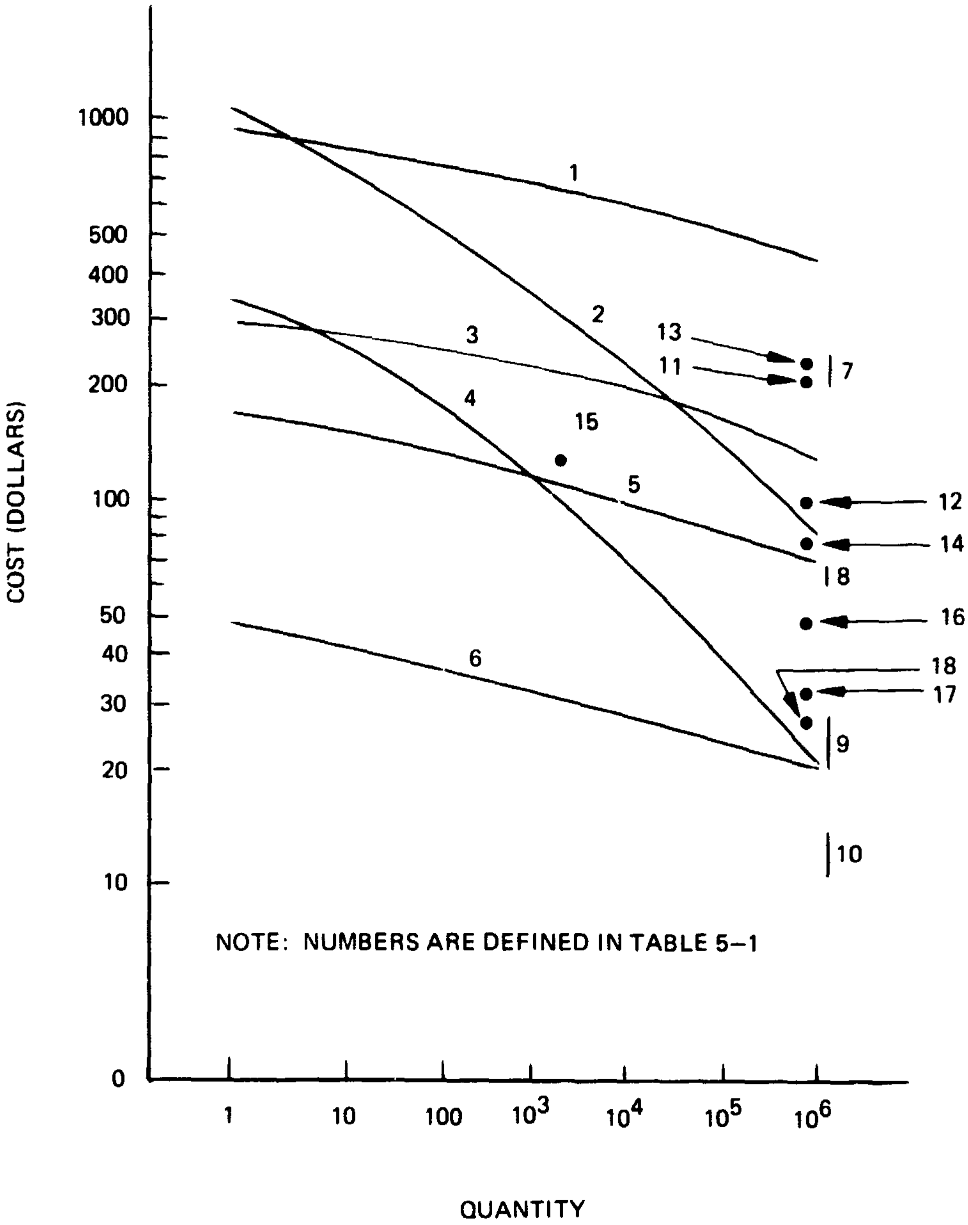

Figure 5-1. Antenna Cost

TABLE 5-1

DEFINITION OF ANTENNA DATA USED IN FIGURE 5-1

NUMBER ON FIGURE 5-1	ANTENNA DESCRIPTION	REFERENCE
1	GE 10 foot	5-2
2	CCIR 10 foot	5-1
3	GE 5 foot	5-2
4	CCIR 5 foot	5-1
5	General Dynamic 10 foot	5-4
6	General Dynamic 5 foot	5-4
7	10 foot price range of Technical Appliance Corp. (TACO)	
8	10 foot price range of Finney Co.	
9	5 foot price range of Lapointe Industries, Inc.	
10	5 foot price range of Finney Co.	
11	TRW 10 foot	5-5
12	TRW 5 foot	5-5
13	TRG (CDC) 10 foot	
14	TRG (CDC) 5 foot	
15	GE 10 foot mesh antenna	5-3
16	7 foot price estimated by Stanford University	5-7
17	7 foot price estimated by Lewis Research Center, NASA	5-8
18	7 foot Finney Co. Consumer quality UHF TV antenna	

quantity, the price is mainly a function of the cost of the material. The prices at $Q = 10^6$ can be broken down into two cost groups for the 5-foot dish. The dividing line is about $50.00.

The average price of the upper group is about $100.00 and that of the lower group is about $20.00 for the 5-foot dish. The same type of feed, i.e., a feed tube and a helix costing about $10.00, is assumed for both antenna types. Thus, the difference in price of the two types of antennas is mainly due to the reflector. The lower cost antennas can be thought of as representing consumer type quality and are chosen as representative of community receiving antennas.

The model cost vs. quantity curve is based on the GE and CCIR data for quantity one and on GD and CCIR data for quantity 10^6. The resulting price-quantity variation is equivalent to an 86 percent manufacturing learning curve. The mathematical expression for antenna cost of quantity one is:

$$C = 177.50 + 2.74\, D^{2.5}, \text{ dollars} \qquad (5\text{-}1)$$

where C = antenna cost for Q = 1
D = antenna diameter in feet

The 86 percent manufacturing learning curve can be expressed as:

$$\begin{aligned} \log QF = {} & 1.889\,(10^{-3}) - 0.144 \log Q \qquad (5\text{-}2) \\ & - 1.446\,(10^{-2})(\log Q)^2 \\ & + 9.453\,(10^{-4})(\log Q)^3 \end{aligned}$$

where QF = quantity factor
Q = antenna quantity

The cost of one antenna ANTCT of the quantity of Q is:

$$ANTCT = C\ QF \qquad (5\text{-}3)$$

The flow chart of subroutine ANCTP, for calculating per unit antenna cost, is shown in Figure 5-2 and the subroutine is listed in Figure 5-3. The inputs are antenna diameter in meters and quantity. The output is ANTCT. Table 5-2 shows representative antenna costs based on the computer model. The costs are estimates of the selling price of the antennas as opposed to factory costs.

TABLE 5-2

ANTENNA COST BASED ON MODEL

DIAMETER	$Q = 10^3$	$Q = 10^6$
5' dish	$ 96.00	$ 21.70
10' dish	$303.20	$ 68.50

5.1.2 Receiver Cost Model

The receiver considered for the model consists of a preamplifier/FM to AM converter at the TV set. The TV set is not considered in the cost model. Three types of preamplifiers are suitable for community type receivers at 620 to 790 MHz and 2.50 to 2.69 GHz, i.e., transistor, tunnel diode and uncooled parametric amplifiers. The transistor preamplifier is not applicable at 11.7 to 12.2 GHz. Receivers employing these preamplifier types plus the option of no preamplifier, are considered for the model. The corresponding receiver noise temperatures used in the model are taken from Reference 5-1.

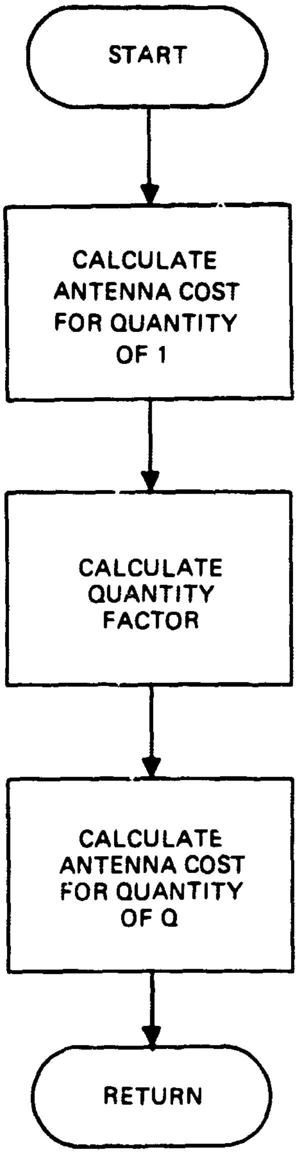

Figure 5-2. Flow Chart of ANCTP

```
ANCTP,ANCTP
            CSCX FORTRAN V
         SUBROUTINE ANCTP (D,Q, ANTCT)
   C     D=ANT. DIA  - Q=TOTAL QUANTITY
   C     ANTCT=TOTAL UNIT COST IN DOLLARS
         DF=D/0.3048
         X=ALOG(Q)/ALOG(10.)
         C0=1.889*10**(-3)
         C1=-0.144752
         C2=-1.4466*10**(-2)
         C3=9.453*10**(-4)
         Y=C0+C1*X+C2*X**2+C3*X**3
         QI=10**Y
         ANTCT=(177.5+2.74*DF**2.5)*QI
         RETURN
         END
```

Figure 5-3. Subroutine ANCTP

The costs of the different types of receivers are also given in Reference 5-1, which was written in 1969. Nevertheless, the costs are in reasonable agreement with some recent reports (References 5-5, 5-6, 5-7 and 5-8) and conversations over the telephone with Avantec, Aerospace Research Inc., Anzac Electronics, Applied Research Inc., Sanders Associates, etc. Representative converter costs (no preamplifier) are shown in Figure 5-4 and the source and type of data is defined in Table 5-3. Costs of receivers with transistor, tunnel diode and parametric preamplifiers given by CCIR, GE and TRW are listed in Table 5-4. From Figure 5-4 and Table 5-4, it can be seen that receiver cost is a function of quantity and frequency.

In the computer program the receiver costs at $Q = 10^6$ are based on Reference 5-1. The variation of cost with quantity is taken from Reference 5-8. The variation is a function of frequency and initial cost, which is a function of the beginning production year.

The flow chart for computing receiver costs is shown in Figure 5-5 and the subroutine RCCST is listed in Figure 5-6. The inputs are frequency, required noise temperature, quantity, beginning year, and the preferred receiver. The outputs are receiver cost and type.

The program first selects the proper kind of preamplifier by inputting the required noise temperature. The corresponding receiver cost is calculated by-knowing the frequency, quantity and beginning year. The user can also select a particular type of receiver and the program calculates the corresponding unit cost and indicates whether the receiver satisfies the required noise temperature or not.

Table 5-5 shows some representative receiver costs based on the computer model. Again these are estimates of selling price, rather than factory cost. Table 5-6 illustrates receiver noise temperatures used in the model.

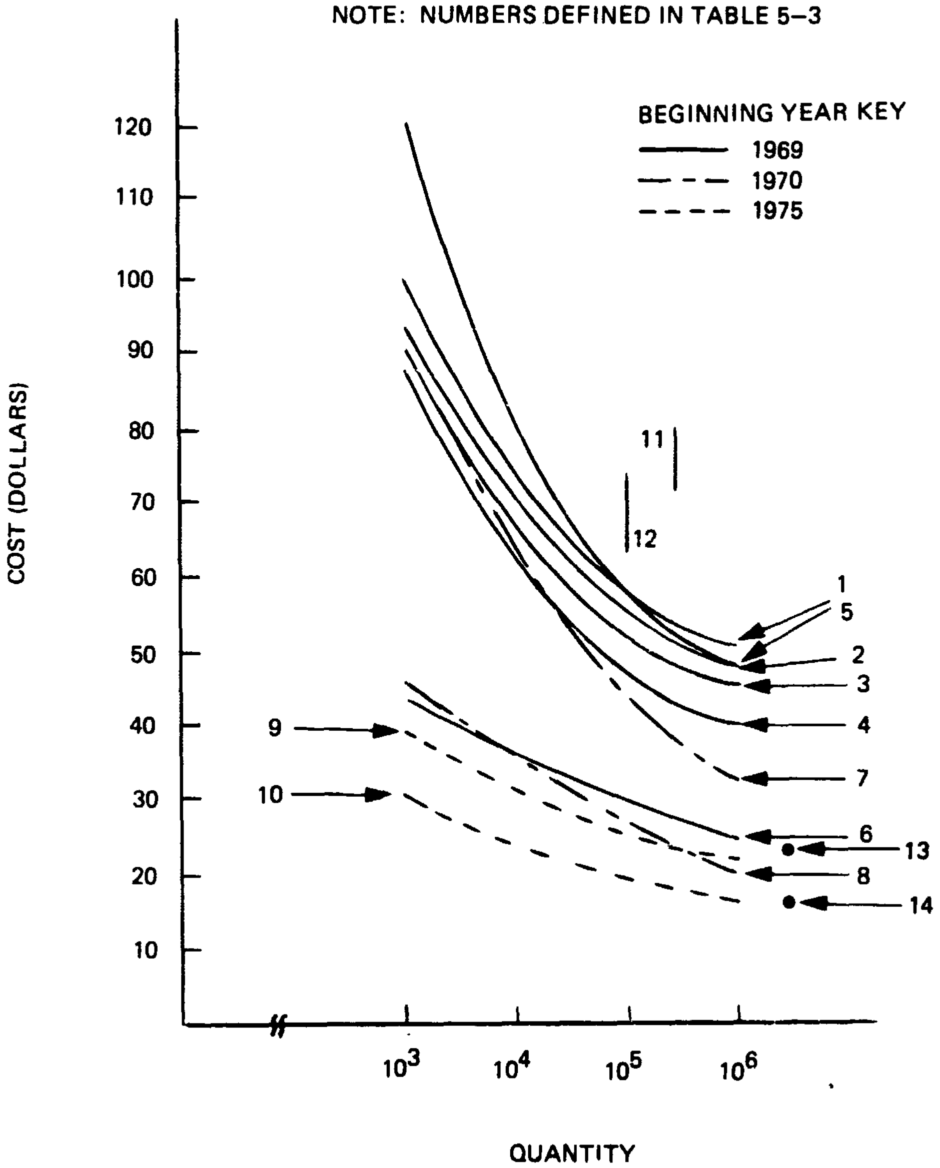

Figure 5-4. Converter Cost (No Preamplifier)

TABLE 5-3

DEFINITION OF CONVERTER DATA USED IN FIGURE 5-4

NUMBER ON FIGURE 5-4	CONVERTER DESCRIPTION	REFERENCE
1	CCIR 12 GHz	5-1
2	CCIR 8.5 GHz	5-1
3	CCIR 2.25 GHz	5-1
4	CCIR 0.8 GHz	5-1
5	GE 12 GHz	5-6
6	GE 2.25 GHz	5-6
7	NASA (Lewis) 12 GHz	5-8
8	NASA (Lewis) 1.25 GHz	5-8
9	GE 12 GHz	5-6
10	GE 2.25 GHz	5-6
11	Stanford 2.62 GHz	5-7
12	CSC 0.85 GHz (incl. preamplifier)	
13	TRW 8.5-12 GHz	5-5
14	TRW 0.9-2.5 GHz	5-5

TABLE 5-4

COST OF RECEIVER WITH PREAMPLIFIERS ($Q = 10^6$)

(Reference 5-1, 5-2, and 5-3)

		COST, DOLLARS		
REFERENCE	FREQUENCY, GHz	WITH TRANSISTOR	WITH TUNNEL DIODE	WITH PARAMP
CCIR	0.85	45.00	46.50	52.00
	2.25	51.00	52.00	59.00
	8.45	NA	56.00	68.00
	12.2	NA	58.50	70.00
GE	2	21.00	23.00	31.00
	12.	26.00	28.00	36.00
TRW	0.9	20.00	NA	218.00
	2.5	30.00	74.00	224.00
	12	NA	74.00	224.00

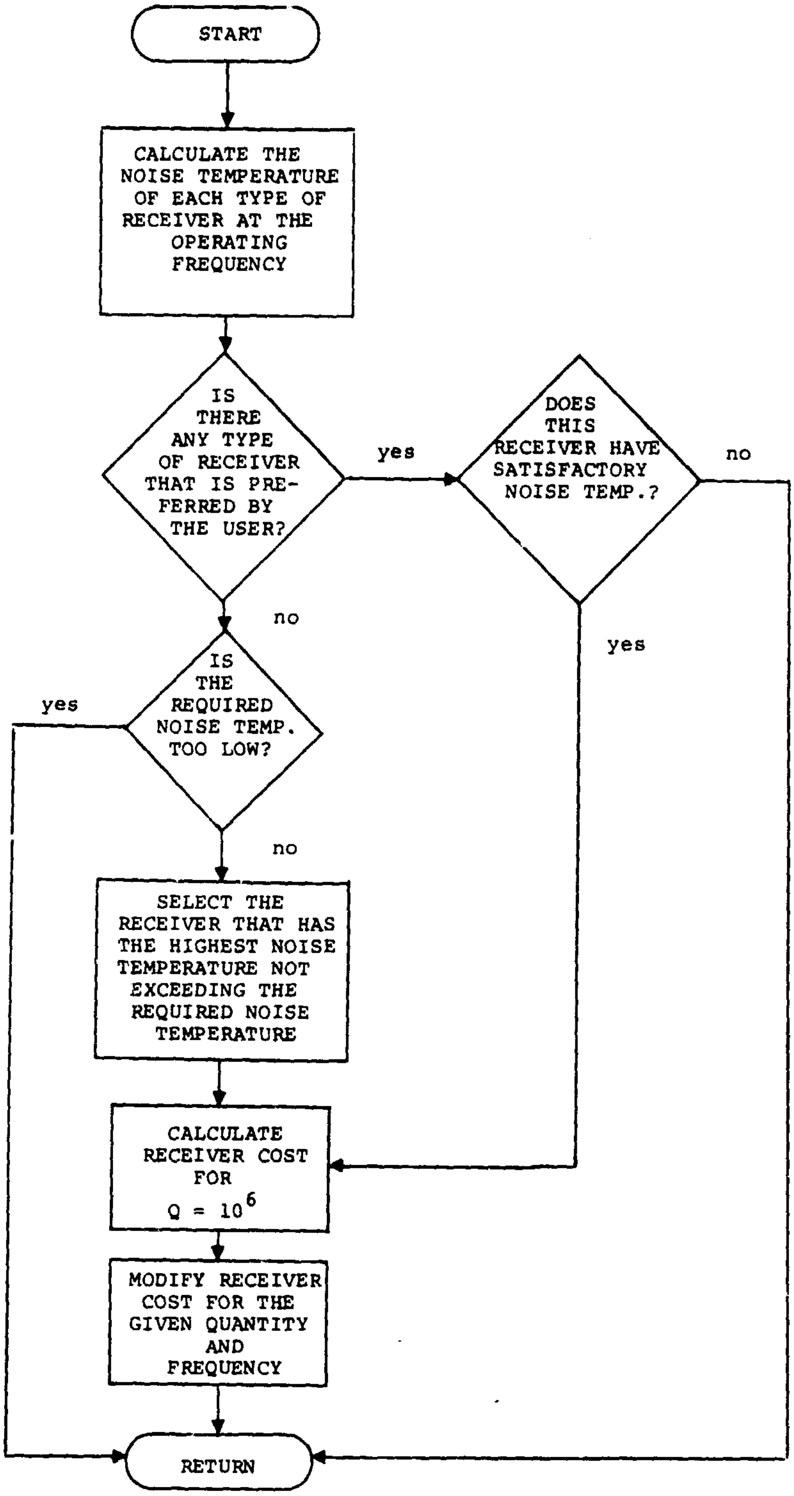

Figure 5-5. Flow Chart of Subroutine RCCST

```
RCCST,RCCST
              CSCX FORTRAN V
          SUBROUTINE RCCST (FCAR,SNT,RQ,BY,KRI,RC,IPAT)
          Y=BY-1969.
          F=FCAR*1.0E-9
          TN=1243.57+133.1*F-9.7*F*F+0.538*F**3
          TS=164.2*F+530.4
          IF (F-2.25) 360,360,390
    360   TD=570.0
          TP=350.0
          GO TO 410
    390   TD=593.3-14.786*F+3.94446*F*F
          TP=240.39+48.8*F-0.0389*F*F
          IF (SNT-TP) 391,401,401
    391   IPAT=100
    392   RC=0.0
          GO TO 680
    401   IF (KRI-4) 402,410,410
    402   IF (KRI-1) 420,460,403
    403   IF (KRI-3) 490,510,510
    410   IF (SNT-TN) 440,420,420
    420   RC1=39.9+1.648*F-0.0696*F*F
          IPAT=0
          GO TO 540
    440   IF (F-2.25) 450,450,480
    450   IF (SNT-TS) 480,460,460
    460   RC1=41.355+4.285*F
          IPAT=1
          GO TO 540
    480   IF (SNT-TD) 510,490,490
    490   RC1=48.147+0.86*F
          IF (F-2.25) 492,492,494
    492   RC1=5.5*(F-0.85)/1.4+46.5
          GO TO 498
    494   IF (F-8.45) 495,495,497
    495   RC1=4*(F-2.25)/6.2+52.0
          GO TO 498
    497   RC1=2.5*(F-8.45)/3.75+56.0
    498   IPAT=2
          GO TO 540
    510   RC1=46.81+6.677*F-0.724*F*F+0.02722*F**3
          IPAT=3
          IF (SNT-TP)530,540,540
    530   RC1=0.0
          IPAT=100
    540   IF (F-2.25) 550,550,590
```

Figure 5-6. Subroutine RCCST

```
550 RC=RC1
    GO TO 630
590 RC=RC1*(1.0-1.25*Y*(F-2.25)/328.35)
630 Q=ALOG(RQ)/ALOG(10.)
    Q1=111.15-31.45*Q+2.75*Q*Q
    Q2=11*(F-2.25)/9.75+21.0
    Q3=(95.75-21.75*Q+1.25*Q*Q)*(F-2.25)/9.75+Q1
    RC=RC*Q3/Q2
    IF (KRI-1) 672,673,674
672 IF (SNT-TN)679,680,680
673 IF (SNT-TS)679,680,680
674 IF (KRI-3) 675,676,680
675 IF (SNT-TD)679,680,680
676 IF (SNT-TP)679,680,680
679 IPAT=110
680 RETURN
    END
```

Figure 5-6. Continued

TABLE 5-5

RECEIVER COST BASED ON MODEL (BEGINNING PRODUCTION YEAR, 1971)

		QUANTITY 10^3	QUANTITY 10^6
620-790 MHz	No Preamp.	$76.00	$41.00
	With Transistor Preamp.	$82.00	$44.00
	With Tunnel Diode Preamp.	$85.00	$46.00
	With Paramp.	$94.00	$51.00
2.50-2.69 GHz	No Preamp	$89.00	$44.00
	With Transistor Preamp.	$106.00	$52.00
	With Tunnel Diode Preamp.	$106.00	$52.00
	With Paramp.	$121.00	$60.00
11.8-12.2 GHz	No Preamp.	$119.00	$46.00
	With Tunnel Diode Preamp.	$141.00	$54.00
	With Paramp.	$168.00	$65.00

TABLE 5-6

RECEIVER NOISE TEMPERATURES BASED ON MODEL

	FREQUENCY		
RECEIVER TYPE	0.655 GHz	2.59 GHz	12.15 GHz
MIXER	1063°K NF = 6.7 dB	1450°K NF = 7.8 dB	2250°K NF = 9.9 dB
TRANSISTOR	375°K NF = 3.6 dB	800°K NF = 5.75 dB	NA
TUNNEL DIODE	375°K NF = 3.6 dB	450°K NF = 4.1 dB	900°K NF = 6.15 dB
UNCOOLED PARAMP	100°K NF = 1.3 dB	200°K NF = 2.28 dB	800°K NF = 5.75 dB

5.2 SPACE SEGMENT COST

The space segment cost can be expressed as:

$$SPCOST = (C_R + VCOST)\ NOSAT + C_{NR} \qquad (5-4)$$

where SPCOST = space segment cost

C_R = spacecraft recurring costs (engineering and fabrication)

VCOST = launch vehicle cost

NOSAT = number of spacecraft

C_{NR} = spacecraft non-recurring costs (development, test and evaluation)

Estimating these costs for a broadcasting satellite system is not straightforward since there are no broadcasting satellites now in orbit and hence no historical cost data on which to base estimates. Further, to implement such a satellite system would in general require additional hardware development, which further complicates the costing picture.

CSC has investigated various available methods and models to determine their applicability to the stated problem. In general, these models appear to be inadequate primarily because the data base and techniques used in their development are not representative of a broadcasting satellite. An attempt to estimate spacecraft cost by summing subsystem cost was particularly frustrating for the reasons already mentioned, i.e., there is no good hard costing data available and well-intentioned estimates rapidly become very poor "guesstimates." The result was that almost no correlation could be obtained between data obtained from different manufacturers; hence, the data could not be used to generate an acceptable cost model.

The chosen model is based on one of several equations developed by NASA. The equations were formulated, based on normalized historical project cost and parametric data from 17 projects using a multiple regression technique. The parameters found to be most significant with respect to space segment cost, excluding the launch vehicle, were (1) spacecraft weight, (2) equivalent units of design, development, and flight effort, (3) communication and data handling weight, (4) average spacecraft power, and (5) the number of experiments aboard. The selected model, based on the NASA equation containing Items 1 and 2, for estimating space segment cost, less launch vehicle cost, is:

$$SPCOST_{LL} = 0.158\ (SATWT)^{0.6158}\ (NOSAT + EU)^{0.9684} \qquad (5\text{-}5)$$

where SATWT is the satellite weight
EU is an equivalent unit.

SATWT includes the total spacecraft weight less experiments and inordinately heavy but inexpensive items. EU plus NOSAT denotes an equivalent unit as defined by NASA and provides a means of measuring total project non-recurring activity in relation to an equivalent unit of effort that goes into one flight spacecraft. Using the guidelines provided by NASA, a value of 5.1 is assigned to EU. This value is representative of a broadcasting satellite system and is derived in the following manner. A value of 2.0 is assigned to design and development for the non-recurring effort (range of 1.5 to 2.0), a value of 0.1 is assigned for the thermal mechanical test unit, a value of 0.5 (range of 0.3 to 0.5) is assigned for the engineering unit, a value of 1.5 is assigned for the prototype unit, and a value of 0.0 (range of 0.0 to 0.7) is assigned to redesign between flights. For recurring effort, one spare is assumed to give a total value of 5.1. In addition, the number of flight units is the actual satellite count NOSAT. Hence, the NASA equivalent unit, the last term of Equation 5-5, is 5.1 + NOSAT. Equation 5-5 also includes an adjustment of the original NASA equation to reflect the difference in the cost of doing business between NASA and the private sector.

$SPCOST_{LL}$ includes design, development, fabrication, and test of all flight units. Also included is the cost of mission analysis, program management and administration, quality control, software studies, test equipment, spacecraft integration, environmental testing, change orders, change of scope, and project-borne launch support. It does not include experiment costs.

$SPCOST_{LL}$ is shown in Figure 5-7 as Curve 1, for a NOSAT of 2. For purposes of comparison consider the following relationship:

$$SPCOST_{LL} = SATWT\ (R)\ NOSAT + DTE_S \qquad (5-6)$$

where R is the cost per pound of the spacecraft,
DTE_S is the DT&E cost, including one spare.

Assume an R of 10, 9 and 8 thousand dollars per pound and a DTE_S of 35, 65 and 90 million dollars for spacecraft weights of 1000, 2000 and 4000 pounds, respectively. The resulting curve for $SPCOST_{LL}$, again assuming a NOSAT of 2, is shown as Curve 2 of Figure 5-7.

The agreement between the two curves is good and is considered meaningful since the data used to derive Curve 2 is representative of the costs used today in engineering estimates. Equation 5-5 is selected for the model, however, since its development is more rigorous and has the potential for greater flexibility through modification of the equivalent unit. Equation 5-5, as developed by NASA, was not intended for use above about 1500 pounds, nevertheless it is considered applicable in lieu of a better model which in CSC's opinion does not presently exist.

The total space segment cost SPCOST, as defined in Equation 2-2 of Section 2, is the sum of $SPCOST_{LL}$ plus the launch vehicle costs. Launch vehicle costs are discussed in Paragraph 5.3.

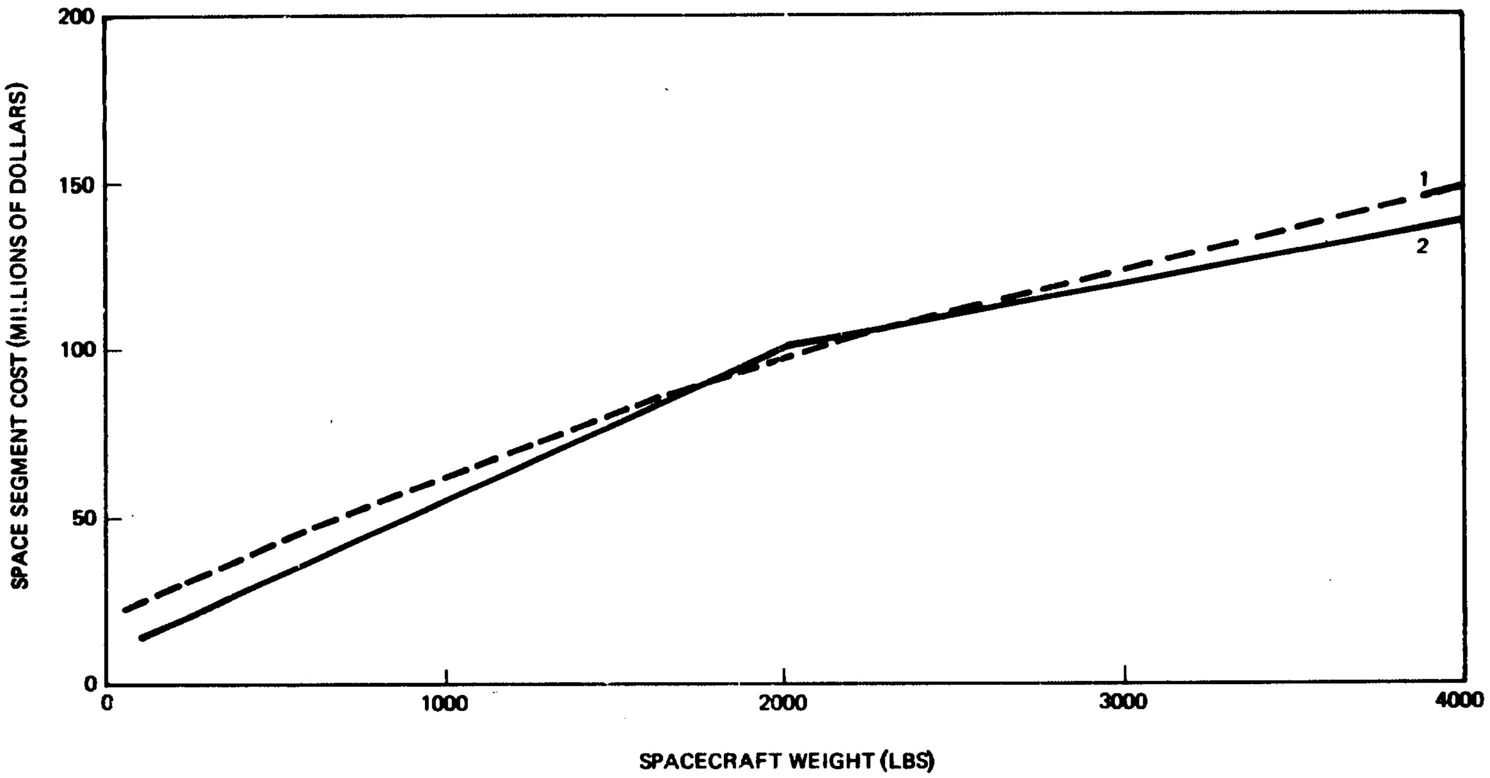

Figure 5-7. Space Segment Cost (Less Launch Vehicle) Broadcasting Satellite

5.3 VEHICLE SELECTION MODEL

In the Vehicle Selection Subroutine LANCHV, listed in Figure 5-8, there are three matrices. The martices are included in Tables 5-7, 5-8 and 5-9. A matrix is chosen, automatically, on the basis of what type of mission has been selected: spin-stabilized direct insertion; spin-stabilized, Apogee Kick Motor (AKM) insertion; or 3-axis stabilized direct insertion. As has been previously noted, no AKM is utilized for orbital insertion on 3-axis stabilized satellites. A vehicle is chosen from the matrix on the basis of vehicle performance compared to spacecraft weight.

5.3.1 Vehicle Capabilities

The capabilities of the selected vehicles is based on NASA's "Launch Vehicle Estimating Factors." When inadequate or unclear data existed in this document, manufacturers and/or appropriate NASA personnel were contacted.

The capability for direct insertion is based on a characteristic velocity of 39,700 fps. For missions employing an AKM, the transfer weight is multiplied by a factor of 0.472 which takes into account AKM Performance and subtracts the inert AKM weight giving useful payload on orbit.

5.3.2 Vehicle Costs

Costs, with the exception of several Atlas-Agena and Titan-Agena vehicles, are based on the NASA Economic Data Document (BMI-NLVP-DD-3), October, 1971. The recurring costs include vehicle hardware and support costs and an approximate figure of $0.5M, if an AKM is employed.

```
LANCHV,LANCHV
           CSCX FORTRAN V
        SUBROUTINE LANCHV(WT,MODES,MDAKM,IVHCL,VCOST)
        DIMENSION TREAX(20),SPIN(20),SPAKM(20)
        DIMENSION CSPIN(20),C3AX(20),CSPAK(20)
        DATA(SPIN(I),I=1,10)/500.,635.,810.,970.,1900.,1900.,
       13400.,4500.,7200.,9000./
        DATA(SPAKM(I),I=1,21)/450.,460.,523.,540.,575.,595.,635.,
       1703.,715.,795.,1100.,1200.,1340.,1500.,1680.,1820.,2070.,
       24610.,6100.,7400.,9400./
        DATA(TREAX(I),I=1,12)/500.,635.,810.,970.,1750.,1800.,
       12800.,3400.,3800.,4500.,7200.,9000./
        DATA(CSPIN(I),I=1,10)/10.2,10.2,10.2,11.9,15.0,16.1,25.6,
       126.8,28.2,29.9/
        DATA(CSPAK(I),I=1,21)/6.7,6.7,6.7,7.0,7.0,7.2,7.0,7.2,6.8,
       16.8,10.8,10.8,10.8,12.4,15.5,15.5,16.6,25.9,27.3,28.8,30.4/
        DATA(C3AX(I),I=1,12)/10.2,10.2,10.2,11.9,15.0,16.1,21.0,
       125.6,26.1,26.8,28.2,29.9/
        KEY =MODES+MDAKM
        GO TO (10,20,30),KEY
    10   DO  18 I=1,11
         IF(WT-TREAX(I)) 19,19,18
    18    CONTINUE
         GO TO 50
   19      IVHCL=I
        VCOST =C3AX (I)
         RETURN
   20   DO 28 I=1,13
        IF(WT-SPIN(I)) 29,29,28
   28    CONTINUE
        GO  TO 50
   29    IVHCL=I
         VCOST=CSPIN(I)
        RETURN
   30    DO 38 I=1,27
          IF(WT-SPAKM(I)) 39,39,38
   38    CONTINUE
         GO TO 50
    39   IVHCL=I
         VCOST =CSPAK(I)
         RETURN
    50   IVHCL=0
         VCOST =10.E15
         RETURN
         END
```

Figure 5-8. Subroutine LANCHV

TABLE 5-7. SPIN STABILIZED, AKM MISSIONS
[ ]: See Notes in Table 5-10

VEHICLE	CAPABILITY (lbs) [1]	COST ($M) [6]			LAUNCH SITE ETR Complex No.	SHROUD	
		RECUR [2]	NON-RECUR [3]	COST/LAUN [4]		NAME	DIA./VOL [5]
DELTA 2313	450	6.0	1	6.7	17	DELTA 8'	86/400
DELTA 303	460	6.0	1	6.7	17	DELTA	57/130
DELTA 2314	523	6.0	1	6.7	17	DELTA 8	86/400
DELTA 603	540	6.2	1	7.0	17	DELTA	57/130
DELTA 604	575	6.2	1	7.0	17	DELTA	57/130
DELTA 904	595	6.4	1	7.2	17	DELTA	57/130
DELTA 2614	635	6.2	1	7.0	17	DELTA 8	86/400
DELTA 2914	703	6.4	1	7.2	17	DELTA 8	86/400
SLV-3A/TE364-4	715	6.1	1	6.8	13	OV1	75/300
SLV-3A(U)/TE364-4	795	6.1	1.9	6.8	36	OV1	75/300
SLV-3A/ASCENT AGENA	1100	9.6 [7]	2.2	10.8	13	AGENA	58/500

TABLE 5-7. Continued

VEHICLE	CAPABILITY (lbs) [1]	COST ($M) [6]			LAUNCH SITE ETR Complex No.	SHROUD	
		RECUR [2]	NON-RECUR [3]	COST/LAUN [4]		NAME	DIA./VOL [5]
SLV-3A(U)/ASCENT AGENA	1200	9.6 [7]	3.1	10.8	13	P123	113/1400
SLV-3A(U)/ASCENT AGENA	1340	9.6 [7]	3.1	10.8	13	AGENA	58/500
T III BS/ASCENT AGENA	1500	11.1 [8]	2.2 [9]	12.4	40	III B AGENA	116/3000
SLV-3D/CENTAUR D-1A	1680	13.8	1	15.5	36	INTELSAT	115/1600
SLV-3D/CENTAUR D-1A	1820	13.8	1.9	15.5	36	INTELSAT	115/1600
T III B/CENTAUR D-1T	2070	14.8 [7]	5.8	16.6	41	VIKING	150/2500
TITAN 3 C(26)	4610	23.3	1	25.9	41	UPLF	112/940-3160
TITAN 3 C_7	6100	24.4	1	27.3	41	UPLF	112/940-3160
TITAN III D/CENTAUR	7400	25.7	1	28.8	41	BUBULOUS	150/2500
TITAN III D_7/CENTAUR	9400	27.2	1	30.4	41	BUBULOUS	150/2500

TABLE 5-8. SPIN STABILIZED, DIRECT MISSIONS

[ ]: See Notes in Table 5-10

VEHICLE	CAPABILITY (lbs) [1]	COST ($M)			LAUNCH SITE ETR Complex No.	SHROUD	
		RECUR [2]	NON-RECUR [3]	COST/LAUN [4]		NAME	DIA./VOL [5]
SLV-3A/ASCENT AGENA	500	9.1	0	10.2	13	AGENA	58/500
SLV-3A(U)/ASCENT AGENA	635	9.1	0.9	10.2	13	P123	113/1400
SLV-3A(U)/ASCENT AGENA	810	9.1	1	10.2	13	AGENA	58/500
T III BS/ASCENT AGENA	970	10.6	2.2	11.9	40	IIIB-AGENA	116/3000
SLV-3D/CENTAUR/TE364-4	1900	13.4	0	15.0	36A/B	INTELSAT	115/1600
T III B/CENTAUR/TE364-4	1900	14.4	5	16.1	41	VIKING	150/2500
TITAN III C(26)	3400	22.8	0	25.6	41	UPLF	112/940-3160
TITAN III C_7	4500	23.9	0	26.8	41	UPLF	112/940-3160
TITAN III D/CENTAUR	7200	25.2	0	28.2	41	BUBULOUS	150/2500
TITAN III D_7/CENTAUR	9000	26.7	0	29.9	41	BUBULOUS	150/2500

TABLE 5-9. 3-AXIS, DIRECT MISSIONS

[ ]: See Notes in Table 5-10

VEHICLE	CAPABILITY (lbs) [1]	COST ($M)			LAUNCH SITE ETR Complex No.	SHROUD	
		RECUR [2]	NON-RECUR [3]	COST/LAUNCH [4]		NAME	DIA./VOL [5]
SLV-3A/AEGENA	500	9.1	0	10.2	13	AEGENA	58/500
SLV-3A (U)/ASCENT AEGENA	635	9.1	0.9	10.2	13	P123	113/1400
SLV-3A (U)/ASCENT AEGENA	810	9.1	0.9	10.2	13	AEGENA	58/500
TITAN IIIBS/ASCENT AEGENA	970	10.6	2.2	11.9	40	IIIB/AEGENA	116/3000
SLV-3D/CENTAUR/BURNER II	1750	13.4	0	15.0			
TITAN IIIB/CENTAUR/BURNER II	1800	14.4	5.0	16.1	40	BURNER II	115/1170
TITAN IIID/BURNER II	2800	18.8	0	21.0	41	BURNER II	115/1170
TITAN IIIC(26)	3400	22.8	0	25.6	41	UPLF	112/940-3160
TITAN IIIC/BURNER II	3800	23.3	0	26.1	41	BURNER II	115/1170
TITAN IIIC$_7$	4500	23.9	0	26.8	41	UPLF	112/940-3160
TITAN IIID/CENTAUR	7200	25.2	0	28.2	41	BUBULOUS	150/2500
TITAN IIID$_7$/CENTAUR	9000	26.7	0	29.9	41	BUBULOUS	150/2500

TABLE 5-10

[]: NOTES

[1] Useful Payload.

[2] Includes Vehicle Hardward and Support Costs, and $0.5M when AKM is Used.

[3] No S/C Integration Costs Included. Includes Pad Modifications, Vehicle Modifications, Vehicle Integration, and $1M for an AKM Development.

[4] Adds 12 Percent to Recurring Cost for Non-US Government Users.

[5] Diameter in Inches, Volume (Useful) in Cubic Feet.

[6] Based on NASA Economic Data Document, BMI-NLVP-DD-3; October, 1971. Based, Generally, on 4 Vehicles Purchased and Launched.

[7] NASA Figure Not Available.

[8] Based on Manufacturer's Recently Negotiated USAF Purchase.

[9] Pad Modifications and Vehicle Modifications Not Included as USAF Will Probably Absorb.

Nonrecurring cost does not include spacecraft integration costs. It does include modification to launch facilities, vehicle integration, vehicle modifications (not absorbed by NASA or other Government agencies) and $1M when an AKM is developed for the mission.

The cost per launch is based on an additional 12 percent to the recurring cost, for a non-US Government user.

5.3.3 Launch Sites

Launch facilities are available at ETR for all selected vehicles with the exception of the Titan III B. The USAF has recently negotiated with Martin Marietta to incorporate the III B, and pad modifications will be made under this agreement.

REFERENCES

SECTION 5

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5-2 "Orbit/Spectrum Utilization Study," Vol. III, *Economic Considerations*, Doc. No. 70 SD 4246, General Electric Co., Valley Forge Space Center, Philadelphia, Pa.

5-3 "UHF Receiving Antenna Design," General Electric Co., Space Systems Organization, NASA Report CR-72509, Valley Forge Space Center, Phildelphia, Pa.

5-4 "Study of Feasibility of Space Communications Techniques for the National Data Buoy System," General Dynamics, Report No. GDC-AAX70-021.

5-5 Jensen, J., et al., "Television Broadcast Satellite Study," TRW Systems Group, TRW No. 08848-6002-RO-00, 1969.

5-6 Hesler, J. P.; White, O. S., "Low Cost Ground Converters for High Power Communications Satellites," General Electric Co., AIAA Paper No. 70-440, N.Y., 1970.

5-7 Lusignan, B., "Low Cost ETV Satellite Receivers," Stanford University, AIAA Paper No. 70-439, 1970.

5-8 Miller, E., "Development of Low-Cost Receiving Systems for Television Signals Transmitted from Synchronous Satellite," NASA Lewis Research Center, TM X-67800.

SECTION 6

COMPUTER MODEL EXAMPLE OUTPUTS

This section contains several example outputs from the computer model. The input parameters were chosen arbitrarily to define broadcasting satellite systems operating in the three frequency bands of interest. The requirements imposed on each of the systems are identical with the exception of frequency. The examples, include both dual-spin and 3-axis stabilized satellites at 700 MHz and 2.5 GHz, and a 3-axis configuration at 12 GHz. The resulting performance/cost curves are shown in Figures 6-1, 6-2, 6-3, and 6-4.

The primary system requirements are shown on each figure and complete computer listings are included in Figures 6-5, 6-6, 6-7, and 6-8. The calculated system characteristics are listed in Figures 6-9, 6-10, 6-11, and 6-12, for the minimum cost systems.

The term GRD ANT BW, contained under the group heading FREQUENCY PLAN in Figures 6-5, 6-6, 6-7, and 6-8, refers to the minimum allowable beamwidth. AKM MODE 0 and AKM MODE 1, listed in Figures 6-9 and 6-11, refer to launch vehicle operation without and with an AKM, respectively. Also, it should be remembered that the term RFPWR/TV CHAN, contained in Figures 6-9, 6-10, 6-11, and 6-12, is the power at the satellite antenna input, not the transmitter output power.

The minimum cost system delineated in each frequency region would not necessarily be the selected system. For example, referring to Figures 6-1, 6-2, and 6-3 it is seen that there are several candidate systems (denoted by the calculated points plotted on the figures) that result in essentially minimum cost systems. The final selection, therefore, must include other factors like who will be paying for the ground segment, ground terminal maintenance, etc? The computer program prints out a complete set of system characteristics for each candidate system to aid in selecting the final system. The broadness of the performance/cost curves, in the area of minimim system cost, varies as a function of the system requirements. For example, in Figure 6-4, the minimum portion of the system cost curve for the 12 GHz system is quite narrow. This results from an abrupt increase in ground segment cost at the point where a parametric preamplifier is selected. Hence, the minimum cost system specifies a TDA. The cost of the ground segment does not change until the paramp is selected since the receiving antenna is held constant to a diameter of 0.55 meters, due to the 3° minimum beamwidth constraint included in the system requirements. It is of interest to note that the program will not calculate past the arrow shown in the figure, since this value of EIRP requires a receiver noise temperature better than that modeled for the best performing (paramp) community receiver.

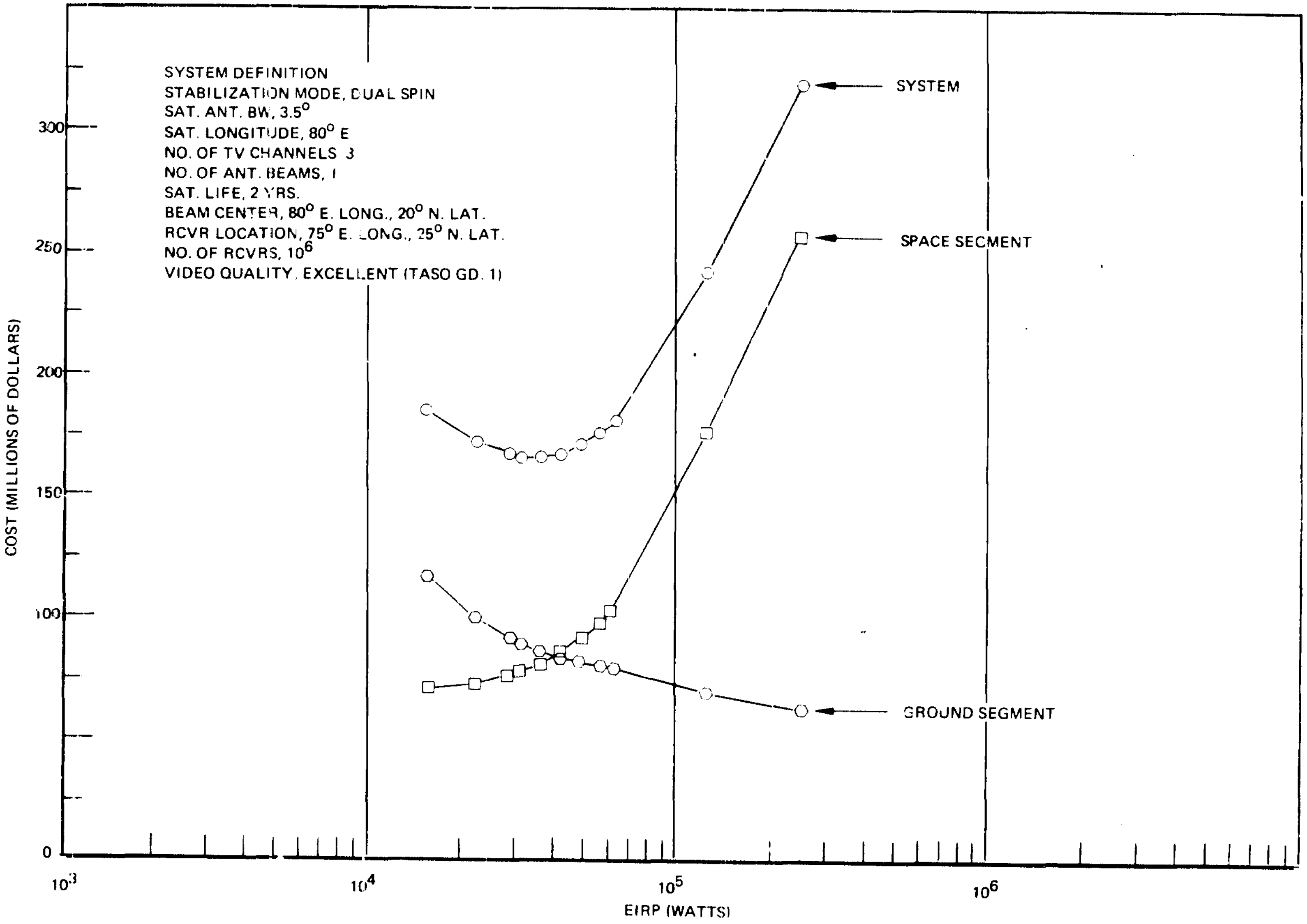

Figure 6-1. Cost Curves, Frequency 700 MHz

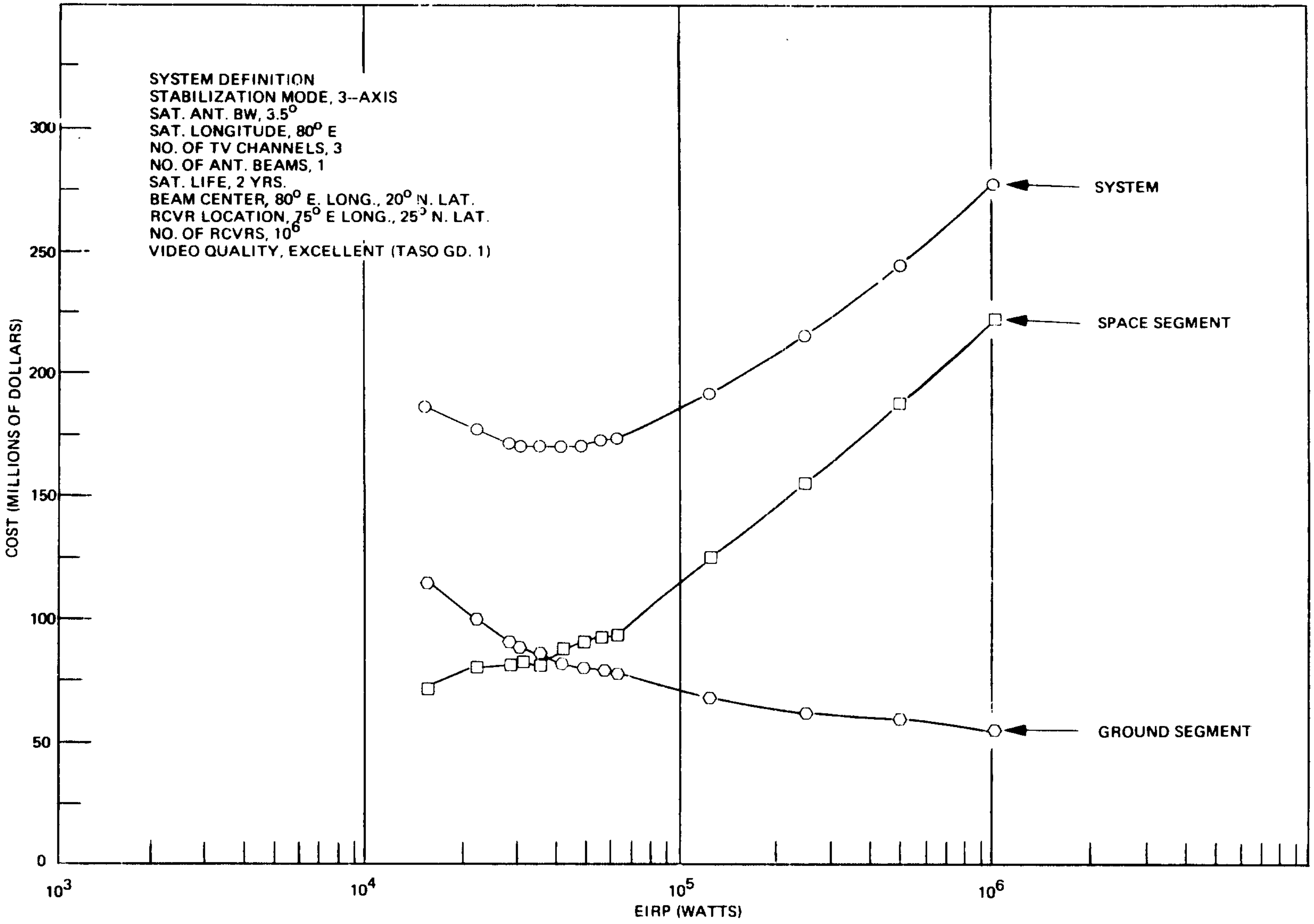

Figure 6-2. Cost Curves, Frequency 700 MHz

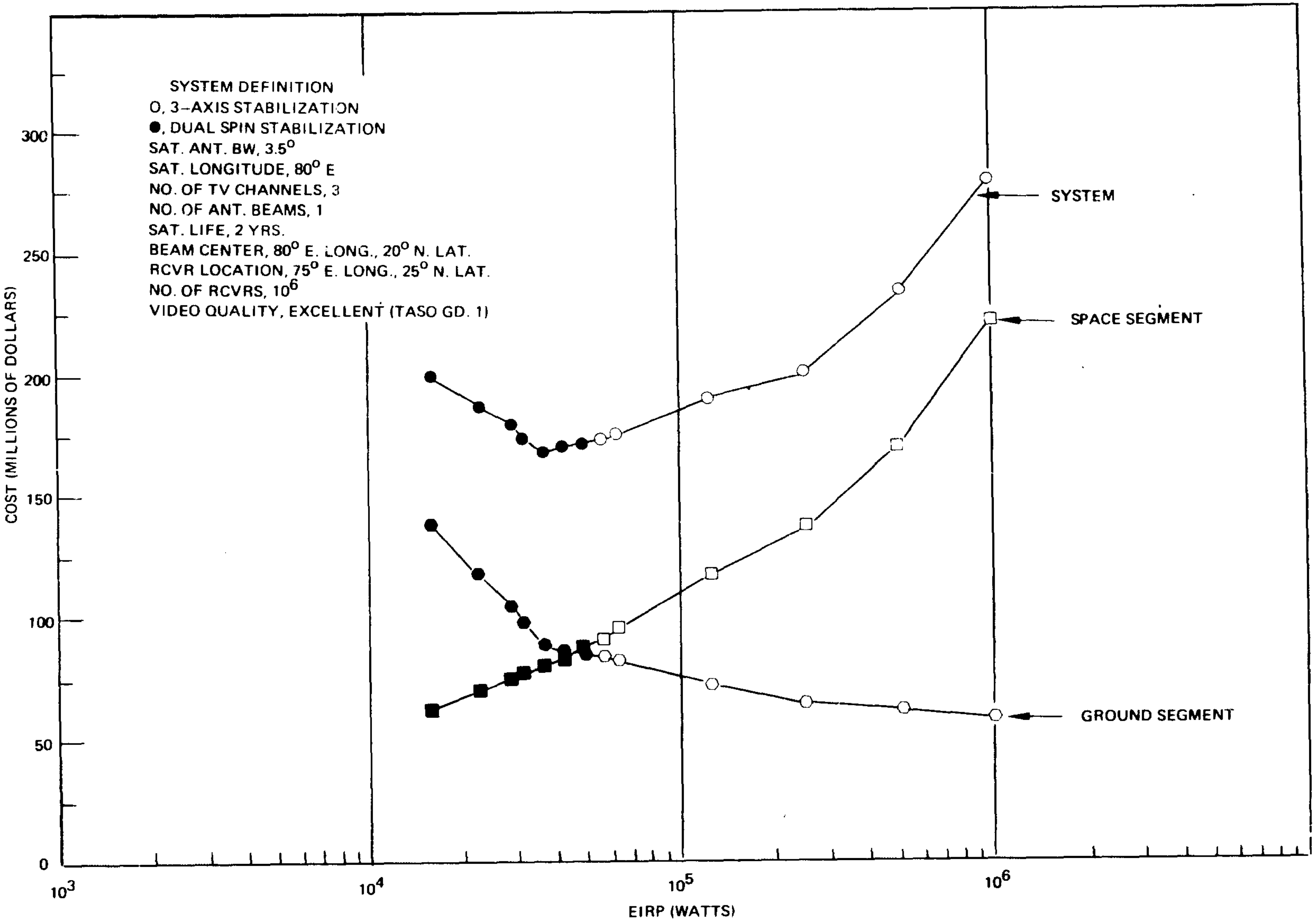

Figure 6-3. Cost Curves, Frequency 2.5 GHz

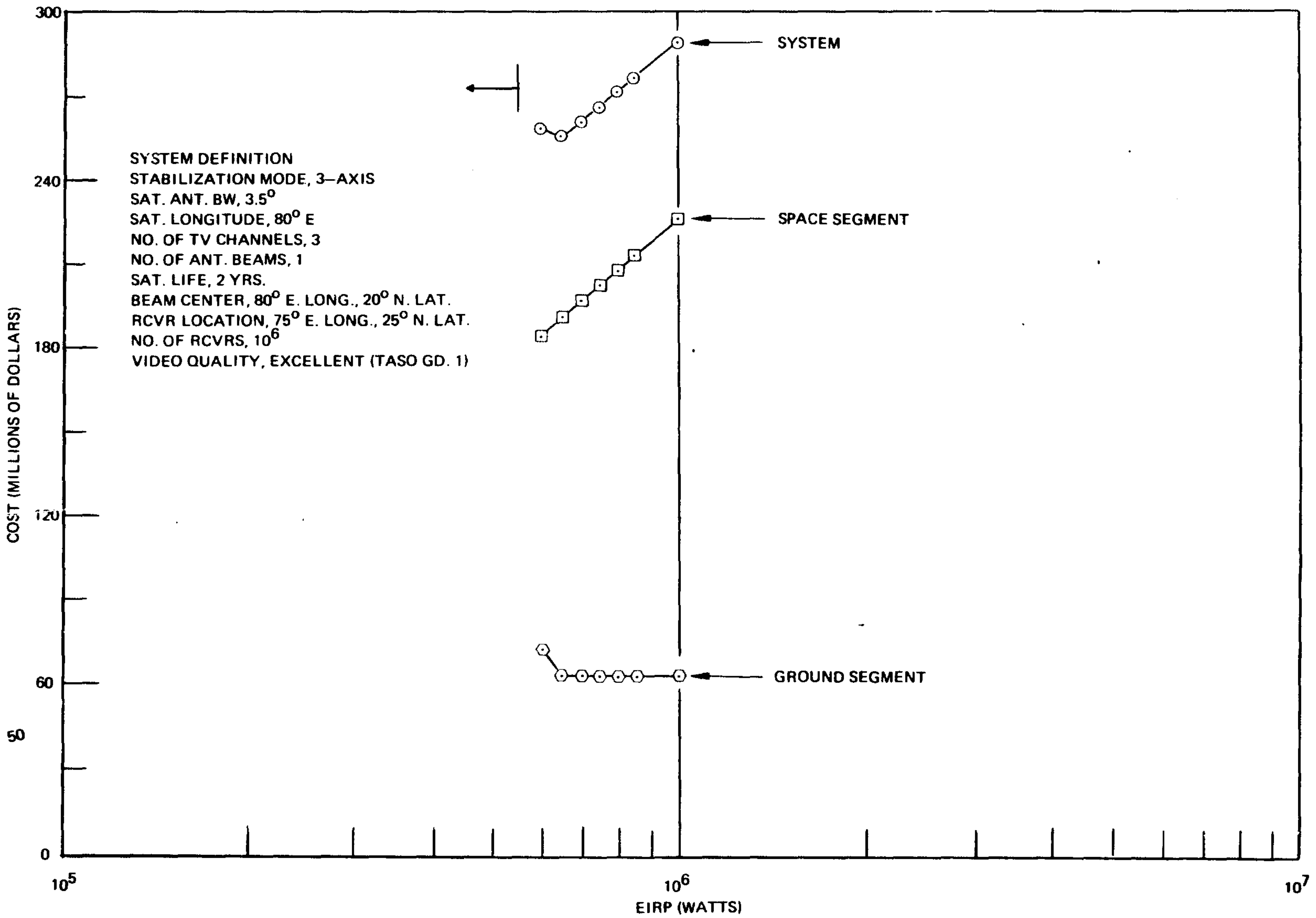

Figure 6-4. Cost Curves, Frequency 12 GHz

```
SYSTEM DESCRIPTION
    SAT LONG   80.0000       SATELLITES    1       BROADCAST     8 HRS
    SAT LAT        .0000     TV CHAN       3       SAT LIFE      2 YRS
    PT ERR         .1000     NO. BEAMS     1       START YR      1972
    STAB MODE    2           AUD CHAN/TV   2       NO POINTS     6


FREQUENCY PLAN
    .70000000+09 HZ
    .74000000+09 HZ
    .78000000+09 HZ
    SPECF      15.00 DB        GRD ANT BW   3.00 DEG
    SAT ANT EFF   .500         ERP MAX .10000000+07 WATTS


BEAM CHARACTERISTICS NO.   1 ******
    REC LONG     75.0000                REC LAT       25.0000
    BC LONG      80.0000                BC LAT        20.0000
    SAT ANT BW    3.5000                GRD ANT EFF     .4500
    MAX VID BW     .50000000+07 HZ      MAX AUD BW      .15000000+05 HZ
    RAIN RATE     16.00    MM/HR        MAN MADE NOISE     1
    REL HUMIDITY     3                  GALACTIC NOISE     1
    NO RECEIVERS 1000000                REC SPECIFIED      4
    PROB SCINT      .9000


RECEIVER CHARACTERISTICS
    VIDEO SUB GUARD   .500000+06 HZ     SUB CAR GUARD     .200000+06 HZ
    CAR PEAK DEV      .250000+05 HZ     FM THRESHHOLD    1.00 DB
    VIDEO T MRG      3.000       DB     AUD-SC T MRG     3.00 DB
    MAX RF BW         .350000+08 HZ     RF-BW-K-FAC      1.000
    VIDEO K-FAC     16.300       DB     REQ VIDEO S/N  45.000 DB
    REQ AUD S/N     20.000       DB     CABLE LOSS        .000 DB

ERPMZ=    .10000000+07
```

Figure 6-5. System Definition (700 MHz, Dual-Spin)

```
SYSTEM DESCRIPTIØN
    SAT LØNG   80.0000       SATELLITES   1        BRØADCAST     8 HRS
    SAT LAT      .0000       TV CHAN      3        SAT LIFE      2 YRS
    PT ERR       .1000       NØ. BEAMS    1        START YR      1972
    STAB MØDE  1             AUD CHAN/TV  2        NØ PØINTS     6

FREQUENCY PLAN
    .70000000+09 HZ
    .74000000+09 HZ
    .78000000+09 HZ
    SPECF        15.00 DB     GRD ANT BW  3.00 DEG
    SAT ANT EFF   .500        ERP MAX .10000000+07 WATTS

BEAM CHARACTERISTICS NØ.  1 ******
    REC LØNG     75.0000                 REC LAT       25.0000
    BC LØNG      80.0000                 BC LAT        20.0000
    SAT ANT BW    3.5000                 GRD ANT EFF     .4500
    MAX VID BW     .50000000+07 HZ       MAX AUD BW      .15000000+05 HZ
    RAIN RATE     16.00    MM/HR         MAN MADE NØISE    1
    REL HUMIDITY    3                    GALACTIC NØISE    1
    NØ RECEIVERS 1000000                 REC SPECIFIED     4
    PRØB SCINT      .9000   %

RECEIVER CHARACTERISTICS
    VIDEØ SUB GUARD   .500000+06 HZ     SUB CAR GUARD     .200000+06 HZ
    CAR PEAK DEV      .250000+05 HZ     FM THRESHHØLD    1.00 DB
    VIDEØ T MRG      3.000       DB     AUD-SC T MRG     3.00 DB
    MAX RF BW         .350000+08 HZ     RF-BW-K-FAC      1.000
    VIDEØ K-FAC     16.300       DB     REQ VIDEØ S/N   45.000 DB
    REQ AUD S/N     20.000       DB     CABLE LØSS        .000 DB
ERPMZ=    .10000000+07
```

Figure 6-6. System Definition (700 MHz, 3-Axis)

```
SYSTEM DESCRIPTION
    SAT LONG   80.0000        SATELLITES    1       BROADCAST     8 HRS
    SAT LAT      .0000        TV CHAN       3       SAT LIFE      2 YRS
    PT ERR       .1000        NO. BEAMS     1       START YR      1972
    STAB MODE   3             AUD CHAN/TV   2       NO POINTS     6


FREQUENCY PLAN
    .25000000+10 HZ
    .25400000+10 HZ
    .25800000+10 HZ
    SPECF      15.00 DB        GRD ANT BW  3.00 DEG
    SAT ANT EFF   .500         ERP MAX .10000000+07 WATTS


BEAM CHARACTERISTICS NO.  1 ******
    REC LONG     75.0000                 REC LAT       25.0000
    BC LONG      80.0000                 BC LAT        20.0000
    SAT ANT BW    3.5000                 GRD ANT EFF     .4500
    MAX VID BW     .50000000+07 HZ       MAX AUD BW      .15000000+05 HZ
    RAIN RATE     16.00    MM/HR         MAN MADE NOISE     1
    REL HUMIDITY    3                    GALACTIC NOISE     1
    NO RECEIVERS 1000000                 REC SPECIFIED      4
    PROB SCINT      .9000


RECEIVER CHARACTERISTICS
    VIDEO SUB GUARD   .500000+06 HZ     SUB CAR GUARD     .200000+06 HZ
    CAR PEAK DEV      .250000+05 HZ     FM THRESHHOLD    1.00 DB
    VIDEO T MRG      3.000       DB     AUD-SC T MRG     3.00 DB
    MAX RF BW         .350000+08 HZ     RF-BW-K-FAC      1.000
    VIDEO K-FAC     16.300       DB     REQ VIDEO S/N  45.000 DB
    REQ AUD S/N     20.000       DB     CABLE LOSS       .000 DB

ERPMZ=   .10000000+07
```

Figure 6-7. System Definition
(2.5 GHz, 3-Axis & Dual-Spin)

```
SYSTEM DESCRIPTION
    SAT LONG   80.0000       SATELLITES   1      BROADCAST    8 HRS
    SAT LAT      .0000       TV CHAN      3      SAT LIFE     2 YRS
    PT ERR       .1000       NO. BEAMS    1      START YR     1972
    STAB MODE  1             AUD CHAN/TV  2      NO POINTS    9


FREQUENCY PLAN
    .12000000+11 HZ
    .12040000+11 HZ
    .12080000+11 HZ
    SPECF       15.00 DB      GRD ANT BW  3.00 DEG
    SAT ANT EFF  .500         ERP MAX .10000000+07 WATTS


BEAM CHARACTERISTICS NO.  1 ******
    REC LONG    75.0000                 REC LAT      25.0000
    BC LONG     80.0000                 BC LAT       20.0000
    SAT ANT BW   3.5000                 GRD ANT EFF    .5600
    MAX VID BW    .50000000+07 HZ       MAX AUD BW     .15000000+05 HZ
    RAIN RATE    16.00   MM/HR          MAN MADE NOISE    1
    REL HUMIDITY    3                   GALACTIC NOISE    1
    NO RECEIVERS 1000000                REC SPECIFIED     4
    PROB SCINT     .9000


RECEIVER CHARACTERISTICS
    VIDEO SUB GUARD  .500000+06 HZ     SUB CAR GUARD     .200000+06 HZ
    CAR PEAK DEV     .250000+05 HZ     FM THRESHHOLD    1.00 DB
    VIDEO T MRG     3.000         DB   AUD-SC T MRG     3.00 DB
    MAX RF BW        .350000+08 HZ     RF-BW-K-FAC      1.000
    VIDEO K-FAC    16.300         DB   REQ VIDEO S/N  45.000 DB
    REQ AUD S/N    20.000         DB   CABLE LOSS        .000 DB

ERPMZ=   .10000000+07
```

Figure 6-8. System Definition (12 GHz, 3-Axis)

```
GROUND SEGMENT CHARACTERISTICS              5
    GRD ANT COST      31.81 $          RECEIVR COST      52.65 $
    GRD ANT DIAM       2.01 MET        RECEIVR TYPE       3
    SAT ANT GAIN      32.50 DB         REC NOISE T      356.28 DEG K
    GRB ANT BMWD      16.75 DEG        REC ELEV ANG      60.23 DEG
    REQ VIDEO S/N     45.00 DB         SYS NOISE T      361.86 DEG K
    C/N VID THRS       8.34 DB         RF BANDWIDTH********** HZ
    VID THRS IMP    5736.66 SEC

    RFPWR/TV CHAN     14.15 WATTS        EIRP         25177.69 WATTS

    RFPWR/TV CHAN     15.81 WATTS        EIRP         28131.28 WATTS

    RFPWR/TV CHAN     17.56 WATTS        EIRP         31250.00 WATTS


SATELLITE CHARACTERISTICS
    SAT WEIGHT  1072.20   LBS          ANT WEIGHT   104.95  LBS
    ANT DIAMTR    25.27  FEET          XPONDER WT   158.07  LBS
    COMM POWER   501.12 WATTS          PWR SYS WT   358.24  LBS
    HEAT DISSP   452.73 WATTS          STAB-AC WT   166.12  LBS
    POWER, BOL   724.15 WATTS          THERM CONT    52.44  LBS
    ARRAY AREA   232.45 SQ FT          STRUCTURE    192.37  LBS


LAUNCH VEHICLE
    STAB MODE   2     AKM MODE  0     VEHICLE  5     COST  15.00000 M$


LAUNCH VEHICLE
    STAB MODE   2     AKM MODE  1     VEHICLE 11     COST  10.80000 M$


COSTS
    SYSTEM 162.13174 M$     GROUND  84.46425 M$     SPACE  77.66749 M$


JKEY=  3


ERPMZ=   .15625000+05
```

Figure 6-9. Minimum Cost System Characteristics
(700 MHz, Dual-Spin)

```
GROUND SEGMENT CHARACTERISTICS                  4
    GRD ANT COST      21.42 $          RECEIVR COST       52.65 $
    GRD ANT DIAM       1.51 MET        RECEIVR TYPE         3
    SAT ANT GAIN      32.50 DB         REC NOISE T       458.02 DEG K
    GRB ANT BMWD      22.37 DEG        REC ELEV ANG       60.23 DEG
    REQ VIDEO S/N     45.00 DB         SYS NOISE T       463.48 DEG K
    C/N VID THRS       8.34 DB         RF BANDWIDTH********** HZ
    VID THRS IMP    5736.66 SEC

    RFPWR/TV CHAN     32.33 WATTS        EIRP            57534.58 WATTS

    RFPWR/TV CHAN     36.13 WATTS        EIRP            64293.15 WATTS

    RFPWR/TV CHAN     40.14 WATTS        EIRP            71428.57 WATTS

SATELLITE CHARACTERISTICS
    SAT WEIGHT   1376.99    LBS        ANT WEIGHT     104.95   LBS
    ANT DIAMTR     25.27   FEET        XPONDER WT     200.53   LBS
    COMM POWER   1267.38 WATTS         PWR SYS WT     417.81   LBS
    HEAT DISSP   1163.92 WATTS         STAB-AC WT     216.60   LBS
    POWER, BOL   1819.84 WATTS         THERM CONT     254.32   LBS
    ARRAY AREA    259.98 SQ FT         STRUCTURE      132.78   LBS

LAUNCH VEHICLE
    STAB MODE  1      AKM MODE  0     VEHICLE  5      COST  15.00000 M$

COSTS
    SYSTEM 167.08046 M$      GROUND  74.07504 M$      SPACE  93.00543 M$

ERPMZ=    .84821427+05
```

Figure 6-10. Minimum Cost System Characteristics (700 MHz, 3-Axis)

```
GROUND SEGMENT CHARACTERISTICS                   4
    GRD ANT COST       25.40 $           RECEIVR COST      60.43 $
    GRD ANT DIAM        1.73 MET         RECEIVR TYPE        3
    SAT ANT GAIN       32.50 DB          REC NOISE T      385.32 DEG K
    GRB ANT BMWD        5.68 DEG         REC . EV ANG      60.23 DEG
    REQ VIDEO S/N      45.00 DB          SYS NOISE T      391.44 DEG K
    C/N VID THRS        8.34 DB          RF BANDWIDTH********** HZ
    VID THRS IMP     5736.66 SEC

    RFPWR/TV CHAN      22.38 WATTS         EIRP          39811.00 WATTS

    RFPWR/TV CHAN      23.10 WATTS         EIRP          41100.45 WATTS

    RFPWR/TV CHAN      23.83 WATTS         EIRP          42410.71 WATTS
SATELLITE CHARACTERISTICS
    SAT WEIGHT  1164.54   LBS            ANT WEIGHT     31.58  LBS
    ANT DIAMTR     7.08   FEET           XPONDER WT    203.15  LBS
    COMM POWER   706.54 WATTS            PWR SYS WT    453.50  LBS
    HEAT DISSP   633.59 WATTS            STAB-AC WT    188.79  LBS
    POWER, BOL  1116.20 WATTS            THERM CONT    138.44  LBS
    ARRAY AREA   159.46 SQ FT            STRUCTURE      99.07  LBS


LAUNCH VEHICLE
    STAB MODE  1      AKM MODE   0      VEHICLE  5       COST  15.00000M$

COSTS
    SYSTEM 171.19122 M$      GROUND  85.83401 M$      SPACE  85.35721 M$


SATELLITE CHARACTERISTICS
    SAT WEIGHT  1212.02   LBS            ANT WEIGHT     31.58  LBS
    ANT DIAMTR     7.08   FEET           XPONDER WT    203.15  LBS
    COMM POWER   706.54 WATTS            PWR SYS WT    447.51  LBS
    HEAT DISSP   633.59 WATTS            STAB-AC WT    175.07  LBS
    POWER, BOL   985.32 WATTS            THERM CONT     97.09  LBS
    ARRAY AREA   316.29 SQ FT            STRUCTURE     217.62  LBS


LAUNCH VEHICLE
    STAB MODE  2      AKM MODE   0      VEHICLE  5       COST  15.00000M$
LAUNCH VEHICLE
    STAB MODE  2      AKM MODE   1      VEHICLE 13       COST  10.80000M$


COSTS
    SYSTEM 168.74396 M$      GROUND  85.83401 M$      SPACE  82.90995 M$


ERPMZ=    .49107142+05
```

Figure 6-11. Minimum Cost System Characteristics
(2.5 GHz, 3-Axis & Dual-Spin)

```
GROUND SEGMENT CHARACTERISTICS                1
    GRD ANT COST      12.43 $          RECEIVR COST      51.38 $
    GRD ANT DIAM        .55 MET        RECEIVR TYPE        2
    SAT ANT GAIN      32.50 DB         REC NOISE T      986.53 DEG K
    GRB ANT BMWD       3.75 DEG        REC ELEV ANG      60.23 DEG
    REC VIDEO S/N     45.00 DB         SYS NOISE T     1091.55 DEG K
    C/N VID THRS       8.34 DB         RF BANDWIDTH********** HZ
    VID THRS IMP    5736.66 SEC

    RFPWR/TV CHAN    362.32 WATTS        EIRP          644174.90 WATTS

    RFPWR/TV CHAN    363.80 WATTS        EIRP          647094.15 WATTS

    RFPWR/TV CHAN    365.27 WATTS        EIRP          649999.99 WATTS


SATELLITE CHARACTERISTICS
    SAT WEIGHT   4579.86    LBS        ANT WEIGHT     25.59   LBS
    ANT DIAMTR      1.47   FEET        XPONDER WT    408.83   LBS
    COMM POWER   8610.61  WATTS        PWR SYS WT   1337.02   LBS
    HEAT DISSP   7512.82  WATTS        STAB-AC WT    503.25   LBS
    POWER, BOL  11068.43  WATTS        THERM CONT   1641.55   LBS
    ARRAY AREA   1581.20  SQ FT        STRUCTURE     613.62   LBS


LAUNCH VEHICLE
    STAB MODE  1      AKM MODE   0      VEHICLE 11      COST  28.20000M$


COSTS
    SYSTEM 255.51595 M$     GROUND  63.81382 M$     SPACE 191.70213 M$


ERPMZ=   .70000000+06
```

Figure 6-12. Minimum Cost System Characteristics (12 GHz, 3-Axis)

APPENDIX A

COMPUTER PROGRAM LISTING

```
        CBSTOT,,CBSTOT
      DIMENSION RFPWR(6,6),RFBW(6),ACOST(6),RCOST(6),INDR(6),ANTD(6)
      DIMENSION RLAT(6),RLONG(6),BCLAT(6),BCLON(6),AEFF(6),SABW(6)
      DIMENSION  RFPR(6)
      DIMENSION RAINR(6), KMMN(6),KRH(6),KGN(6),NRECV(6),ABWMX(6),
     1VBWMX(6),IRCVT(6),POR(6),SYTEMP(6),ERPM(6)
      DIMENSION FREQ(6),GNDCT(6)
      DIMENSION FR(6),ARADB(6),SCNDB(6),EIRP(6)
      DATA IN,IOUT /5,6/
      DATA (GNDCT(I),I=1,6)/6*10. E16/
C     READ SYSTEM PARAMETER CARD
      ITC=1
      TSYS=9.E16
      READ(IN,8000)SLONG,SLAT,LIFE,NOSAT,NBEAM,NTVCH,NAVCC,
     1ISTYR,PTERR,ITIMBC,MODSTB,NPTS
      WRITE(IOUT,9500)SLONG,NOSAT,ITIMBC,SLAT,NTVCH,LIFE,PTERR,
     1NBEAM,ISTYR,MODSTB,NAVDC,NPTS
C     FREQUENCY PLAN
      READ (IN,8000) FREQ,SPECF,GABWM,SAEFF,ERPMX
        WRITE(IOUT,9501)(FREQ(I),I=1,NTVCH)
       WRITE (IOUT,9507)SPECF,GABWM,SAEFF,ERPMX
C     BEAM CHARACTERISTICS
      IZOOM=0
      DO 10 I=1,NBEAM
      ANTD(I)=100.
      READ(IN,8000)RLONG(I),RLAT(I),BCLON(I),BCLAT(I),SABW(I),
     1VBWMX(I),ABWMX(I),AEFF(I),RAINR(I),KMMN(I),KRH(I),KGN(I),
     2NRECV(I),IRCVT(I),POR(I)
      WRITE(IOUT,9502)I,RLONG(I),RLAT (I),BCLON(I),BCLAT(I),SABW(I),
     1AEFF(I),VBWMX(I),ABWMX(I),RAINR(I),KMMN(I),KRH(I),KGN(I),
     2NRECV(I),IRCVT(I),POR(I)
 10   ERPM(I)=ERPMX
      READ (IN,8000) VASCG,SSGB,PDVSC,FMTHR,VTHRM,ASCTM,RFMBW,RFBWK,
     1VKFAC, RVSN,RASN,CABLS
      WRITE(IOUT,9503)VASCG,SSGB,PDVSC,FMTHR,VTHRM,ASCTM,RFMBW,
     1RFBWK,VKFAC,RVSN,RASN,CABLS
C     29 INPUT VARIABLES
        JKEY =1
 4000  DO 100 I=1,NBEAM
```

```
      ANTMX=1.9925E10/SQRT(FREQ(1)*(FREQ(NTVCH)))/GABWM
      INDR(I)=9999
      IT=0
      ERPMZ=ERPM(I)
      IF(IZOOM.EQ.1)GO TO 7000
      IF(JKEY.EQ.3)ERPM(I)=ERPM(I)*0.5
      GO TO 4005
7000  ERPM(I)=ERPM(I)+DELERP
4005  ANTDM=ANTD(I)*SQRT(ERPMZ/ERPM(I))*1.5
      ERPMZ=ERPM(I)
      N=ALOG(ANTDM/ANTMX)/ALOG(.8)   - 1.
      ANTDM=ANTMX*(.8)**N
      IF(ANTDM.GT.ANTMX)ANTDM=ANTMX
      IKEY=JKEY
       GNDCT(I)=10.E16
      WRITE(IOUT,9997)ERPMZ
90    CALL GRDSG(SLONG,SLAT,NTVCH,NAVDC,RLONG(I),RLAT(I),BCLCN(I),
     1BCLAT(I),VBWMX(I),ABWMX(I),AEFF(I),GABWM,RAINR(I),KMMN(I),
     2KRH(I),KGN(I),FREQ,VASCG,SSGB,PDVSC,FMTHR,VTHRM,ASCTM,
     3RFMBW,RFBWK,VKFAC,RVSN,RASN,CABLS,IKEY,SABW(I),SPECF,SAEFF,
     4ERPMZ,POR(I),SYTEM,RCVNS,ANTDM,RFPR,RFBWX,FR,ELARD,ARADB,
     5SCNDB,GOGT,SAGDB,ABMWD,EIRP,CONVT,VTIR)
       STYR=ISTYR
        RECNM=NRECV(I)
      CALL ANCTP(ANTDM,RECNM,ACST)
      CALL RCCST (FREQ(1),RCVNS,RECNM,STYR,IRCVT(I),RCST,IND)
      IF(GNDCT(I)-(RCST+ACST))15,15,14
14     IF(IND-100) 16,15,15
15    WRITE(IOUT,9600)IT,ACOST(I),RCOST(I),ANTD(I),INDR(I),SAGDB,
     1RCVN,ABMWD,ELARD,RVSN,SYTEMP(I),CONVT,RFBW(I),VTIR
      WRITE(IOUT,9620)(RFPWR(J,I),EIRP(J),J=1,NTVCH)
      GO TO 100
16    ACOST(I)=ACST
      RCOST(I)=RCST
      GNDCT(I)=ACST+RCST
      INDR(I)=IND
         RCVN=RCVNS
      SYTEMP(I)=SYTEM
      IT=IT+1
          DO 18 J=1,NTVCH
18     RFPWR(J,I)=RFPR(J)
      RFBW(I)=RFBWX
      ANTD(I)=ANTDM
      ANTDM=ANTDM*0.8
      IKEY=2
      GO TO 90
```

```
100   CONTINUE
        ERPM(I)=ERPMZ
       MODES=MODSTB
      IF(MODSTB.EQ.3) MODES=1
        SLIFE=LIFE
        FREK=FREQ(1)/1.E9
      DO 200 I=1,NTVCH
      TOT=0
       DO 201 J=1,NBEAM
201    TOT=TOT+RFPWR(I,J)
200   RFPR(I)=TOT
      XSYS=10.E16
      TGD=0.
      DO 300 I=1,NBEAM
300   TGD=TGD+GNDCT(I)*NRECV(I)
      CTGD=TGD/(1.E6)
      XSYS=10.E16
150     CALL SPASEG(FREK,SABW,NTVCH,NBEAM,PTERR,RFPR,MODES
     1,SLIFE,ITIMBC,SLONG,ANTWT,ANTDIA,COMPWR,HDSPLD,PWRBOL,XPNWT,
     2PPSWT,ARAREA,STABWT,THRMWT,STRCWT,SATWT)
      WRITE(IOUT,9650)SATWT,ANTWT,ANTDIA,XPNWT,COMPWR,PPSWT,
     1HDSPLD,STABWT,PWRBOL,THRMWT,ARAREA,STRCWT
      MODAKM=0
140    CALL LANCHV(SATWT,MODES,MODAKM,IVHCL,VCOST)
      WRITE(IOUT,9660)MODES,MODAKM,IVHCL,VCOST
      IF(MODES.EQ.1) GO TO 160
      IF (MODAKM.EQ.1) GO TO 155
      COSTV=VCOST
      IV=IVHCL
      MODAKM=1
      GO TO 140
155    IF(COSTV.LT.VCOST)VCOST=COSTV
160   EU=5.1
      SATCST=0.158*(SATWT**0.6158)*((NOSAT+EU)**0.9684)
      SPCOST=NOSAT*VCOST+SATCST
      CSYS=CTGD+SPCOST
      WRITE(IOUT,9800)CSYS,CTGD,SPCOST
      IF(MODSTB.NE.3)GO TO 170
      IF (MODES.EQ.2) GO TO 170
      XSYS=CSYS
      MODES=2
      GO TO 150
170   ITC=ITC+1
      IF(XSYS.LT.CSYS)CSYS=XSYS
      IF(IZOOM.EQ.0)GO TO 301
      ICNT=ICNT+1
      IF(ICNT.EQ.NPTS)GO TO 99
      GO TO 4000
```

```
301  IF(TSYS.LT.CSYS)GO TO 98
     TSYS=CSYS
     JKEY=3
     WRITE(IOUT,9998)JKEY
     GO TO 4000
98   IZOOM=1
     DELERP=3.*ERPM(I)/(NPTS+1)
     ICNT=0
     WRITE(IOUT,9999)IZCOM
     GO TO 4000
99   CALL EXIT
8000 FORMAT()
9500 FORMAT('1SYSTEM DESCRIPTION'/5X,'SAT LONG',F10.4,6X,
    1'SATELLITES',I4,6X,'BROADCAST',I5,' HRS'/5X,'SAT LAT',
    2F11.4,6X,'TV CHAN',I7,6X,'SAT LIFE',I6,' YRS'/5X,'PT ERR',
    3F12.4,6X,'NO. BEAMS',I5,6X,'START YR',I9/5X,'STAB MODE',
    4I4,11X,'AUD CHAN/TV',I3,6X,'NC POINTS',I5/)
9501 FORMAT('OFREQUENCY PLAN',/(5X,E12.8,' HZ'))
9507 FORMAT(5X,'SPECF',F11.2,' DB',6X,'GRD ANT BW',F6.2,' DEG'/
    15X,'SAT ANT EFF',F6.3,8X,'ERP MAX',E13.8,' WATTS'/)
9502 FORMAT('OBEAM CHARACTERISTICS NO.',I3,' ******'/
    15X,'REC LONG',F11.4,14X,'REC LAT',F13.4/
    25X,'BC LONG',F12.4,14X,'BC LAT',F14.4/
    35X,'SAT ANT BW',F9.4,14X,'GRD ANT EFF',F9.4/
    45X,'MAX VID BW',E16.8,' HZ',4X,'MAX AUD BW',E17.8,' HZ'/
    55X,'RAIN RATE',F9.2,3X,'MM/HR',7X,'MAN MADE NOISE',I5/
    65X,'REL HUMIDITY',I5,16X,'GALACTIC NOISE',I5/
    75X,'NO RECEIVERS',I8,13X,'REC SPECIFIED',I6/
    85X,'PROB SCINT',F10.4,2X,' '/)
9503 FORMAT('ORECEIVER CHARACTERISTICS'/5X,'VIDEO SUB GUARD',
    1E12.6,' HZ',5X,'SUB CAR GUARD',E14.6,' HZ'/5X,
    2'CAR PEAK DEV',E15.6,' HZ',5X,'FM THRESHHOLD',F7.2.' DB'/5X,
    3'VIDEO T MRG',F10.3,6X,' DB',5X,'AUD-SC T MRG',F8.2,' DB'/5X,
    4'MAX RF BW',6X,E12.6,' HZ',5X,'RF-BW-K-FAC',F10.3/5X,
    5'VIDEO K-FAC',F10.3,6X,' DB',5X,'REQ VIDEO S/N',F8.3,' DB'/
    65X,'REQ AUD S/N',F10.3,6X,' DB',5X,'CABLE LOSS',F11.3,' DB')
9600 FORMAT('1GROUND SEGMENT CHARACTERISTICS',10X,I3/5X,
    1'GRD ANT COST',F10.2,' $',10X,'RECEIVR COST',F10.2,' $'/
    25X,'GRD ANT DIAM',F10.2,' MET',8X,'RECEIVR TYPE',I8/5X,
    3'SAT ANT GAIN',F10.2,' DB',9X,'REC NOISE T ',F10.2,' DEG K'/
    45X,'GRB ANT BMWD',F10.2,' DEG',8X,'REC ELEV ANG',F10.2,
    5' DEG'/5X,'REQ VIDEO S/N',F9.2,' DB',9X,'SYS NOISE T ',
    6F10.2,' DEG K'/5X,'C/N VID THRS',F10.2,' DB',9X,
    7'RF BANDWIDTH',E10.7,' HZ'/5X,'VID THRS IMP',F10.2,' SEC'/)
9620 FORMAT((5X,'RFPWR/TV CHAN',F9.2,' WATTS',8X,'EIRP',8X,F9.2,
    1' WATTS')/)
9660 FORMAT('OLAUNCH VEHICLE'/5X,'STAB MODE',I3,5X,'AKM MODE',
    1I3,5X,'VEHICLE',I3,5X,'COST $',F8.5/)
```

```
9800 FORMAT('OCOSTS'/5X,'SYSTEM',F10.5,' M$',5X,'GROUND',F10.5,
    1' M$',5X,'SPACE',F10.5,' M$'/)
9650 FORMAT('OSATELLITE CHARACTERISTICS'/5X,'SAT WEIGHT',F9.2,
    1'   LBS',9X,'ANT WEIGHT',F9.2,'  LBS'/5X,'ANT DIAMTR',
    2F9.2,'  FEET',9X,'XPONDER WT',F9.2,'  LBS'/5X,
    3'COMM POWER',F9.2,' WATTS',9X,'PWR SYS WT',F9.2,'  LBS'/
    45X,'HEAT DISSP',F9.2,' WATTS',9X,'STAB-AC WT',F9.2,'  LBS'/
    55X,'POWER, BOL',F9.2,' WATTS',9X,'THERM CONT',F9.2,'  LBS'/
    65X,'ARRAY AREA',F9.2,' SQ FT',9X,'STRUCTURE',F10.2,'  LBS'/)
9998 FORMAT('OJKEY=',I3/)
9999 FORMAT('OIZOOM=',I3/)
9997 FORMAT('OERPMZ=',E15.8/)
        END
        GRDSG,,GRDSG
      SUBROUTINE GRDSG(SLOD,SLAD,N,NS,RLOD,RLAD,PLCD,PLAD,
    1 FV,FA,AEFFC,ABWMN,RR,IENV,IHUMD,IG,FCAR,BGVSC,BGSSC,DA,
    2 T,VTMDB,ATMDB,BMAX,BWK,VKFDB,SNRVD,SNRSD,CBLDB,IKEY,
    3 SABWD,SPECF,SAEFC,ERPMX,POR, TSYS,TREC,DIA,P,B,
    4FR,ELARD,ARADB,SCNDB,GOGT,SAGDB,ABMWD,EIRP,CONVT,VTIR)
      DIMENSION FCAR(1),ARADB(1),CART(6),ATEMP(6),TR(6),TSYS(1)
      DIMENSION C(6),EIRP(1),SCNDB(6),P(1)
      DIMENSION FR(1),X(10),G(200)
      IF(IKEY-2)10,60,41
10    CALL COVRN(FV,NS,BGVSC,BGSSC,FA,DA,VKFDB,BMAX,
    1 BWK,T,VTMDB,ATMDB,SNRVD,SNRSD, CONDB,COVRT,B,X,DP,FR,BIF,
    2CONVT,VTIR)
      FCARC=SQRT(FCAR(1)*FCAR(N))
      SAG=SAEFC*(208.8/SABWD)**2
      SAGDB=10.*ALOG(SAG)/ALOG(10.)
      IF(ERPMX) 14,14,40
   14 CALL ERPM(FCARC,SABWD,SLAD,SLOD,PLAD,PLOD,SPECF, ERPMX)
40    DIA=1.99251E10/FCARC/ABWMN
41    ERP=ERPMX
      IF(FCARC-2.0E9)44,42,42
42    IF(FCARC-12.2E9)47,47,44
   44 DO 46 I=1,N
      SCNDB(I)=0
   46 CONTINUE
      GO TO 49
   47 DO 48 I=1,N
      CALL SCINT(POR,RLAD,FCAR(I), SCNDB(I))
   48 CONTINUE
   49 CALL GEOM(SLAD,SLOD,RLAD,RLOD,PLAD,PLOD, ELARD,ANPRD,DISTR)
      DO 50 I=1,N
      ARADB(I)=0.14*RR**1.155*(FCAR(I)/1.6E10)**3
   50 CONTINUE
   60 DO 70 I=1,N
      CART(I)=ERP*AEFFC*(FCARC*DIA/FCAR(I)/4./DISTR)**2*10.**
    1(-1.20412*(ANPRD/SABWD)**2)*10.**((ARADB(I)+SCNDB(I))/10.)
```

```
   70 CONTINUE
      CALL ANTGA(FCARC,DIA,AEFFC, G,ABMWD)
      DO 80 I=1,N
      CALL ANTEP(FCAR(I),RR,IENV,IHUMD,IG,ELARD,G, ATEMP(I))
   80 CONTINUE
      DO 90 I=1,N
      TR(I)=CART(I)/COVRT-ATEMP(I)
   90 CONTINUE
      TRECC=TR(1)
      DO 110 I=2,N
      IF(TRECC-TR(I)) 110,110,100
  100 TRECC=TR(I)
  110 CONTINUE
      DO 120 I=1,N
      TSYS(I)=ATEMP(I)+TRECC
  120 CONTINUE
      DO 130 I=1,N
      C(I)=TSYS(I)*COVRT
      EIRP(I)=ERP*C(I)/CART(I)
  130 CONTINUE
      CBLOS=10.**(CBLDB/10.)
      TCABL=290.*(CBLOS-1.0)
      TREC=(TRECC-290.*(CBLOS-1.))/CBLOS
      DO 140 I=1,N
      P(I)=EIRP(I)/SAG
  140 CONTINUE
      GOGT=G(1)
      RETURN
      END
      SCINT,,SCINT
      SUBROUTINE SCINT (POR,GL,FCAR, SCNDB)
C POR=PERCENTAGE OF TIME SCINTILLATION SCNDB
C GL=GEOMAGNETIC LATITUDE
C FCAR=CARRIER FREQUENCY
C SCNDB=DB VARIATION FROM AVERAGE PWR LEVEL
      IF (POR-96.0) 1,1,2
    2 IF (POR-98.5) 11,11,12
   12 S=-86141862.0+2613170.0*POR-26424.3*POR**2+89.0689*POR**3
      SA=S*0.01
      GO TO 7
   11 SA=0.24*(POR-96.0)+7.7
      GO TO 7
    1 IF (POR-90.0) 3,3,4
    4 SA=1.7*(POR-90.0)/6.0+6.0
      GO TO 7
    3 IF (POR-80.0) 5,5,6
    5 SA=0.0
      GO TO 7
    6 SA=0.25*(POR-80.0)+3.5
    7 IF (GL-30.0) 8,8,9
    9 SCNDB=0.0
      GO TO 10
```

```
  8 F=FCAR/(10**9)
    B=(30.0-GL)*4/(17*F)
    SCNDB=SA*B**2
 10 RETURN
    END
      LANCHV,,LANCHV
    SUBROUTINE LANCHV(WT,MODES,MDAKM,IVHCL,VCOST)
    DIMENSION TREAX(20),SPIN(20),SPAKM(20)
    DIMENSION CSPIN(20),C3AX(20),CSPAK(20)
    DATA(SPIN(I),I=1,10)/500.,635.,810.,970.,1900.,1900.,
   13400.,4500.,7200.,9000./
    DATA(SPAKM(I),I=1,21)/450.,460.,523.,540.,575.,595.,635.,
   1703.,715.,795.,1100.,1200.,1340.,1500.,1680.,1820.,2070.,
   24610.,6100.,7400.,9400./
    DATA(TREAX(I),I=1,12)/500.,635.,810.,970.,1750.,1800.,
   12800.,3400.,3800.,4500.,7200.,9000./
    DATA(CSPIN(I),I=1,10)/10.2,10.2,10.2,11.9,15.0,16.1,25.6,
   126.8,28.2,29.9/
    DATA(CSPAK(I),I=1,21)/6.7,6.7,6.7,7.0,7.0,7.2,7.0,7.2,6.8,
   16.8,10.8,10.8,10.8,12.4,15.5,15.5,16.6,25.9,27.3,28.8,30.4/
    DATA(C3AX(I),I=1,12)/10.2,10.2,10.2,11.9,15.0,16.1,21.0,
   125.6,26.1,26.8,28.2,29.9/
    KEY =MODES+MDAKM
    GO TO (10,20,30),KEY
10     DO   18 I=1,11
     IF(WT-TREAX(I)) 19,19,18
18      CONTINUE
     GO TO 50
19       IVHCL=I
    VCOST =C3AX (I)
     RETURN
20  DO 28 I=1,13
    IF(WT-SPIN(I)) 29,29,28
28   CONTINUE
    GO  TO 50
29   IVHCL=I
     VCOST=CSPIN(I)
    RETURN
30   DO 38 I=1,27
      IF(WT-SPAKM(I)) 39,39,38
38   CONTINUE
     GO TO 50
39   IVHCL=I
     VCOST =CSPAK(I)
     RETURN
50   IVHCL=0
     VCOST =10.E15
     RETURN
     END
```

```
        COVRN,,COVRN
      SUBROUTINE COVRN(FV,NS,BGVSC,BGSSC,FA,DA,VKFDB,BMAX,
     1 BWK,T,VTMDB,ATMDB,SNRVD,SNRSD, CONDB,COVRT,B,X,DP,FR,BIF,
     2CONVT,VTIR)
C FV=VIDEO BANDWIDTH,NS=NO. OF SIGNALS=VIDEO+AUDIO SUBCARRIERS
C BGVSC=VIDEO-SUBCARRIER GUARD BAND
C BGSSC=SUBCARRIER-SUBCARRIER GUARD BAND
C FA=HIGHEST AUDIO FREQUENCY - DA=PEAK DEVIATION OF SUBCARRIER
C VKFDB=VIDEO K FACTOR (DB) - BMAX=MAX RF CARRIER BANDWIDTH
C BWK=RF BANDWIDTH K FACTOR - T=FM THRESHOLD DEFINITION (DB)
C VTMDB=VIDEO THRESHOLD MARGIN (DB) - ATMDB=AUDIO SUBCARRIER
C THRESHOLD MARGIN (DB) - SNRVD=REQD VIDEO SNR (DB)
C SNRSD=REQD SOUND SUBCARRIER TO NOISE RATIO (DB)
C CONDB=REQD CARRIER-TO-NOISE RATIO (DB)
C B=REQD RF BANDWIDTH
C X(I)=PEAK DEV RESULTING FROM ITH SIGNAL ONLY
C DP=PEAK DEV OF RF CARRIER
C FR(1)=FV=VIDEO BANDWIDTH - FR(I)=SUBCARRIER FREQ FOR I 1
C BIF=BANDWIDTH OF SUBCARRIER
      DIMENSION FR(1),X(1)
      PKDV(B,BWK,FMAX)=BWK*(B/2.0-FMAX)
      BW(DP,BWK,FMAX)=2.0*(FMAX+DP/BWK)
      NUFDB(DB)=10.0**(DB/10.0)
      FR(1)=FV
      DELPD=0.1E6
      IOUT=6
      VKF=NUFDB(VKFDB)
      SNRV=NUFDB(SNRVD)
      SNRA=NUFDB(SNRSD)
      BIF=BW(DA,1.0,FA)
      DO 10 I=2,NS
      FR(I)=FR(1)+BGVSC+BIF/2.0+(BIF+BGSSC)*(I-2)
   10 CONTINUE
      FMAX=FR(NS)+BIF/2.0
      B=BMAX
      DPMAX=PKDV(B,BWK,FMAX)
      DP=DPMAX
      J=0
   15 CALL THRES(T,0,FR(1),B,DP, CONVT)
      J=J+1
      IF(J-50) 18,16,16
   16 WRITE(IOUT,17)J
   17 FORMAT(1X,'J=',I3)
      STOP
   18 CONV=CONVT+VTMDB
      F1=FR(2)-BIF/2.0
      F2=FR(2)+BIF/2.0
      CALL THRES(T,F1,F2,B,DP, CONAT)
      CONA=CONAT+ATMDB
      IF(CONA-CONV) 20,30,30
```

```
   20 CONDB=CONV
      GO TO 40
   30 CONDB=CONA
   40 COCN=NUFDB(CONDB)
      COLN=B*COCN
      X(1)=SQRT(SNRV*FR(1)**3/6.0/COLN/VKF)
      DO 50 I=2,NS
      F1=FR(I)-BIF/2.0
      F2=FR(I)+BIF/2.0
      X(I)=SQRT(2.0*SNRA*(F2**3-F1**3)/3.0/COLN)
   50 CONTINUE
      CALL PCEV(X,NS, DP1)
      DEL=DP1-DP
      IF(ABS(DEL)-DELPD)70,70,60
   60 DP=(DP+DP1)/2.0
      B=BW(DP,BWK,FMAX)
      GO TO 15
   70 IF(B-BMAX) 100,100,80
   80 DPRAT=DPMAX/DP
      DO 90 I=1,NS
      X(I)=X(I)*DPRAT
   90 CONTINUE
      DP=DPMAX
      B=BMAX
      COLN=COLN/DPRAT**2
      COCN=COLN/BMAX
  100 CONDB=10.0*ALOG(COCN)/ALOG(10.0)
      COVRT=1.38054E-23*B*COCN
      CALL THRES(T,0,FV,B,DP,CONVT)
      CNVTR=NUFDB(CONVT)
      CALL NTCON(B,DP,CNVTR,Y)
      VTIR=Y/CNVTR
      RETURN
      END
        THRES,,THRES
      SUBROUTINE THRES(T,F1,F2,B,D, R9)
C SUBROUTINE FOR C/N WITH THRESHOLD T IN DB. F1 AND F2 ARE
C THE ENDS OF THE DEMODULATED SIGNAL BAND IN HZ. B IS RF BW
C IN HZ AND D IS DEV IN HZ.
C R9=C/N THRESHOLD IN DB
      T2=.05
      P=4*ATAN(1)
      R9=10.0
```

```
      Y0=(F1**2+F2**2+F1*F2)/6.0/B*(10.0**(T/10.0)-1.0)
      R=10.0**(R9/10.0)
  220 CALL NTCON(B,D,R, Y)
      S1=(Y-Y0)/ABS(Y-Y0)
      R9=R9+S1
      R=10.0**(R9/10.0)
      CALL NTCON(B,D,R, Y)
      S2=(Y-Y0)/ABS(Y-Y0)
      IF (S1*S2) 290,270,270
  270 S1=S2
      GO TO 220
  290 J=1
  300 R9=R9+(Y-Y0)/ABS(Y-Y0)/2.0**J
      R=10.0**(R9/10)
      CALL NTCON(B,D,R, Y)
      IF(2.0**(-J)-T2) 360,340,340
  340 J=J+1
      GO TO 300
  360 RETURN
      END
        NTCON,,NTCON
      SUBROUTINE NTCON(B,D,R, Y)
C SUBROUTINE FOR (N TIMES C/N PWR RATIO)
      R5=B/3.464102
      A=.5*(D/R5)**2
      CALL BESSL(A*R,AI0)
      P=4*ATAN(1)
      Y=(D*EXP(-R)/P+R5*EXP(-R*(1.0+A))*AI0/SQRT(4.0*P*R))*2*R
      RETURN
      END
        BESSL,,BESSL
      SUBROUTINE BESSL(X,Y)
C SUBROUTINE FOR BESSEL FCN Y=I0(X) FOR X =-3.75
      IOUT=6
      T=X/3.75
      IF (X+3.75)730,610,610
  610 IF (X-3.75) 620,620,670
  620 Y=1.0+3.5156229*T**2+3.0899424*T**4+1.2067492*T**6
     1 +.2659732*T**8+.0360768*T**10+.0045813*T**12
      GO TO 750
  670 Y=EXP(X)/SQRT(X)*(.39894228+.01328592/T+.00225319/T**2
     1 -.00157565/T**3+.00916281/T**4-.02057706/T**5
     2 +.02635537/T**6-.01647633/T**7+.00392377/T**8)
      GO TO 750
  730 WRITE(IOUT,731)
  731 FORMAT(1X,'X -3.75 NOT ALLOWED')
      STOP
  750 RETURN
      END
```

```
         PDEV,,PDEV
      SUBROUTINE PDEV(X,NS, DP)
C PEAK DEV. IS CALCULATED FROM THE NS COMPONENT DEVIAIONS X(I)
      DIMENSION X(1)
      DP=0
      DO 10 I=1,NS
      DP=DP+X(I)
   10 CONTINUE
      RETURN
      END
         GEOM,,GEOM
      SUBROUTINE GEOM(SLAD,SLOD,RLAD,RLOD,PLAD,PLOD, ELARD,ANPRD,
     1 DISTR)
C INPUT SLAD,SLOD,RLAD,RLOD--OUTPUT ELARD,DISTR
C SLAD IS SAT LAT IN DEG--SLOD IS SAT LONG IN DEG
C RLAD IS EARTH REC LAT IN DEG--RLOD IS REC LONG IN DEG
C PLAD IS POINTING LAT IN DEG--PLOD IN POINTING LONG IN DEG
C ELARD IS ELEV ANGLE OF EARTH STATION ANTENNA IN DEG
C ANPRD IS ANGLE (DEG) OF RECEIVER OFF SATELLITE BEAM CENTER
C DISTR IS THE DISTRANCE BETWEEN SAT AND EARTH STA IN METERS
      RTOD=57.295779513
      R=6378388.0
      H=35793604.0
      RANDH=R+H
      SLAR=SLAD/RTOD
      SLOR=SLOD/RTOD
      RLAR=RLAD/RTOD
      RLOR=RLOD/RTOD
      PLAR=PLAD/RTOD
      PLOR=PLOD/RTOD
      COERS=SIN(SLAR)*SIN(RLAR)+COS(SLAR)*COS(RLAR)*COS(SLOR-RLOR)
      SINA=SQRT(1.0-COERS**2)
      IF (SINA) 20,10,20
   10 ELARD=90
      GO TO 30
   20 ELAR=ATAN(COERS/SINA-R/(RANDH*SINA))
      ELARD=ELAR*RTOD
   30 DSQR=R**2+RANDH**2-2.0*R*RANDH*COERS
      DISTR=SQRT(DSQR)
      COERP=SIN(PLAR)*SIN(RLAR)+COS(PLAR)*COS(RLAR)*COS(PLOR-RLOR)
      CHOSQ=R**2*(2.0*(1.0-COERP))
      COEPS=SIN(SLAR)*SIN(PLAR)+COS(SLAR)*COS(PLAR)*COS(SLOR-PLOR)
      DSQP=R**2+RANDH**2-2.0*R*RANDH*COEPS
      DISTP=SQRT(DSQP)
      COSPR=(DSQR+DSQP-CHOSQ)/2.0/DISTR/DISTP
      P2=1.5707963
      ANPRR=ATAN(SQRT(1.-COSPR**2)/COSPR)+(1.-COSPR/ABS(COSPR))*P2
      ANPRD=ANPRR*RTOD
      RETURN
      END
```

```
        ERPM,,ERPM
      SUBROUTINE ERPM(F,SABWD,SLAD,SLOD,PLAD,PLOD,SPECF, ERPMX)
C F=CARRIER FREQ (HZ)
C SLAD=SAT LAT IN DEG - SLOD=SAT LONG IN DEG
C PLAD=POINTING LAT IN DEG - PLOD=POINTING LONG IN DEG
C SPECF IS SPECTRUM FACTOR IN DB RELATING CARRIER POWER TO
C    HIGHEST POWER IN ANY 4.0-KHZ BAND
C ERPMX IS MAX ALLOWABLE EIRP OF SAT CHANNEL IN WATTS
      DELAD=1.0
C DELAD=DEG INCREMENT ALONG A GREAT CIRCLE ON EARTH SURFACE TO
C    DETERMINE MAX EIRP OF SAT
       P2=1.5707963
       R=6378388.0
       H=35793604.0
       RTOD=57.295779513
       F1=620.0E6
       F2=790.0E6
       F3=2.5E9
       F4=2.69E9
       F5=11.7E9
       F6=12.2E9
  110 IF(F-F1) 300,210,120
  120 IF(F-F2) 210,210,130
  130 IF(F-F3) 300,220,140
  140 IF(F-F4) 220,220,150
  150 IF(F-F5) 300,230,160
  160 IF(F-F6) 230,230,300
  210 M=1
      GO TO 320
  220 M=2
      GO TO 320
  230 M=3
      GO TO 320
  300 WRITE(6,310) F
  310 FORMAT(1X,'FREQUENCY=',1PE15.7,'NOT ACCEPTABLE TO ERPM SUB')
      STOP
  320 SLAR=SLAD/RTOD
      SLOR=SLOD/RTOD
      PLAR=PLAD/RTOD
      PLOR=PLOD/RTOD
      CALFA=SIN(SLAR)*SIN(PLAR)+COS(SLAR)*COS(PLAR)*COS(SLOR-PLOR)
      IF(CALFA) 390,395,390
  390 ALFAR=ATAN(SQRT(1.-CALFA**2)/CALFA)+(1.-CALFA/ABS(CALFA))*P2
      GO TO 397
  395 ALFAR=90./RTOD
  397 ALFAD=RTOD*ALFAR
      CAMXR=ATAN(SQRT(1.0-(R/(R+H))**2)*(R+H)/R)
      CAMXD=RTOD*CAMXR
      CAD=0.0
      ERPMX=1.0E37
```

```
  400 CALL GEOM(0.0,0.0,0.0,CAD,0.0,ALFAD, ELARD,ANPRD,DISTR)
      IF(M-2) 410,510,510
  410 IF(ELARD-20.0) 710,710,420
  420 IF(ELARD-60.0) 720,730,730
  510 IF(ELARD-5.0) 810,810,520
  520 IF(ELARD-25.0) 820,830,830
  710 P=10.**-12.9
      GO TO 1000
  720 P=10.**(-12.9+(ELARD-20.0)/25.0)
      GO TO 1000
  730 P=10.**-11.3
      GO TO 1000
  810 P=10.0**((-152.+SPECF)/10.)
      GO TO 1000
  820 P=10.**((-152.0+.75*(ELARD-5.0)+SPECF)/10.)
      GO TO 1000
  830 P=10.**((-137.+SPECF)/10.)
 1000 GLODB=12.0412*(ANPRD/SABWD)**2
      IF(GLODB-20.) 1007,1005,1005
 1005 GLODB=20.
 1007 EIRPV=12.5663706*P*DISTR**2*10.**(GLODB/10.)
      IF(EIRPV-ERPMX) 1010,1020,1020
 1010 ERPMX=EIRPV
 1020 CAD=CAD+DELAD
      IF(CAD-CAMXD) 400,1030,1030
 1025 FORMAT(1X,1P5E12.6)
 1030 RETURN
      END
        ANTGA,,ANTGA
      SUBROUTINE ANTGA(FA,DIA,AEFF, G,B)
C AEFF  ANTENNA EFFICIENCY
C FA=RF FREQUENCY - DIA=DIA OF PARABOLIC DISH (METER)
C G(I) IS ANTENNA GAIN VECTOR (DB) WHERE I=1+(DEG OFF BEAM CENTER)
C B=ANTENNA BEAMWIDTH IN DEG
      DIMENSION G(1)
      AL=(1.1811*10**10)/FA
      D=DIA/0.0254
      B=1.16*57.295779513*AL/D
      R=D/2
      VO=AEFF*39.5*((R/AL)**2)
      VO=SQRT(VO)
      C1=VO*0.581
      C2=VO*0.419
      DO 1 I=1,91,2
      T1=(I-1)/57.3
      U=(D*3.1416/AL)*SIN(T1)
      IF (U) 2,2,3
    2 B1=1
      B3=1
      GO TO 4
```

```
    3 IF (U-3.0) 5,5,6
    5 A0=1.-2.25*(U/3)**2+1.26562*(U/3)**4-0.31639*(U/3)**6
     1+0.04444*(U/3)**8-0.00394*(U/3)**10+0.21094*(U/3)**12
      A1=U*(0.5-0.5625*(U/3)**2+0.21094*(U/3)**4
     1-0.03954*(U/3)**6+0.00443*(U/3)**8-0.00032*(U/3)**10)
      GO TO 7
    6 F0=0.79788-0.00527*(3/U)**2-0.0001*(3/U)**3
     1+0.00137*(3/U)**4-0.00073*(3/U)**5+0.00015*(3/U)**6
      F1=0.79788+0.0166*(3/U)**2+0.00017*(3/U)**3
     10.00249*(3/U)**4+0.00114*(3/U)**5-0.0002*(3/U)**6
      T0=U-0.7854-0.04166*(3/U)-0.00004*(3/U)**2+0.00263*(3/U)**3
     1-0.00054*(3/U)**4-0.00029*(3/U)**5+0.00014*(3/U)**6
      T1=U-2.35619+0.125*(3/U)+0.000056*(3/U)**2-0.00638*(3/U)**3
     1+0.00074*(3/U)**4+0.000798*(3/U)**5-0.00029*(3/U)**6
      A0=F0*COS(T0)/SQRT(U)
      A1=F1*COS(T1)/SQRT(U)
    7 A2=2*A1/U-A0
      A3=4*A2/U-A1
      B1=A1*2/U
      B3=6*A3/((U/2)**3)
    4 V=C1*B1+C2*B3
      D8=8.686*ALOG(ABS(V))
    1 G(I)=D8
      DO 10 I=93,181,2
   10 G(I)=-20.0
      RETURN
      END
        ANTEP,,ANTEP
      SUBROUTINE ANTEP(FQ,RR,IENV,IHUMD,IG,ELAD,G, ATEMP)
C FQ=RF FREQ - RR=RAIN RATE IN MM/HOUR
C IENV=MAN-MADE NOISE ENVIRONMENT
C IENV=0 NO MAN-MADE NOISE - IENV=1 RURAL
C IENV=2 SUBURBAN - IENV=3 URBAN
C IHUMD=HUMIDITY INDEX
C IHUMD=1 DRY - IHUMD=2 AVERAGE - IHUMD=3 HUMID
C IG=1 FOR CASSIOPEIA OR GENERAL GALACTIC NOISE LEVEL
C IG=2 FOR GALACTIC PLANE
C IG=3 FOR QUIET SUN - IG=4 FOR DISTURBED SUN
C ELAD=ANTENNA ELEV (DEG) - G(I) IS THE ANTENNA GAIN VECTOR (DB)
C WHERE I=1+(DEG OFF BEAM CENTER)
C ATEMP=ANTENNA NOISE TEMP (DEG K)
      DIMENSION TS(100),T(200),DT(200),DF(200),D(200),AT(200)
      DIMENSION G(1),GA(200),B(200),B1(200)
      G0=G(1)-2.14
      DO 6 I=1,181,2
    6 GA(I)=10.0**(G(I)/10.0)
      FR=FQ*1.0E-6
      FG=FR/1000.
```

```
C GALACTIC NOISE (FUNCTION OF FREQUENCY)=TG
      IF (IG-1)70,70,71
   70 AGA=-50.0-33.333*ALOG(FG)/ALOG(10.)+GO
      GO TO 72
   71 IF(IG-3)73,74,75
   73 AGA=-20.0-11.1111*ALOG(FG)/ALOG(10.)+GO
      GO TO 72
   74 AGA=-19.-23.3*ALOG(FG)/ALOG(10.)+GO
      GO TO 72
   75 AGA=-9.-23.3*ALOG(FG)/ALOG(10.)+GO
   72 TG=2900.0*10.**(AGA/10.)
C PRECIPITATION NOISE (FUNCTION OF FREQUENCY)=TP
      FK=FG/16.0
      AFG=-0.14*(RR**1.155)*(FK**3)
      TP=273.0*(1.0-10.0**(AFG/10.))
C MAN-MADE NOISE=TM
      IF (IENV-2) 201,202,203
  201 IF (IENV) 204,204,205
  205 WMN=-155.4-25.*ALOG(FR/3.)/ALOG(10.)
      GO TO 200
  202 WMN=-142.2-24.*ALOG(FR/3.)/ALOG(10.)
      GO TO 200
  203 WMN=-132.2-22.5*ALOG(FR/3.)/ALOG(10.)
      GO TO 200
  204 TM=0.0
      GO TO 206
  200 WMM=WMN/10.0+23.0
      TM=(10.0**WMM)/1.3804
  206 IF (IHUMD-2) 210,211,212
  212 DO 220 I=1,6
  220 TS(I)=290.-(290.-EXP(2.84+.163*FG-.00116*(FG**2)))*.2*(I-1)
      DO 221 I=7,11
  221 TS(I)=EXP(2.84+0.163*FG-0.00116*(FG**2.))-(1.0-(I-6)*0
     1.2)+EXP(2.258+0.102*FG+0.00037*(FG**2.))*(I-6)*0.2
      DO 222 I=12,31
  222 TS(I)=EXP(2.258+0.142*FG+0.00737*(FG*2.))*(1.-(I-11)/2
     10.)+EXP(1.245+0.139*FG+0.002*(FG**2.))*(I-11)/20
      DO 223 I=32,91
  223 TS(I)=EXP(1.245+0.139*FG+0.002*(FG**2.0))*(1.-(I-31)/6
     10.)+EXP(0.42+0.274*FG-0.00395*(FG**2.))*(I-31)/60
      GO TO 301
  211 DO 230 I=1,6
  230 TS(I)=290.0-(290.0-EXP(2.93+0.0284*FG+0.00442*(FG**2.)
     1))*(I-1)*0.2
      DO 231 I=7,11
  231 TS(I)=EXP(2.93+0.0284*FG+0.0442*(FG**2.))*(I-6)*0.2+EX
     1P(2.4+0.002*FG+0.00537*(FG**2.0))*(I-6)*0.2
      DO 232 I=12,31
```

```
  232 TS(I)=EXP(2.4+0.002*FG+0.00527*(FG**2.))*(1.-(I-11)/20
     1.)+EXP(1.36+0.027*FG+0.00442*(FG**2.0))*(I-1)/20.0
      DO 233 I=32,91
  233 TS(I)=EXP(1.36+0.027*FG+0.00442*(FG**2.))*(1.0-(I-31)/
     160.)+EXP(0.68+0.007*FG+0.00643*(FG**2.0))*(I-31)/160.0
      GO TO 301
  210 DO 240 I=1,6
  240 TS(I)=54.0*(6-I)+20
      DO 241 I=7,11
  241 TS(I)=2.*(11-I)+10
      DO 242 I=12,31
  242 TS(I)=0.3*(31-I)+4.0
      DO 243 I=32,91
  243 TS(I)=(91-I)/30.0+2.0
  301 CONTINUE
C ENVIRONMENTAL NOISE TEMPERATURE AS FUNCTION OF ELEV ANGLE
C DENOTED AS T(I), WHERE I IS IN DEGREE, I=181 AT ZENITH
      DO 302 I=1,90
  302 T(I)=290.0
      DO 303 I=91,100
  303 T(I)=TS(I-90)+TM+TP
C IN THE ABOVE CALCULATION THE MAN-MADE NOISE IS ASSUMED
C ONLY AT ELEVATION ANGLE FROM 0 TO 10 DEGREES.
      DO 304 I=101,181
  304 T(I)=TS(I-90)+TP
C THE FOLLOWING IS FOR CALCULATING THE ANTENNA NOISE TEMP
C OF THE PENCIL BEAM ANTENNA
C ELAD=ELEVATION ANGLE IN DEGREE
      DO 400 I=1,181,2
      DO 401 J=1,181,5
C I=PHI
C J=THETA
      P1=(SIN((I-1)/57.2))*COS((J-1)/57.2)
      P2=ATAN(P1/(SQRT(1.-P1**2.)))
      IF (I-91) 420,420,421
  420 P3=(P2*57.2+ELAD)
      K=P3+91
      GO TO 422
  421 P3=(P2*57.2-ELAD)
      K=P3+91
  422 IF (K-181) 412,412,431
  431 K=361-K
  412 DTH=5.0/57.2
C DTH=INCREMENT IN THETA DIRECTION IN RADIAN
  401 DT(J)=T(K)*DTH*2.0*GA(I)*SIN(I/57.3)
      DO 402 L=1,181,5
      DF(1)=0
  402 DF(L+5)=DT(L)+DF(L)
      D(I)=DF(186)*2.0/57.2
      AT(1)=0
```

```
  400 AT(I+2)=AT(I)+D(I)
      AT1=AT(183)
      DO 403 I=1,181,2
      B1(1)=0.0
      B(I)=GA(I)*2*3.1416*2*SIN(I/57.3)/57.3
  403 B1(I+2)=B1(I)+B(I)
      AGD=B1(183)
      ATEMP=AT1/AGD+TG
      RETURN
      END
        ANCTP,,ANCTP
      SUBROUTINE ANCTP (D,Q, ANTCT)
C     D=ANT. DIA  - Q=TOTAL QUANTITY
C     ANTCT=TOTAL UNIT COST IN DOLLARS
      DF=D/0.3048
      X=ALOG(Q)/ALOG(10.)
      C0=1.889*10**(-3)
      C1=-0.144752
      C2=-1.4466*10**(-2)
      C3=9.453*10**(-4)
      Y=C0+C1*X+C2*X**2+C3*X**3
      QI=10**Y
      ANTCT=(177.5+2.74*DF**2.5)*QI
      RETURN
      END
        RCCST,,RCCST
      SUBROUTINE RCCST (FCAR,SNT,RQ,BY,KRI,RC,IPAT)
      Y=BY-1969.
      F=FCAR*1.0E-9
      TN=1243.57+133.1*F-9.7*F*F+0.538*F**3
      TS=164.2*F+530.4
      IF (F-2.25) 360,360,390
  360 TD=570.0
      TP=350.0
      GO TO 410
  390 TD=593.3-14.786*F+3.94446*F*F
      TP=240.39+48.8*F-0.0389*F*F
      IF (SNT-TP) 391;401,401
  391 IPAT=100
  392 RC=0.0
      GO TO 680
  401 IF (KRI-4) 402,410,410
  402 IF (KRI-1) 420,460,403
  403 IF (KRI-3) 490,510,510
  410 IF (SNT-TN) 440,420,420
  420 RC1=39.9+1.648*F-0.0696*F*F
      IPAT=0
      GO TO 540
  440 IF (F-2.25) 450,450,480
```

```
450 IF (SNT-TS) 480,460,460
460 RC1=41.355+4.285*F
    IPAT=1
    GO TO 540
480 IF (SNT-TD) 510,490,490
490 RC1=48.147+0.86*F
    IF (F-2.25) 492,492,494
492 RC1=5.5*(F-0.85)/1.4+46.5
    GO TO 498
494 IF (F-8.45) 495,495,497
495 RC1=4*(F-2.25)/6.2+52.0
    GO TO 498
497 RC1=2.5*(F-8.45)/3.75+56.0
498 IPAT=2
    GO TO 540
510 RC1=46.81+6.677*F-0.724*F*F+0.02722*F**3
    IPAT=3
    IF (SNT-TP)530,540,540
530 RC1=0.0
    IPAT=100
540 IF (F-2.25) 550,550,590
550 RC=RC1
    GO TO 630
590 RC=RC1*(1.0-1.25*Y*(F-2.25)/328.35)
630 Q=ALOG(RQ)/ALOG(10.)
    Q1=111.15-31.45*Q+2.75*Q*Q
    Q2=11*(F-2.25)/9.75+21.0
    Q3=(95.75-21.75*Q+1.25*Q*Q)*(F-2.25)/9.75+Q1
    RC=RC*Q3/Q2
    IF (KRI-1) 672,673,674
672 IF (SNT-TN)679,680,680
673 IF (SNT-TS)679,680,680
674 IF (KRI-3) 675,676,680
675 IF (SNT-TD)679,680,680
676 IF (SNT-TP)679,680,680
679 IPAT=110
680 RETURN
    END
      SPASEG,,SPASEG
    SUBROUTINE SPASEG(FREQ,ANTBW,NCHNL,NBEAM,PTERR,RFPCHL,
   1MODES,SATLIF,ITIMBC,ANGLE,ANTWT,ANTDIA,PWRCOM,HTDL,PWRBOL,
   2TRNSWT,PPSSWT,SAAREA,STABWT,THRMWT,STRWT,SATWT)
    DIMENSION FREQ(1)
    DIMENSION RFPCHL(6)
    CALL ANTSS(FREQ,ANTBW,NBEAM,PTERR,ANTWT,ANTHKP,ANTDIA,ANTDF,
   1KFB)
```

```
      CALL TRSPCR(KFB,RFPCHL,NCHNL,NBEAM,SATLIF,PWRCOM,HTDL,TRNSWT)
      HKPDC=100.0
      HKPAC=45.0
10    CALL PPSS(HKPAC,HKPDC,SATLIF,ANTDIA,ITIMBC,PWRCOM,MODES,
     1PWRBOL,PPSSWT,PPSHKP,SAAREA)
      SATWT=8.05*(PWRBOL**0.69)
20    CALL STABSS(ANTDIA,PTERR,SATLIF,MODES,ANTDF,ANGLE,SATWT,HTDL,
     1SAAREA,STABWT,STABDC,STABAC)
      CALL THRMSS(HTDL,PWRBOL,MODES,THRMWT,THMHKP)
      CALL TTANC(MODES,TTCWT,TTCHKP)
      HKP1= ANTHKP + PPSHKP + THMHKP + STABDC +TTCHKP
      HKP2= STABAC
      HKP= HKP1 + HKP2
      DIFHKP= ABS(1.0 - HKP/(HKPAC + HKPDC))
      HKPDC= HKP1
      HKPAC= HKP2
      IF(DIFHKP-0.01)30,30,10
30    CALL STRUCT(SATWT,MODES,STRWT)
      WTOT=ANTWT + TRNSWT + PPSSWT + STABWT + THRMWT+STRWT+TTCWT
      DIFWT= ABS( 1.0 - WTOT/SATWT)
      SATWT=WTOT
      IF(DIFWT-0.01)40,40,20
40    CONTINUE
      RETURN
      END
        ANTSS,,ANTSS
      SUBROUTINE ANTSS(FREQ,ANTBW,NBEAM,PTERR,ANTWT,ANTHKP,ANTDIA,
     1ANTDF,KFB)
      WAVEL=0.9843/FREQ
      ANTDIA=(66.5*WAVEL)/(ANTBW + 2.0*PTERR)
      IF(FREQ - 0.8)10,10,20
10    KFB=1
      GO TO 50
20    IF(FREQ - 2.7)30,30,40
30    KFB=2
      GO TO 50
40    KFB=3
50    IF(ANTDIA-9.0)60,60,110
60    IF(KFB-2)80,80,90
80    ANTWW=10.0*10.0**(0.05*ANTDIA)
      FEEDWT=0.9*ANTDIA + 2.0
      GO TO 100
90    ANTWW=14.0*10.0**(0.05*ANTDIA)
      FEEDWT=0.236*ANTDIA + 0.4
100   TTCANT= 9.0
      ANTWT= ANTWW + (NBEAM-1.0)*FEEDWT + TTCANT
      ANTHKP= 2.0
      GO TO 160
```

```
110   IF(KFB - 2.0)120,130,130
120   ANTDF=0.88
      GO TO 150
130   ANTDF=0.84
150   TTCANT=9.0
      ANTWW=22.4*10.0**(0.025*ANTDIA)
      ANTWT= ANTWW + TTCANT
      ANTHKP=0.0
160   CONTINUE
      RETURN
      END
        TRSPDR,,TRSPDR
      SUBROUTINE TRSPDR(KFB,RFPCHL,NCHNL,NBEAM,SATLIF,PWRCOM,
     1HTDL,TRNSWT)
      DIMENSION WGL(10),PDL(10),PLEXL(10),WLLM(10),WHLM1(10),
     1WHLM2(10),WHLM3(10),RFPCHL(6)
      DATA(WGL(II),II=1,3)/1.0715,1.0715,1.175/
      DATA(PDL(JJ),JJ=1,6)/1.0,1.047,1.047,1.097,1.148,1.148/
      DATA(PLEXL(KK),KK=1,6)/1.0,1.0,1.0966,1.0,1.0,1.122/
      DATA(WHLM1(KK),KK=1,6)/1.0,1.0,22.0,1.0,1.0,44.0/
      DATA(WHLM2(KK),KK=1,6)/1.0,1.0,14.0,1.0,1.0,28.0/
      DATA(WHLM3(KK),KK=1,6)/1.0,1.0,3.2,1.0,1.0,5.5/
      DATA(WLLM(KK),KK=1,6)/1.0,1.0,0.5,1.0,1.0,1.1/
      II=KFB
      JJ=NBEAM
      KK=NCHNL
      TTOP=0.0
      PPRW=0.0
      TTPP=0.0
      PAMWT=0.0
      TLL=WGL(II)+PDL(JJ)+PLEXL(KK)
      DO 110 J=1,NCHNL
      TOPI=RFPCHL(J)*TLL
      IF (TOPI-200.0)5,5,7
 5    RCVRW=0.012*TOPI +6.6
      GO TO 8
 7    RCVRW=14.0*(TOPI/1000.0)**0.275
 8    IF (KFB-2)10,40,75
10    WHLM=WHLM1(KK)
      IF(TOPI-150.0)20,20,30
20    EFF=0.41/(10.0**(0.86*(TOPI/1000.0)))
      PAWT=66.0*(TOPI/1000.0)**0.69
      GO TO 100
30    EFF=0.24+0.216*(TOPI/1000.0)-0.0252*((TOPI/1000.0)**2.0)
      PAWT=56.0*(TOPI/1000.0)**0.415
      GO TO 100
40    WHLM=WHLM2(KK)
      IF(TOPI-50.0)45,45,50
45    EFF=0.422-1.75*(TOPI/1000.0)
      PAWT=66.0*(TOPI/1000.0)**0.324
      GO TO 100
```

```
50    IF(TOPI-200.0)55,55,60
55    PAWT=0.26*TOPI-2.5
      EFF=0.6*(TOPI/1000.0)**0.176
      GO TO 100
60    PAWT=72.0*(TOPI/1000.0)**0.22
      IF(TOPI-700.0)65,65,70
65    EFF=0.6*(TOPI/1000.0)**0.176
      GO TO 100
70    EFF=0.55+0.01*(TOPI/1000.0)
      GO TO 100
75    WHLM=WHLM3(KK)
      PAWT=30.0*(TOPI/1000.0)**0.37
      IF(TOPI-150.0)80,80,90
80    EFF=0.42*(TOPI/1000.0)**0.067
      GO TO 100
90    EFF=0.48*(TOPI/1000.0)**0.124
100   TPPI=TOPI/(0.85*EFF)
      TTOP=TTOP+TOPI
      PPRW=PPRW+RCVRW
      PAMWT=PAMWT+PAWT
110   TTPP=TTPP+TPPI
      IF(TOPI-200.0)120,120,130
120   R=2.0
      SWWT=3.0*NCHNL
      GO TO 160
130   IF(SATLIF-2.0)140,140,150
140   R=3.0
      SWWT=6.0*NCHNL
      GO TO 160
150   R=4.0
      SWWT=9.0*NCHNL
160   PAWTT=PAMWT*R + SWWT
      PPR=PPRW + 2.0
      PWRCOM=TTPP + PPR
      HTDL=TTPP*(1.0-EFF*0.85) + 0.9*PPR + TTOP*(1.0-1.0/TLL)
      WPR=20.0*NCHNL + 2.0
      TRNSWT=(WLLM(KK) + WHLM + WPR + PAWTT)*1.10
      RETURN
      END
        PPSS,,PPSS
      SUBROUTINE PPSS(HKPAC,HKPDC,SATLIF,ANTDIA,ITIMBC,
     1PWRCOM,MODES,PWRBCL,PPSSWT,PPSHKP,SAAREA)
      PWRINV=HKPAC/0.85
      WTINV=(PWRINV*0.02)+4.0
25    HKPTOT=PWRINV+HKPDC
      ENGREQ=(HKPTOT*1.2)/(0.88*0.98)
      ENGCAP=2*(ENGREQ/0.36)
      WTBAT=ENGCAP/9.3
      PWRCHG=ENGREQ/(0.94*4.0*0.80)
      WTCHG=2*(0.12*PWRCHG**0.675)
```

```
      PWRREG=PWRINV+HKPDC+PWRCOM
      PWRBUS=PWRREG/0.88
      WTREG=0.0724*(PWRREG)**0.915
      IF(ITIMBC-12)40,40,30
 30   PWREOL=PWRBUS+PWRCHG
      GOTO50
 40   PWREOL=PWRBUS
 50   DGRADE=0.05
      PWRBOL=PWREOL/((1.0-DGRADE)**SATLIF)
      IF(MODES-2) 70,60,60
 60   WTSOL=PWRBOL*0.253
      SAAREA=PWRBOL*0.321
      WTDOM=0.0
      WTHRNS=PWRBOL*0.052
      HKDOM=0.0
      GOTO110
 70   IF(PWRBOL-1500.0) 80,90,90
 80   WTSOL=PWRBOL*0.114
      WTHRNS=PWRBOL*0.052
      GOTO100
 90   WTSOL=PWRBOL*0.045
      WTHRNS=PWRBOL*0.026
100   SAAREA=PWRBOL/7.0
      WTDOM=25+0.0025*PWRBOL
      HKDOM=5.0
110   WTPCU=25.0
      WTSHNT=20.0
      PPSSWT=WTINV+WTBAT+WTCHG+WTREG+WTSOL+WTSHNT+WTPCU
     1+WTHRNS+WTDOM
      PPSHKP=HKDOM
      RETURN
      END
        STABSS,,STABSS
      SUBROUTINE STABSS(ANTDIA,PTERR,SATLIF,MODES,ANTDF,ANGLE,
     1SATWT,HTDL,SAAREA,STABWT,STABDC,STABAC)
      TOTA=SAAREA+0.785*(1.0-ANTDF)*(ANTDIA**2.0)+0.035*HTDL
      H=(6.5E-5)*(TOTA**2.0)
      IF(H-2.1)10,10,20
 10   F=1.0
 20   F=5.0
 30   DV1=64.4*H*SATLIF/(SATWT*5.0)
      DV2=5.79*SATLIF*SIN(2.0*((ANGLE+15.3)*0.0175))
      IF (MODES-2)40,50,50
 40   DV3=200.0
      WRW=24.0*H**0.42
      WE=40.0-10.0*PTERR
      WS=32.0
      WG=15.0
      WTC=23.0
      WFW=WRW+WE+WS+WG
      STABDC=90.0
```

```
      STABAC=9.0*F
      GO TO 60
 50   DV3=250.0
      WDMA=SATWT/50.0
      WS=20.0
      WE=54.0-10.0*PTERR
      WND=10.0
      WTC=15.0
      WFW=WDMA+WS+WE+WND
      STABDC=50.0-10.0*PTERR
      STABAC=0.0
 60   DV=DV1+DV2+DV3
      WTACS=WTC+1.18*DV*SATWT/(DV+32.2*200.0)
      STABWT=WFW+WTACS
      RETURN
      END
        THRMSS,,THRMSS
      SUBROUTINE THRMSS(HTDL,PWRBCL,MODES,THRMWT,THMHKP)
      IF(MODES - 2)10,20,20
 10   WLOUV=0.07*HTDL
      WHP=0.08*HTDL
      WINSUL=0.04*HTDL
      THRMWT=(WLOUV+WHP+WINSUL)*1.15
      THMHKP=10.0
      GO TO 30
 20   THRMWT=100.0*(PWRBCL/1000.0)**2.0
      THMHKP=10.0
 30   RETURN
      END
'FE FR5 STRUCT,,STRUCT
      SUBROUTINE STRUCT(SATWT,MODES,STRWT)
      IF(MODES-2)10,20,20
 10   STRWT=0.15*SATWT-75.0
      GO TO 30
 20   STRWT = 0.18* SATWT
 30   RETURN
      END
'FE FR5 TTANC,,TTANC
      SUBROUTINE TTANC(MODES,TTCWT,TTCHKP)
      IF (MODES-2)10,20,20
 10   TTCWT=50.0
      TTCHKP=20.0
      GO TO 30
 20   TTCWT=40.0
      TTCHKP=15.0
 30   RETURN
      END
```

APPENDIX B
COMPUTER PROGRAM VARIABLE DEFINITIONS

A (NTCON): A parameter representing $0.5\ (D/R5)^2$ in the subroutine.

ABMWD (CBSTOT, GRDSG): Ground antenna beamwidth, in degrees.

ABWMN (GRDSG): Minimum allowable antenna beamwidth of the ground terminal in degrees.

ABWMX (CBSTOT): Vector of maximum allowable audio bandwidth per audio channel, in Hz.

ACOST (CBSTOT): Ground antenna cost vector, in degrees.

ACST (CBSTOT): Ground antenna cost, in dollars.

AEFF (ANTGA): Efficiency of the ground terminal antenna specified as a positive value less than one.

AEFF (CBSTOT): Efficiency of the ground terminal antenna specified as a positive value less than one.

AEFFC (GRDSG): Efficiency of the ground terminal antenna specified as a positive value less than one.

AFG (ANTEP): The decibel path loss in rain.

AGA (ANTEP): The stellar noise level of the ground antenna in dB above kT_0B.

AGD (ANTEP): The value by which AT1 is divided to get the antenna temperature exclusive of the stellar contribution.

AI0 (NTCON): A point I_0 (A·R) in the range of the modified Bessel function of the first kind corresponding to the point A·R in the domain of the function.

AL (ANTGA): Wavelength in inches corresponding to the carrier frequency.

ALFAD (ERPM): The angle in degrees, croresponding to ALFAR, along a great circle between the satellite subpoint and the point at which the satellite beam is pointed.

ALFAR (ERPM): The angle in radians along a great circle between the satellite subpoint and the point at which the satellite beam is pointed.

ANGLE (SPASEG, STABSS): Longitude of satellite, in degrees East.

ANPRD (ERPM, GEOM): The off-axis angle in degrees of a point on earth from the satellite beam axis.

ANPRR (GEOM): The off-axis angle in radians of a point on the earth from the satellite beam axis.

ANTBW (SPASEG, ANTSS): Satellite antenna beamwidth, in degrees.

ANTCT (ANCTP): Cost of Q antennas, in dollars.

ANTD (CBSTOT): Ground antenna diameter, in meters.

ANTDF (STABSS, SPASEG, ANTSS): Antenna dish factor, in percent open area.

ANTDIA (CBSTOT, SPASEG, STABSS, ANTSS): Satellite antenna diameter, in feet.

ANTDM (CBSTOT): Ground antenna diameter, in meters.

ANTHKP (SPASEG, ANTSS): Satellite antenna subsystem housekeeping power, in watts.

ANTMX (CBSTOT): Maximum ground antenna diameter, in meters.

ANTWT (CBSTOT, SPASEG, ANTSS): Satellite antenna subsystem weight, in pounds.

ANTWW (ANTSS): Weight of satellite antenna without feeds, in pounds.

ARADB (GRDSG, CBSTOT): An N dimensional vector giving the rain attenuation in dB for each of the N carriers.

ARAREA (CBSTOT): Solar array area, in square feet.

ASCTM (CBSTOT): Audio subcarrier threshold margin, in dB.

AT (ANTEP): A vector used in summing to find AT1 in determining the antenna noise temperature.

AT1 (ANTEP): A factor times the antenna noise temperature exclusive of the stellar noise.

ATEMP (GRDSG, ANTEP): An N dimensional vector representing the antenna temperature for each of the N carrier frequencies.

ATMDB (GRDSG, COVRN): Decibel value of the desired carrier-to-noise ratio margin above threshold for the most critical audio subcarrier channel.

A1 (ANTGA): An approximation of a value of the Bessel function J_1.

A2 (ANTGA): An approximation of a value of the Bessel function J_2.

A3 (ANTGA): An approximation of a value of the Bessel function J_3.

Aϕ (ANTGA): A value of the Bessel function J_0 used in calculating antenna gain.

B (ANTGA): Half power antenna beamwidth, in degrees.

B (COVRN, GRDSG, THRES, NTCON): The RF bandwidth in Hz required for the modulated carrier.

B (ANTEP): A vector used in integrating to find the antenna temperature.

B (SCINT): A parameter involving the geomagnetic latitude and the frequency used in calculating the scintillation attenuation SCNDB for latitudes not exceeding 30°.

BCLAT (CBSTOT): Vector of latitudes of satellite antenna beam centers, in degrees.

BCLON (CBSTOT): Vector of longitudes of satellite antenna beam centers, in degrees East.

BGSSC (COVRN, GRDSG): Width of the guard band in Hz between the edges of the bands of adjacent audio subcarriers.

BGVSC (COVRN, GRDSG): Width of the guard band in Hz between the highest video frequency and the lowest frequency of the first subcarrier passband.

BIF (COVRN, GRDSG): The common bandwidth in Hz of the audio modulated subcarriers.

BMAX (COVRN, GRDSG): The maximum RF bandwidth in Hz that the modulated RF carrier is allowed to utilize.

BWK (COVRN, GRDSG): A factor greater than or equal to one, which has the effect of reducing the RF bandwidth of a modulated FM carrier below that which would be predicted by Carson's formula.

BY (RCCST): Beginning receiver production year.

B1 (ANTGA): An approximation of a value of the function Λ_1, used in calculating the antenna gain.

B1 (ANTEP): A vector used in integrating to find the antenna temperature.

B3 (ANTGA): An approximation of a value of the function Λ_3 used in calculating the antenna gain.

C (GRDSG): An N dimensional vector defining the required required power at each of the carrier frequencies based on a common value of satellite EIRP at each of the carrier frequencies.

CABLS (CBSTOT): Cable loss, in dB.

CAD (ERPM): The angle in radians along a great circle between the satellite subpoint and each point for which maximum allowable EIRP is computed.

CALFA (ERPM): Cosine of the angle along a great circle between the satellite subpoint and the point at which the satellite beam is pointed.

CAMXD (ERPM): The largest angle in degrees, corresponding to CAMXR, along a great circle between the satellite subpoint and the most distant point visible from the satellite.

CAMXR (ERPM): The largest angle in radians along a great circle between the satellite subpoint and the most distant point visible from the satellite.

CART (GRDSG): An N dimensional vector of power in watts received by the ground terminal at each of the N carrier frequencies on the basis of a common assumed value of satellite EIRP for each of the channels.

CBLDB (GRDSG): Cable loss in dB between the antenna terminals and the preamplifier, or converter, if no preamplifier is used.

CBLOS (GRDSG): The numerical value of cable loss (≥ 1.0) corresponding to the value in dB defined by CBLDB.

CHOSQ (GEOM): The square of the chord length between the receiver or other designated point and the center of the satellite beam.

COCN (COVRN): The ratio of the carrier power to the total noise in the RF receiving band of the FM carrier.

COEPS (GEOM): The cosine of the angle along a great circle between the satellite subpoint and the center of the satellite beam being considered.

COERP (GEOM): The cosine of the angle along a great circle between the receiver or other designated point and the center of the satellite beam being considered.

COERS (GEOM): Cosine of the angle along a great circle between the satellite subpoint and the receiver or other designated point.

COLN (COVRN): The ratio of the FM carrier power to the noise density.

COMPWR (CBSTOT): Transponder prime communication power, in watts.

CONA (COVRN): The value of the carrier-to-noise ratio in dB calculated by summing the value at threshold CONAT of the lowest audio subcarrier and the audio threshold margin ATMDS.

CONAT (COVRN): The value of the carrier-to-noise ratio in dB at threshold of the lowest audio subcarrier.

CONDB (COVRN, GRDSG): Carrier-to-noise ratio in dB required at the input to the FM demodulator.

CONV (COVRN): The value of the carrier-to-noise ratio in dB calculated by summing the value at threshold CONVT of the video channel and the video threshold margin CONVT.

CONVT (COVRN, GRDSG, CBSTOT): The value of the carrier-to-noise ratio in dB at threshold of the video channel.

COSPR (GEOM): The cosine of the off-axis angle of the receiver or other designated point from the axis of the satellite beam being considered.

COSTV (CBSTOT): Launch vehicle cost, in \$ millions.

COVRT (COVRN, GRDSG): Carrier-to-noise temperature ratio in dB required at the input to the FM demodulator.

CSPAK (LANCHV): Launch vehicle cost vector for spin stabilization mode with AKM, in \$ millions.

CSPIN (LANCHV): Launch vehicle cost vector for spin stabilization mode, in \$ millions.

CSYS (CBSTOT): Total system cost, in \$ millions.

CT6D (CBSTOT): Total ground segment cost, in \$ millions.

C1 (ANTGA): A constant times $V\phi$.

C2 (ANTGA): A constant times $V\phi$.

C3AZ (LANCHV): Launch vehicle cost vector for 3-axis stabilization mode, in $ millions.

D (ANTEP): A vector having all its components identical and used in computing the antenna noise temperature.

D (ANTGA): Ground antenna diameter, in inches.

D (THRES, NTCON): The peak deviation in Hz of the modulated FM carrier.

D (ANCTP): Ground antenna diameter, in meters.

DA (GRDSG, COVRN): Peak deviation in Hz of the audio modulated FM subcarrier.

DEL (COVRN): The difference in Hz between the peak deviation calculated from the individual peak deviations and last estimated value of DP.

DELAP (ERPM): The size of the increments in degrees along a great circle on the earth's surface used to determine the maximum EIRP of the satellite.

DELERP (CBSTOT): Incremental value of EIRP, in watts, used to refine system cost/EIRP curve.

DELPD (COVRN): The accuracy in Hz of estimating the peak deviation by successive approximation.

DF (ANCTP): Ground antenna diameter, in feet.

DF (ANTEP): A vector used in integrating to find the antenna noise temperature.

DGRADE (PPSS): Rate of power degradation of solar cells due to radiation, in percent per year.

DIA (ANTGA): Antenna diameter, in meters.

DIA (GRDSG): Diameter in meters of the ground terminal parabolic antenna.

DIFHKP (SPASEG): Difference in total housekeeping power from its previous value, in watts.

DIFWT (SPASEG): Difference in total satellite weight from its previous value, in lbs.

DISTP (GEOM): The distance in meters from the satellite to the point on the earth at the center of the satellite beam being considered.

DISTR (GEOM, ERPM): The distance in meters from the satellite to the receiver or other specified point on the earth.

DP (GRDSG, PDEV, COVRN): The peak deviation in Hz of the modulated FM carrier.

DP1 (COVRN): Peak deviation of the FM carrier based on individual peak deviations.

DPMAX (COVRN): The peak deviation in Hz corresponding to the maximum allowable bandwidth.

DPRAT (COVRN): The ratio of the maximum allowable peak deviation DPMAX to the peak deviation DP of the carrier.

DSQP (GEOM): The square of the metric distance from the satellite to the point on the earth at the center of the satellite beam being considered.

DSQR (GEOM): The square of the metric distance from the satellite to the receiver or other specified point on the earth.

DT (ANTEP): A vector used in integrating to find the antenna noise temperature.

DTH (ANTEP): Radian increment in theta direction.

DV (STABSS): Total velocity change requirements for attitude control subsystem, in feet/seconds.

DV1 (STABSS): Velocity increment corrections for perturbations due to solar pressure torque, in feet per second.

DV2 (STABSS): Velocity increment correction for East-West stationkeeping, in feet per second.

DV3 (STABSS): Velocity increment corrections for initial orbital positioning inaccuracies, in feet per second.

D8 (ANTGA): Antenna gain in dB for a particular direction.

EFF (TRSPDR): Transmitter efficiency, in percent.

EIRP (GRDSG, CBSTOT): An N dimensional vector of satellite effective isotropic radiated power in watts for each of the carriers in the beam.

EIRPV (ERPM): The maximum allowable EIRP of the satellite in watts corresponding to a maximum allowable flux density specified at one of the points considered on the earth's surface.

ELAD (ANTEP): Elevation angle of the ground receiving antenna, in degrees.

ELAR (GEOM): Elevation angle of the satellite in radians from a specified point on the earth's surface.

ELARD (ERPM, GRDSG, GEOM, CBSTOT): Elevation angle of the satellite in degrees from a specified point on the earth's surface.

ENGCAP (PPSS): Energy capacity of batteries, in watt/hours.

ENGREQ (PPSS): Energy required for housekeeping load, in watt/hours.

ERP (GRDSG): A value of satellite EIRP, in watts.

ERPM (CBSTOT): A value of the satellite EIRP, in watts.

ERPMX (ERPM, GRDSG, CBSTOT): The maximum satellite EIRP in watts allowed for a particular satellite beam.

ERPMZ (CBSTOT): A value of the satellite EIRP, in watts.

EU (CBSTOT): Equivalent unit.

F (ERPM): RF carrier frequency, in Hz.

F (STABSS): Momentum requirement factor on AC housekeeping power.

F (SCINT, RCCST): The carrier frequency, in GHz.

FA (GRDSG, COVRN): Highest audio frequency, in Hz.

FA (ANTGA): Frequency in Hz.

FCAR (SCINT, RCCST): The carrier frequency, in Hz.

FCAR (GRDSG): A vector of dimension N giving the frequency in Hz for each of the RF carriers in order from the lowest FCAR(1) to the highest FCAR(N).

FCARC (GRDSG): The geometric center frequency of the highest and lowest RF carrier frequencies.

FEEDWT (CANTSS): Weight of feed structure for satellite antenna, in lbs.

FG (ANTEP): The RF frequency, in GHz.

FK (ANTEP): One sixteenth the gigahertz RF frequency.

FMAX (COVRN): The highest frequency in Hz modulating the FM carrier.

FMTHR (CBSTOT): FM threshold, in dB.

FQ (ANTEP): RF frequency, in Hz.

FR (ANTEP): The RF frequency, in MHz.

FR (GRDSG, COVRN, CBSTOT): An NS dimensional vector of frequency in Hz defining the frequency plan of the composite baseband signal modulating an RF carrier.

FREK (CBSTOT): Carrier frequency, in GHz.

FREQ (CBSTOT, SPASEG, ANTSS): Carrier frequency vector, in Hz.

FV (COVRN, GRDSG): Highest video frequency, in Hz.

F1 (ANTGA): A parameter used in calculating a value of the Bessel function J_1.

F1 (THRES, COVRN): The lower end in Hz of the frequency band of an audio subcarrier.

F1 (ERPM): The lowest frequency of the lowest satellite broadcasting frequency band, in Hz.

F2 (THRES, COVRN): The upper end in Hz of the frequency band of an audio subcarrier.

F2 (ERPM): The highest frequency of the lowest satellite broadcasting frequency band in Hz.

F3 (ERPM): The lowest frequency of the middle satellite broadcasting frequency band in Hz.

F4 (ERPM): The highest frequency of the middle satellite broadcasting frequency band in Hz.

F5 (ERPM): The lowest frequency of the highest satellite broadcasting frequency band in Hz.

F6 (ERPM): The highest frequency of the highest satellite broadcasting frequency band, in Hz.

Fϕ (ANTGA): A parameter used in calculating a value of the Bessel function J_0.

G (GRDSG, ANTGA, ANTEP): A vector representing the gain of the ground antenna such that the Ith component of the gain is the dB gain for I-1 degrees off the beam axis for odd values of I.

GA (ANTEP): A vector representing the numerical power gain of the ground antenna such that the Ith component of the gain is the gain for I-1 degrees off the beam axis for odd values of I.

GABWM (CBSTOT): Minimum ground antenna beamwidth, in degrees.

GL (SCINT): Absolute value of geomagnetic latitude of the receiver, in degrees.

GLODB (ERPM): Satellite antenna off-axis gain loss, in dB.

GNDCT (CBSTOT): Maximum ground segment cost vector, in dollars.

GOGT (GRDSG, CBSTOT): Gain of the ground terminal antenna in dB.

G_φ (ANTEP): The antenna dB gain relative to that of a half-wave dipole.

H (STABSS): Momentum capacity of reaction wheel, in ft./lb./sec.

H (ERPM, GEOM): Altitude of a synchronous satellite in meters.

HDSPLD (CBSTOT): Heat dissipation load of satellite, in watts.

HKDOM (PPSS): Housekeeping power required by orientation mechanism, in watts.

HKP (SPASEG): Total satellite housekeeping power, in watts.

HKPAC (SPASEG, PPSS): Total satellite AC housekeeping power, in watts.

HKPDC (SPASEG, PPSS): Total satellite DC housekeeping power, in watts.

HKPTOT (PPSS): Total satellite housekeeping power, in watts.

HKP1 (SPASEG): Total satellite DC housekeeping power, in watts.

HKP2 (SPASEG): Total satellite AC housekeeping power, in watts.

HTDL (SPASEG, TRSPDR, STABSS, THRMSS): Satellite heat dissipation load, in watts.

I (ANTEP): Angle (ϕ + 1) where ϕ is the elevation angle in degrees measured from straight down.

I (CBSTOT, COVRN, ANTEP): A loop counting index.

ICNT (CBSTOT): Counting index for additional points required to refine system cost/EIRP curve.

IENV (GRDSG, ANTEP): Integer which describes the man-made noise environment of the ground terminal (see page 3-12).

IG (GRDSG, ANTEP): Integer which describes the stellar noise level for the receiving ground terminal antenna (see page 3-12).

IHUMD (GRDSG, ANTEP): Integer which describes the relative humidity of the ground terminal environment (see page 3-12).

II (TRSPDR): Carrier frequency index.

IKEY (CBSTOT, GRDSG): Program logic key (see #30 on page 3-13, 14).

IND (CBSTOT): Receiver type key.

INDR (CBSTOT): Receiver type vector.

IOUT (CBSTOT, BESSL, COVRN): The number 6 corresponding to the output device of the computer.

IPAT (RCCST): Receiver type, an output; 0 is no preamp, 1 is transistor, 3 is paramp, 100 is none available, 110 is none available.

IT (CBSTOT): Counting index for number of iterations occurring in ground segment model.

ITC (CBSTOT): Counting index.

ITIMBC (CBSTOT, PPSS, SPASEG): Broadcast time per day, in hours.

IRCVT (CBSTOT): Receiver-type vector.

ISTYR (CBSTOT): Start year.

IV (CBSTOT): Launch vehicle type.

IVHCL (CBSTOT, LANCHV): Launch vehicle type.

IZOOM (CBSTOT): Program logic key to initiate calculation of additional points to refine system cost/ EIRP curve.

J (CBSTOT, TRSPDR): Index counter for number of video channels.

J (COVRN, THRES): A loop counting index.

J (ANTEP): Angle (θ + 1) where θ is the azimuthal angle in degrees.

JJ (TRSPDR): Index counter for number of beams.

JKEY (CBSTOT): Program logic key.

K (ANTEP): An angle measured in degrees.

KEY (LANCHV): Stabilization mode key.

KFB (TRSPDR, ANTSS, SPASEG): Integer key designating one of three carrier frequency bands.

KGN (CBSTOT): See IG.

KK (TRSPDR): Index counter for number of video channels.

KMMN (CBSTOT): See IENV.

KRH (CBSTOT): See IHUMD.

KRI (RCCST): Receiver type; 0 is no preamp, 1 is transistor, 2 is TDA, 3 is paramp, 4 is pick best available.

L (ANTEP): A loop counting index.

LIFE (CBSTOT): Satellite lifetime.

M (ERPM): Designation of the satellite frequency bands by integers from 1 to 3 in the same order as the frequencies.

MDAKM (LANCHV): Spin stabilization key for use of AKM.

MODAKM (CBSTOT): AKM key for launch vehicle selection for spin stabilization mode.

MODES (CBSTOT, LANCHV, STRUCT, TTANC, THRMSS, STABSS,PPSS, SPASEG): Stabilization mode key.

MODSTB (CBSTOT): Stabilization mode key.

N (CBSTOT): Scale factor for estimation of maximum ground antenna diameter.

N (GRDSG): Number of RF carrier frequencies.

NAVDC (CBSTOT): Number of audio channels per video channel.

NBEAM (CBSTOT, SPASEG, ANTSS, TRSPDR): Number of antenna beams.

NCHNL (SPASEG, TRSPDR): Number of video channels.

NOSAT (CBSTOT): Number of satellites.

NPTS (CBSTOT): Additional points required to refine system cost/EIRP curve.

NRECV (CBSTOT): Vector of number of ground receivers.

NS (COVRN, GRDSG, PDEV): Total number of signals modulating the RF carrier, including the video signal and all the audio subcarriers.

NTVCH (CBSTOT): Number of video channels.

P (ERPM): Maximum allowable flux density at a particular specified point on the earth's surface.

P (GRDSG): An N dimensional vector of the satellite RF power in watts required at the antenna input for each of the N carrier frequencies for the satellite beam being considered.

P (THRES, NTCON): π

PAMWT (TRSPDR): Sum of power amplifier weights, in lbs.

PAWT (TRSPDR): Power amplifier weight, in lbs.

PAWTT (TRSPDR): Total power amplifier weight, with switching weight and provisions for redundancy, in lbs.

PDL (TRSPDR): Power divider loss vector.

PDVSC (CBSTOT): Peak deviation of subcarriers, in Hz.

PLAD (ERPM, GEOM, GRDSG): Latitude in degrees of the point on the earth's surface at which the satellite beam center is pointing.

PLAR (ERPM, GEOM): Latitude in radians of the point on the earth's surface at which the satellite beam center is pointing.

PLEXL (TRSPDR): High level multiplexer loss vector.

PLOD (ERPM, GEOM, GRDSG): Longitude in degrees of the point on the earth's surface at which the satellite beam center is pointing.

PLOR (ERPM, GEOM) · Longitude in radians of the point on the earth's surface at which the satellite beam center is pointing

POR (GRDSG, CBSTOT, SCINT): The probability in percent that the scintillation is less than the value to be calculated.

PPR (TRSPDR): Preamp/receiver prime power, in watts.

PPRW (TRSPDR): Sum of weights of receivers for all channels, in lbs.

PPSHKP (SPASEG, PPSS): Prime power subsystem housekeeping power, in watts.

PPSSWT (SPASEG, PPSS): Prime power subsystem weight, in lbs.

PPSWT (CBSTOT): Prime power subsystem weight, in lbs.

PTERR (CBSTOT, SPASEG, ANTSS, STABSS): Satellite antenna pointing error, in degrees.

PWRBOL (CBSTOT, SPASEG, PPSS, THRMSS): Beginning-of-life satellite prime power, in watts.

PWRBUS (PPSS): Power input to regulator, in watts.

PWRCHG (PPSS): Charge power required at battery input, in watts.

PWRCOM (SPASEG, PPSS, TRSPDR): Total communications prime power, in watts.

PWREOL (PPSS): End-of-life satellite prime power, in watts.

PWRINV (PPSS): Power at inverter input, in watts.

PWRREG (PPSS): Power output of regulator, in watts.

P1 (ANTEP): A value of $\sin \phi \cos \theta$.

P2 (ANTEP): An angle measured in radians.

P2 (ERPM, GEOM): $\pi/2$

P3 (ANTEP): An angle measured in degrees.

Q (ANCTP): Integer value of number of ground antennas within beam.

Q (TCCST): Log_{10} RQ.

QI (ANCTP): A parameter which is a function of Y.

Q_1 (RCCST): A parameter which is a function of Q.

Q_2 (RCCST): A parameter which is a function of F.

Q_3 (RCCST): A parameter which is a function of Q, Q_1 and F.

R (ANTGA): Radius of the ground antenna, in inches.

R (ERPM, GEOM): Radius of the earth, in meters.

R (NTCON, THRES): The numerical value of the carrier-to-noise ratio.

R (TRSPDR): Redundancy factor.

RAINR (CBSTOT): Rain rate vector, in millimeters/hour.

RANDH (GEOM): The distance of a synchronous satellite from the earth's center, in meters.

RASN (CBSTOT): Required audio S/N, in dB.

RC (RCCST): Cost of RQ receivers in dollars. A function of BY, F and RQ.

RCOST (CBSTOT): Receiver cost vector, in dollars.

RCST (CBSTOT): Cost per receiver, in dollars.

RCVN (CBSTOT): Receiver noise temperature, in degrees Kelvin.

RCVNS (CBSTOT): Receiver noise temperature, in degrees Kelvin.

RCVRW (TRSPDR): Weight of receiver, in watts.

RC1 (RCCST). Cost of 10^6 receivers as a function of type and frequency.

RECNM (CBSTOT): Number of receivers.

RFBW (CBSTOT): A value of RF bandwidth, in Hz.

RFMBW (CBSTOT): Maximum RF bandwidth, in Hz.

RFPCHL (SPASEG, TRSPDR): Vector of RF power per video channel, in watts.

RFPWR (CBSTOT): RF power matrix, in watts.

RLAD (GRDSG, GEOM): The latitude in degrees of the receiver being considered on the surface of the earth.

RLAR (GEOM): The latitude in radians of the receiver being considered on the surface of the earth.

RLAT (CBSTOT): Receiver latitude vector, in degrees.

RLOD (GRDSG, GEOM): The longitude in degrees of the receiver being considered on the surface of the earth.

RLONG (CBSTOT): Receiver longitude vector, in degrees East.

RLOR (GEOM): The longitude in radians of the receiver being considered on the surface of the earth.

RQ (RCCST): Integer value of number of ground receivers within beam.

RR (GRDSG, ANTEP): Rain rate in millimeters per hour.

RTOD (ERPM, GEOM): 180/π degrees per radian.

RUSN (CBSTOT): Required video S/N, in dB.

R5 (NTCON): Radius of gyration of the assumed noise spectrum.

R9 (THRES): The value of the carrier-to-noise ratio in dB at threshold.

S (SCINT): A parameter which is a function of the probability POR and which is used in calculating the scintillation attenuation SCNDB for values of POR greater than 98.5% and latitudes not exceeding 30°.

SA (SCINT): A parameter which is a function of POR and is used in calculating the scintillation attenuation SCNDB.

SAAREA (SPASEG, PPSS, STABSS): Solar array area, in square feet.

SABW (CBSTOT): Vector of satellite antenna beamwidth, in degrees.

SAEFC (GRDSG): Positive number less than one defining the satellite antenna efficiency.

SAEFF (CBSTOT): Satellite antenna efficiency, given as a positive number less than one.

SAG (GRDSG): The numerical value of satellite antenna gain.

SAGDB (GRDSG, CBSTOT): The decibel value of satellite antenna gain corresponding to SAG.

SATCST (CBSTOT): Total satellite cost, in $ millions.

SATLIF (SPASEG, TRSPDR, PPSS, STABSS): Satellite lifetime, in years.

SATWT (CBSTOT, SPASEG, STABSS, STRUCT): Total satellite weight, in lbs.

SCNDB (GRDSG, GRDSG, SCINT): An N dimensional vector giving the scintillation attenuation in dB that is not exceeded POR percent of the time for each of the N carriers.

SINA (GEOM): Sine of the angle along a great circle between the satellite subpoint and the receiver or other designated point.

SLAD (ERPM, GEOM): Latitude of the satellite subpoint, in degrees.

SLAR (ERPM, GEOM): Latitude of the satellite subpoint, in radians.

SLAT (CBSTOT): Satellite latitude vector, in degrees.

SLIFE (CBSTOT): Satellite lifetime, in years.

SLOD (ERPM, GRDSG): Longitude of the satellite subpoint, in degrees.

SLONG (CBSTOT): Satellite longitude vector, in degrees East.

SLOR (ERPM, GEOM): Longitude of the satellite subpoint, in radians.

SNRA (COVRN): The numerical ratio corresponding to SNRSD.

SNRSD (GRDSG, COVRN): The required sound subcarrier-to-noise ratio in dB at the output of the demodulator used for all the subcarrier channels.

SNRV (COVRN): The numerical ratio corresponding to SNRVD.

SNRVD (GRDSG, COVRN): The required picture (black-to-white) signal-to-weighted-noise ratio in dB at the ground station.

SNT (RCCST): Receiver noise temperature, in degrees Kelvin.

SPAKM (LANCHV): Vector of launch vehicle type for spin stabilization mode with AKM.

SPECF (ERPM, GRDSG, CBSTOT): Spectrum factor in dB defining the ratio of the power of the modulated carrier to the power in the 4.0-kHz bandwidth having the highest power.

SPCOST (CBSTOT): Total space segment cost, in $ millions.

SPIN (LANCHV): Vector of launch vehicle type for spin stabilization mode.

SSGB (CBSTOT): Subcarrier-subcarrier guard band, in Hz.

STABAC (SPASEG, STABSS): Satellite stabilization subsystem AC housekeeping power, in watts.

STABDC (SPASEG, STABSS): Satellite stabilization subsystem DC housekeeping power, in watts.

STABWT (SPASEG, STABSS, CBSTOT): Weight of satellite stabilization subsystem, in lbs.

STRCWT (CBSTOT): Weight of satellite structure subsystem, in lbs.

STRWT (SPASEG, STRUCT): Weight of satellite structure subsystem, in lbs.

STYR (CBSTOT): Start year.

SWWT (TRSPDR): Weight of switching assembly, in lbs.

SYTEM (CBSTOT): System noise temperature, in degrees Kelvin.

SYTEMP (CBSTOT): System noise temperature, in degrees Kelvin.

S1 (THRES): Plus or minus one, depending on the sign of $Y - Y\phi$.

S2 (THRES): Plus or minus one, depending on the sign of $Y - Y\phi$.

T (ANTEP): A vector defining the environmental noise temperature seen by the antenna in each of the directions corresponding to each component of the vector.

T (BESSL): X/3.75.

T (GRDSG, THRES, COVRN): The value in dB defining the FM threshold by the deviation of the demodulator output signal-to-noise ratio from that precicted by the formula for performance above threshold.

TCABL (GRDSG): The noise temperature contribution of the cable between the antenna and the preamp to the overall system noise temperature.

TD (RCCST): Noise temperature of a tunnel diode type receiver as a function of frequency.

TG (ANTEP): The stellar contribution to the ground antenna noise temperature in degrees Kelvin.

TGD (CBSTOT): Total ground segment cost, in dollars.

THMHKP (SPASEG, THRMSS): Satellite thermal control subsystem housekeeping power, in watts.

THRMWT (SPASEG, THRMSS, CBSTOT): Satellite thermal control subsystem weight, in lbs.

TLL (TRSPDR): Transmitter line loss, in dB.

TM (ANTEP): The man-made noise temperature seen by the ground antenna.

TN (RCCST): Noise temperature of a mixer (no preamp) type receiver as a function of frequency.

TOPI (TRSPDR): Transmitter output power of ith channel, in watts.

TOT (CBSTOT): Total satellite RF power, in watts.

TOTA (STABSS): Satellite maximum projected area, in square feet.

TP (ANTEP): The precipitation contribution to environmental noise temperature seen by the ground antenna.

TP (RCCST): Noise temperature of a paramp type receiver as a function of frequency.

TPPI (TRSPDR): Transmitter prime power for ith channel, in watts.

TR (GRDSG): An N dimensional vector representing the required receiver-cable noise temperature based on a common value of EIRP at the satellite for each of the N carrier frequencies.

TREAX (LANCHV): Vector of launch vehicle type for 3-axis stabilization mode.

TREC (GRDSG): The receiver temperature exclusive of the cable temperature.

TRECC (GRDSG): The smallest component of the receiver-cable noise temperature vector TR.

TRNSWT (SPASEG, TRSPDR): Satellite transponder subsystem weight, in lbs.

TS (ANTEP): A vector defining the noise temperature resulting from humidity and seen by the antenna in each of the directions corresponding to each component of the vector.

TS (RCCST): Noise temperature of a transistor tupe receiver as a function of frequency.

TSYS (CBSTOT): Total system cost, in $ millions.

TSYS (GRDSG): An N dimensional vector of the required ground system noise temperature, in degrees Kelvin, for each of the N carrier frequencies. This temperature vector is referenced to the terminals of the receiving antenna.

TTCANT (ANTSS): Weight of earth coverage horn and TT&C antenna, in lbs.

TTCHKP (SPASEG, TTANC): Satellite TT&C subsystem housekeeping power, in watts.

TTCWT (TTANC): Satellite TT&C subsystem weight, in lbs.

TTOP (TRSPDR): Total transmitter output power, in watts.

TTPP (TRSPDR): Total transmitter prime power, in watts.

T1 (ANTGA): A factor used in approximating a value of the Bessel function J_1.

T2 (THRES): The accuracy in dB of the threshold value of the carrier-to-noise ratio.

T0 (ANTGA): A factor used in approximating a value of the Bessel function J_0.

U (ANTGA): A parameter which is a function of the antenna size, wavelength, and the off-axis angle. It is used in calculating antenna gain.

V (ANTGA): The voltage gain of the antenna in a particular direction.

VASCG (CBSTOT): Video-Audio subcarrier guard band, in Hz.

VBWMX (CBSTOT): Vector of maximum allowable video bandwidth, in Hz.

VCOST (CBSTOT, LANCHV): Launch vehicle cost, in $ millions.

VKF (COVRN): The numerical ratio corresponding to VKFDB.

VKFAC (CBSTOT): See VKFDB.

VKFDB (COVRN, GRDSG): Video improvement factor in dB, including both the effects of preemphasis and spectral weighting.

VTHRM (CBSTOT): Video threshold margin, in dB.

VTIR (COVRN, GRDSG, CBSTOT): Video threshold impulse rate given in impulses per second, including both positive and negative going pulses.

VTMDB (GRDSG, COVRN): Value in dB of the desired carrier-to-noise margin above threshold for the video channel.

V0 (ANTGA): A parameter used in computing gain that includes the effect of antenna efficiency and the ratio of the antenna radius to the wavelength.

WAVEL (ANTSS): Wavelength of carrier frequency, in feet.

WDMA (STABSS): Weight of despin mechanical assembly, in lbs.

WE (STABSS): Weight of electronics, in lbs.

WFW (STABSS): Stabilization subsystem weight without attitude control subsystem, in lbs.

WG (STABSS): Weight of 3-axis gyro package, in lbs.

WGL (TRSPDR): Wave guide loss vector, in dB.

WHLM (TRSPDR): Total weight vector of high level multiplexers, in lbs.

WHLM1 (TRSPDR): Weight vector of high level multiplexers, 620-790 MHz, in lbs.

WHLM2 (TRSPDR): Weight vector of high level multiplexers, 2.50-2.69 GHz, in lbs.

WHLM3 (TRSPDR): Weight vector of high level multiplexers, 11.7 - 12.2 GHz, in lbs.

WHP (THRMSS): Weight of heat-pipe assembly, in lbs.

WINSUL (THRMSS): Weight of insulation, in lbs.

WLLM (TRSPDR): Weight vector of low level multiplexers, in lbs.

WLOUV (THRMSS): Weight of louvre assembly, in lbs.

WMM (ANTEP): The man-made contribution to noise power density in bels above kT_0.

WMN (ANTEP): Man-made noise power in decibels below one watt in a one hertz bandwidth at the ground antenna location.

WND (STABSS): Weight of nutation damper, in lbs.

WPR (TRSPDR): Weight of preamp/receiver, in lbs.

WRW (STABSS): Weight of reaction wheels, in lbs.

WS (STABSS): Weight of sensor package, in lbs.

WT (LANCHV): Total satellite weight, in lbs.

WTACS (STABSS): Weight of attitude control subsystem, in lbs.

WTBAT (PPSS): Weight of batteries, in lbs.

WTC (STABSS): Hardware weight for APS subsystem, in lbs.

WTCHG (PPSS): Weight of chargers, in lbs.

WTDOM (PPSS): Weight of directive orientation mechanism, in lbs.

WTHRNS (PPSS): Weight of power distribution harness, in lbs.

WTINV (PPSS): Weight of inverter, in lbs.

WTPCU (PPSS): Weight of power control unit, in lbs.

WTOT (SPASEG): Sum of subsystem weights, in lbs.

WTREG (PPSS): Weight of regulator, in lbs.

WTSHNT (PPSS): Weight of shunt assembly, in lbs.

WTSOL (PPSS): Weight of solar array and deployment, in lbs.

X (ANCTP): $\text{Log}_{10}Q$.

X (BESSL): The point in the domain of the modified Bessel function of the first kind I_0 ().

X (COVRN, GRDSG, PDEV): The vector X defining each component peak deviation X(I) in Hz produced by the Ith of NS modulating signals for all values of I from 1 to NS inclusive.

XPNWT (CBSTOT): Satellite transponder subsystem weight, in lbs.

Y (BESSL): The point $I_0(X)$ in the range of the modified Bessel functions of the first kind.

Y (THRES, NTCON): The product of impulse rate and carrier-to-noise ratio which exists for a particular carrier-to-noise ratio and a particular system.

Y (ANCTP): A parameter which is a function of X.

Y (RCCST): Difference between 1969 and BY.

Y0 (THRES): The product of impulse rate and carrier-to-noise ratio required at threshold.