RECOMMENDATION ITU-R F.1107*

PROBABILISTIC ANALYSIS FOR CALCULATING INTERFERENCE INTO THE FIXED SERVICE FROM SATELLITES OCCUPYING THE GEOSTATIONARY ORBIT

(Question ITU-R 116/9)

(1994)

The ITU Radiocommunication Assembly,

considering

a) that the World Administrative Radio Conference for Dealing with Frequency Allocations in Certain Parts of the Spectrum (Malaga-Torremolinos, 1992) (WARC-92) has allocated to a number of satellite services, operating in the geostationary orbit, spectrum that is also allocated to the fixed service (FS);

b) that emissions from space stations operating in the geostationary orbit and sharing the same spectrum may produce interference in receiving stations of the FS;

c) that it may be impractical to coordinate between the many terrestrial stations and the many space stations, and that, therefore, sharing criteria should be established to preclude the need for detailed coordination;

d) that in devising such sharing criteria, account needs to be taken of the operational and technical requirements of networks in the satellite service as well as of the requirements of the FS and measures available to them;

e) that it has been determined that a probabilistic basis for developing sharing criteria results in a more efficient use of the spectrum than from criteria developed using worst case analysis;

f) that it is difficult and burdensome to assemble sufficient statistically accurate information about real existing and planned terrestrial and satellite system stations;

g) that computer simulations of FS and satellite services operating in the geostationary orbit can generate statistically accurate information suitable for determining sharing criteria for a wide variety of sharing scenarios,

recommends

1. that information derived from computer simulations of FS and satellite services operating from the geostationary orbit and using the same spectrum may be acceptable for developing sharing criteria;

2. that when deriving information for developing sharing criteria the material in Annex 1 should be taken into account.

ANNEX 1

Method of developing criteria for protecting the fixed service from emissions of space stations operating in the geostationary orbit

1. Introduction

WARC-92 allocated to the broadcasting-satellite service (TV and sound), the mobile-satellite service and the space science services spectrum which is also shared by the FS. WARC-92 also approved several Resolutions and Recommendations that requested the ITU-R resolve the sharing issues resulting from the various allocations. This Annex describes a methodology that will aid in the development of sharing criteria between the FS and those satellite services provided from the geostationary orbit.

* This Recommendation should be brought to the attention of Radiocommunication Study Groups 4 (WP 4-9S), 7, 8 (WP 8D), 10 and 11 (WP 10-11S) and 2 (TG 2/2).

Recommendation ITU-R SF.358 proposes power flux-density (pfd) protective levels for the FS for some portions of the spectrum. Similarly Nos. 2561 to 2580.1 of Article 28 of the Radio Regulations provide definitive pfd limits for similar bands. Neither reference, however, addresses all the bands indicated by WARC-92 nor do they provide sufficient information on how to extend the criteria, other than by extrapolation, to different fixed and satellite service sharing scenarios.

Appendix 1 to Annex 1 of Recommendation ITU-R SF.358 does indicate that statistical simulation methods for determining pfd levels to protect the FS from satellites operating in the geostationary orbit are acceptable but it does not provide a detailed methodology for developing the data. This Annex describes the geometric considerations needed to calculate the data. It also provides a description and the basic language source code for a program that can generate data representative of many of the sharing scenarios that currently exist or will result from the WARC-92 allocations. The resulting program data can be analysed to determine the effects of satellite pfd levels on the FS for a variety of scenarios. Scenario differences can be determined by user input parameters to the program. Some examples are provided in Appendix 1 to this Annex of how the data from the simulation program can be utilized to help resolve WARC-92 or similar issues.

2. Geometric considerations

In order to calculate the interference into a radio-relay network from satellites in the geostationary orbit, it is necessary to identify all satellites visible to each radio-relay station. This may be accomplished by determining the limits of the visible geostationary orbit for each station and accordingly all satellites between those limits would be visible.

Figure 1 provides a representation of the geometry of the geostationary orbit and a radio-relay station. Some of the important parameters needed to calculate interference into the radio-relay station are:

θ : elevation angle of the satellite above the horizon

β : spherical arc subtended by the sub-satellite point, S', and the radio-relay station, P

Ω : angle subtended by β as viewed from the satellite, S.

If the radio-relay antenna has 0° elevation and diffraction is ignored then the azimuth displacement, A, measured from South, to the intersection of the horizon with the geostationary orbit can be calculated as:

$$|A| = \cos^{-1}\left(\tan \varphi/(K^2 - 1)^{1/2}\right) \tag{1}$$

where:

$K = R/a$

- a : radius of the Earth
- R : radius of the geostationary orbit

φ : latitude of the radio-relay station.

The relative longitudinal separation between the radio-relay station and the horizontal plane/geostationary orbit intercept can be expressed as:

$$\lambda = \sin^{-1}\left(\sin A(1 - K^{-2})^{1/2}\right) \tag{2}$$

Since the visible stationary orbit is symmetrical around the 0° azimuth line the total number of satellites visible to the station will appear in the longitudinal span of the orbit equal to 2λ.

The azimuth A_z to each visible satellite is:

$$A_z = \tan^{-1}(\tan \lambda_r / \sin \varphi) \tag{3}$$

where λ_r is the difference between the longitude of the satellite and the radio-relay station, i.e. the relative longitude.

FIGURE 1

Geometry of the geostationary-satellite orbit and a radio-relay station

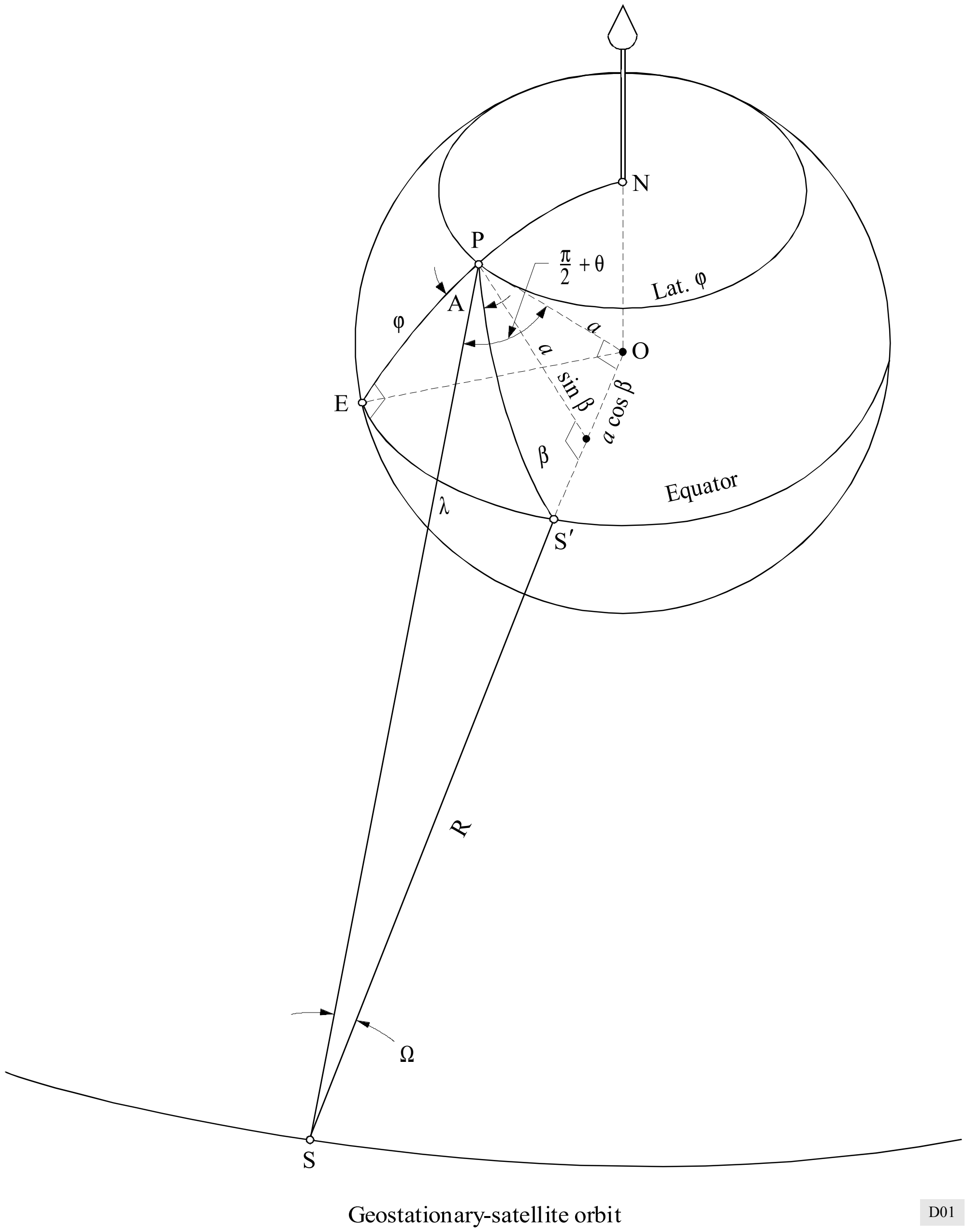
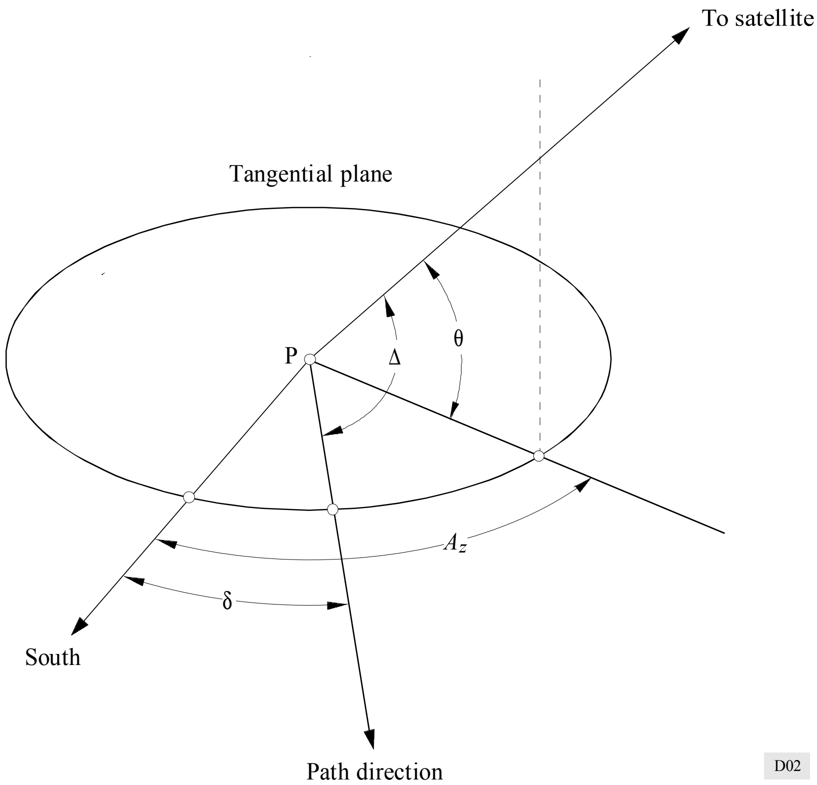


FIGURE 2

Geometry determining the off-beam angle to a satellite



The ITU-R customarily limits or defines pfd levels from a satellite as a function of the elevation angle, θ. The angle can be determined as follows:

$$\theta = (\pi/2) - (\beta + \Omega) \tag{4}$$

where:

$$\beta = \cos^{-1} (\cos \varphi \cos \lambda_r) \tag{5}$$

$$\Omega = \tan^{-1} \left(\sin \beta / (K - \cos \beta) \right) \tag{6}$$

Generally pfd is defined in the form:

Error! (7)

where:

pfd_{low} : allowable level for low angles of arrival, usually expressed in dB(W/m^2) in a 4 kHz band

pfd_{hi} : allowable level for high angles of arrival also expressed in dB(W/m^2) in a 4 kHz band.

Finally the angle Δ between the incidence of the interfering satellite pfd level and the pointing direction of the radio-relay station receiver (Fig. 2) can be determined by:

$$\Delta = \cos^{-1} \left(\cos \theta \cos (A_z - \delta) \right) \tag{8}$$

where δ is the pointing direction of the radio-relay station receiver relative to South.

If the radio-relay receive antenna gain is assumed to be equal in all planes (horizontal to vertical) then the gain in the direction of the interfering satellite, $G(\Delta)$, may be determined from the antenna gain pattern equations in Recommendation ITU-R F.699.

3. Interference calculations

The total interference power received at the radio-relay receiver can be determined by summing the contributions from each visible satellite. Each contribution can be determined as follows:

$$I_B = f(\theta) \times g(\Delta) \times \lambda^2 / 4\pi h \tag{9}$$

where:

$$f(\theta) = 10^{F(\theta) / 10} \tag{10}$$

$$g(\Delta) = 10^{G(\Delta) / 10} \tag{11}$$

λ : wavelength of the carrier

h : feeder loss

Equation (9) contains the factor $\lambda / 4\pi\, h$ because $f(\theta)$ is in units of W/m^2 per 4 kHz.

4. Network simulation for interference determination

The selection of a methodology to select pfd values for protecting the FS is limited by very practical considerations. For example, it is theoretically possible to determine the interference effects of a satellite service on the FS by performing an exact calculation involving the convolution of all existing and planned transmissions of the satellite service against all existing and planned receptors of the FS while taking into account temporal, spatial and spectral factors. The practical considerations, however, in accumulating the requisite data for such a calculation, for even one type of sharing scenario, generally preclude this possibility.

Other methods of calculating protective criteria such as using “worst case” analysis may in certain cases be conservative for determining the use of a valuable and limited resource. Additionally, laboratory experiments do not lend themselves to convenient solutions for spatial and quantitative reasons. Finally, because of the uncertainty of being able to anticipate all of the situations which may develop, concerning new services or where continual evolution of existing services takes place, the results of any of the above techniques are subject to continual re-evaluation.

For these reasons, an analytic computer simulation of the problem is the most expedient method of getting useful results. Computer simulations using Monte Carlo methods for generating representative service implementations can create simulated data which can be used in place of actual or measured databases.

Appendix 1 provides a listing and description of a Monte Carlo implemented computer simulation that allows a variety of FS/satellite scenarios to be examined. The program can be used to test specific FS systems performance with specific satellite configurations emitting specific pfd levels. Iterative runs of the program can be used to determine the trade-offs of system parameters that would allow sharing.

Figures 3-7 provide results of appropriate example FS/satellite service sharing scenarios.

APPENDIX 1

Description of an example computer simulation program

1. Network assumptions

The satellite and radio-relay models implemented in the program assume that:

– the orbit is completely filled with uniformly spaced platforms, operating with the same level of effective radiated power and producing the same pfd on the earth surface; and

– the radio-relay network is composed of 50 hop routes randomly distributed over an approximately 65° by 22.5° longitude by latitude surface. All receivers have the same noise temperature, antenna characteristic (Recommendation ITU-R F.699), and spacing (50 km);

– free-space calculations are used. Atmospheric and polarity advantages are not considered.

2. Input/output

The simulation program allows operator selection and control of the following input parameters:

– latitude of the centre of the routes (trendline),

– receiver noise temperature,

– maximum receive antenna gain,

– number of radio-relay routes to be analysed,

– satellite spacing,

– orbit avoidance,

– low angle pfd,

– high angle pfd.

The program produces two output files containing databases that the user can analyse.

The first database (RAD_RTS.DAT) would appropriately be used to analyse the interference effects of analogue radio-relay networks for various satellite network configurations. The file is a series of records where each record gives the total baseband interference (pW) in a 4 kHz bandwidth for a 50 hop radio-relay route. The data could most typically be used to provide cumulative distribution graphs showing the amount of interference impairment that percentages of the analogue networks would experience as a function of the interference levels. The size of the file is twice the number of radio-relay routes analysed, since there are two directions for each route. The maximum size file will be 600 records and is a function of the maximum number of routes that can be handled by the program which is 300.

The second database file (RAD_STE.DAT) can similarly be used to analyse the effects of satellite interference on digital FS networks. Each record in the file is the interference (I) (W) input into a radio-relay site receiver. The records are arranged in groups of 50, so that analysis for each complete 50 hop route, in both directions, can be performed. Each route will produce 100 records (50×2). The maximum size file will contain 30 000 records ($50 \times 2 \times 300$).

In the event that the maximum size files from one computer run is not a sufficiently large enough sample of data, the program can be re-run and the subsequent data will be automatically appended.

3. Program operation

The program begins by selecting the user-specified latitude for the centre of the radio-relay route and then proceeds to calculate the longitude as a random variable (bounded by the 65° surface limits) of the centre of the route. The azimuth (relative to South) of the route direction or trendline, is calculated as a random variable with a uniform distribution between 0 and 2π. The location of the first radio-relay site is determined from the latitude, longitude and trendline angle. The sum of the interference into the site receiver from all visible satellites is then calculated and stored for further use.

The location of the next site on the route is determined by assuming that its direction is a uniformly distributed random variable within $\pm 25°$ of the route trendline and that the route length is 50 km. Interference into the new site receiver from all visible satellites is again calculated as described above.

Next site selection and interference calculations are repeated for all 50 hops in the route wherein a new route is randomly selected and the interference calculation process is repeated for up to 300 times. In the event that orbit avoidance is to be considered (user option), the program tests each site to determine if the site direction falls within the range to be avoided. If it does, the site location is discarded and a new direction and site is chosen.

The stored interference information is used to create the output files (RAD_RTS.DAT, RAD_STE.DAT).

In the case of analogue networks the baseband interference is the desired information. The program derives this information by assuming that there is a linear relationship between the receiver input interference-to-noise ratio and the baseband interference-to-noise ratio as follows:

$$i_c / n_c = i_b / n_b \tag{12}$$

or:

$$i_b = (i_c / n_c) \; n_b \tag{13}$$

The receiver input interference is determined by the network characteristics as explained above is in main § 3 of Annex 1. Therefore:

$$i_c = I_s \text{ (see equation (9))}$$

The receiver thermal input noise is a function of the radio-relay system noise temperature

$$n_c = k \, T_s \, b$$

where:

k: Boltzmann's constant

T_s: system noise temperature

b: voice channel bandwidth (4 kHz).

Recommendation ITU-R SF.358 indicates that for an appropriate radio-relay model the channel thermal noise power is:

$$n_b = 25 \text{ pW0p}$$

The program uses this value to determine the baseband interference for each site receiver per equation (13) and sums all 50 site interferences for each route to determine the total interference per route.

The second file (RAD_STE.DAT) created by the program is a compilation of the I_s values calculated.

Calculations made by the program are constrained by the following factors:

– The centre point of a route must lie between 15° and 70° latitude.

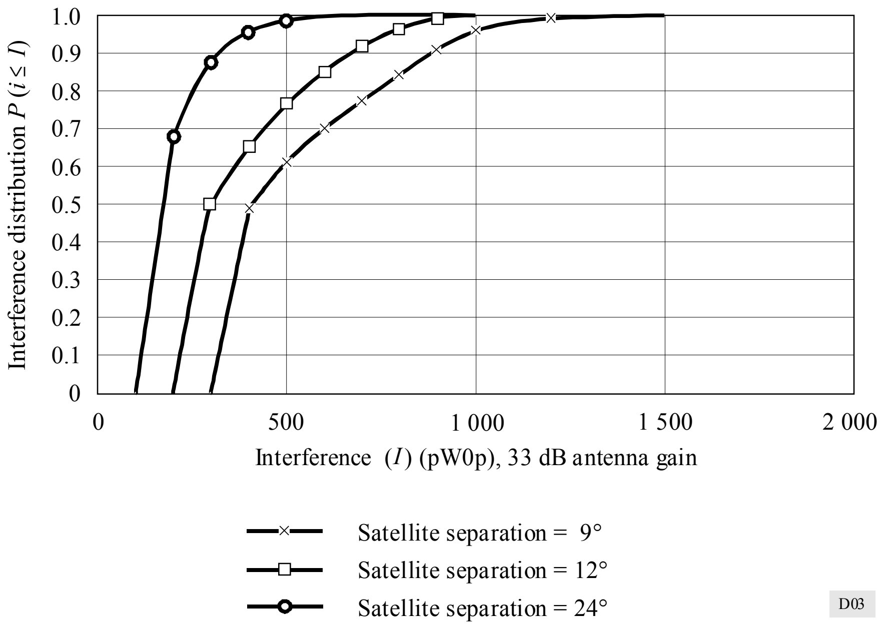
– The program assumes satellites are in exact equatorial planes, and does not allow for inclined orbits.

4. Sample scenario results

Figure 3 gives the results of an analysis of the RAD_RTS.DAT data for three 2 GHz sharing scenarios. All fixed systems were assumed to be 50 hop FDM routes implemented with 33 dB gain receive antennas and receivers with noise temperature of 1 750 K. These FS parameters are representative of those described in Recommendation ITU-R F.758. The three satellite network models considered limit pfd levels to –154 to –144 dB(W/m²) in 4 kHz and differ only in maximum orbit occupancy (9°, 12° and 24° spacing).

FIGURE 3

2 GHz interference distribution
40° lat., pfd = –154/–144 dB(W/(m²/4 kHz))



The results indicate that, for satellite spacings of 6° or more, the FDM FS systems would experience interference less than 1 000 pW in about 95% of the routes, assuming a uniform distribution of route directions. It also suggests that the FS might accept higher pfd levels from satellites with reduced orbit occupancy and still meet the 10% criteria.

Figure 4 illustrates the results of an analysis of the RAD_STE.DAT data. Here the resultant interference database was applied to an assumed FS system sharing spectrum with 2 GHz, 64-QAM, space diversity, digital FS routes typical of Recommendation ITU-R F.758. Using techniques described in Recommendation ITU-R PN.530, graphs depicting the cumulative effect on unavailability (the amount of time that the error ratio was less than 1 in 10^{-3}) were derived. The abscissa of Fig. 4 is a factor that increases unavailability of space diversity 50 hop digital routes as a result of the satellite interference. For example, about 80% of the routes experiencing interference from the satellite constellation with 24° separation would have less than a 50% increase in unavailability. This analysis gives some insight as to the apparent sensitivity of fixed digital systems and suggests that the impact on sharing be understood when changes to the definition of unavailability (i.e. ITU-T G.826) for digital systems are being considered.

FIGURE 4

2 GHz unavailability distribution
40° lat., pfd = –154/–144 dB(W/(m^2/4 kHz)),
Antenna gain: 33 dB/space div.

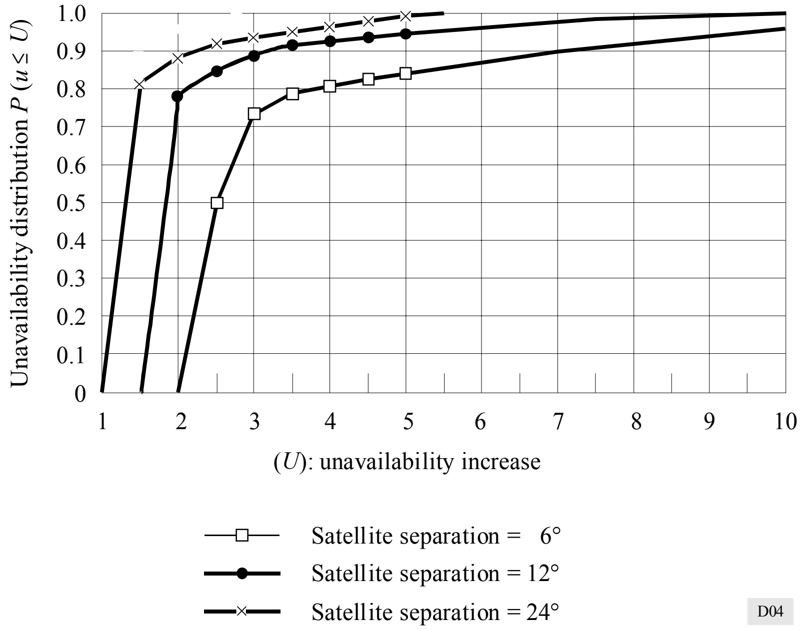
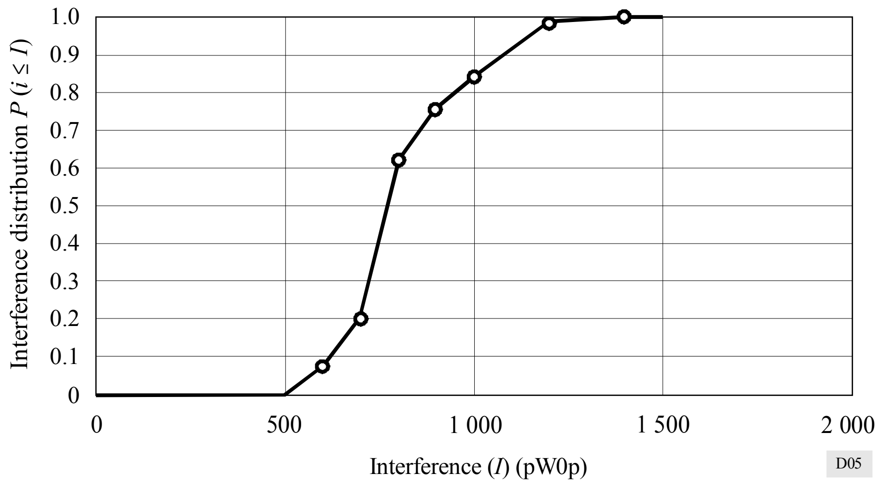


Figure 5 shows the results of sharing spectrum between an assumed satellite system spaced at 60° (possibly BSS (sound) or MSS systems) and a representative fixed analogue system configuration in the 1.5 GHz band. The allowable satellite high angle pfd level is assumed to be –135 dB(W/m^2) in 4 kHz. The low angle pfd was kept at –154 dB(W/m^2). The high angle pfd is 9 dB higher than pfd levels in adjacent bands. The results (from RAD_RTS.DAT) indicate over 85% of the fixed systems would have less than 1 000 pW of interference for that configuration.

FIGURE 5

Interference distribution, satellite separation = 60°
1.5 GHz, pfd = –154/–134 dB(W/(m^2/4 kHz)), 25° lat.



Figures 6 and 7 give the results of a partial study. The purpose of the study was to analyse in a quantitative manner the sensitivity of the interference distributions of the FS to changes in satellite pfd levels and to changes in the band of operation, assuming all other parameters in the sharing scenario were kept constant. The results suggest that the FS systems selected for operation in a shared enviroment have to be chosen with care if the same level of performance is to be maintained in all bands.

FIGURE 6

1.5 GHz, satellite/FS interference study
40° lat., satellite separation = 45°, pfd = dB(W/(m²/4 kHz))

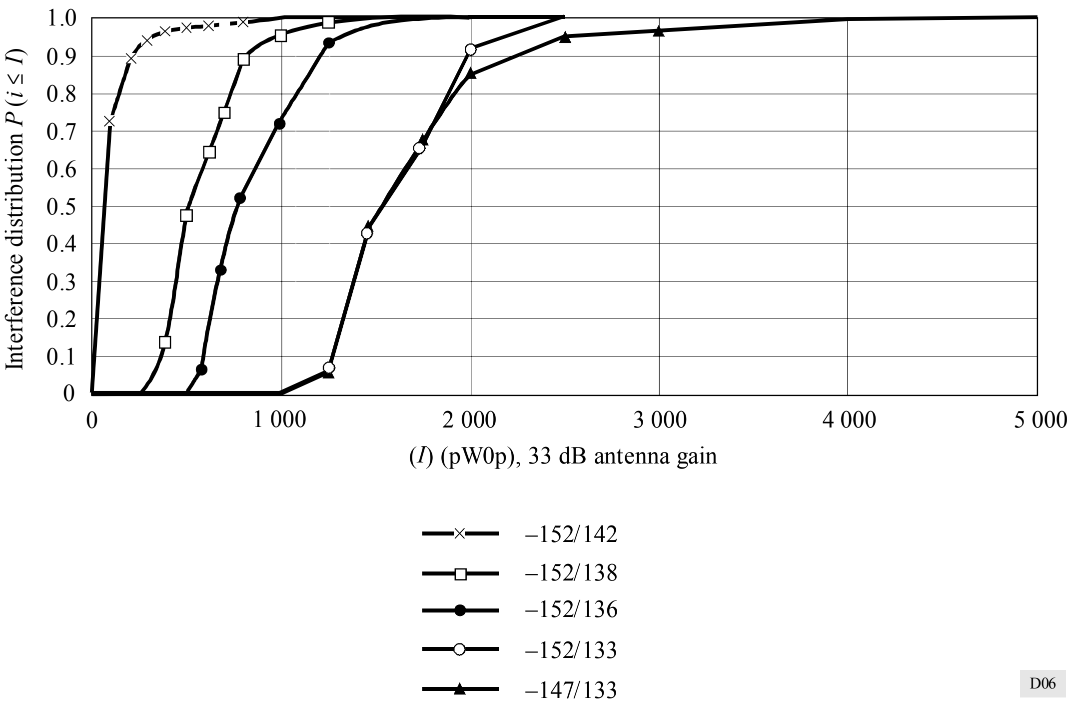
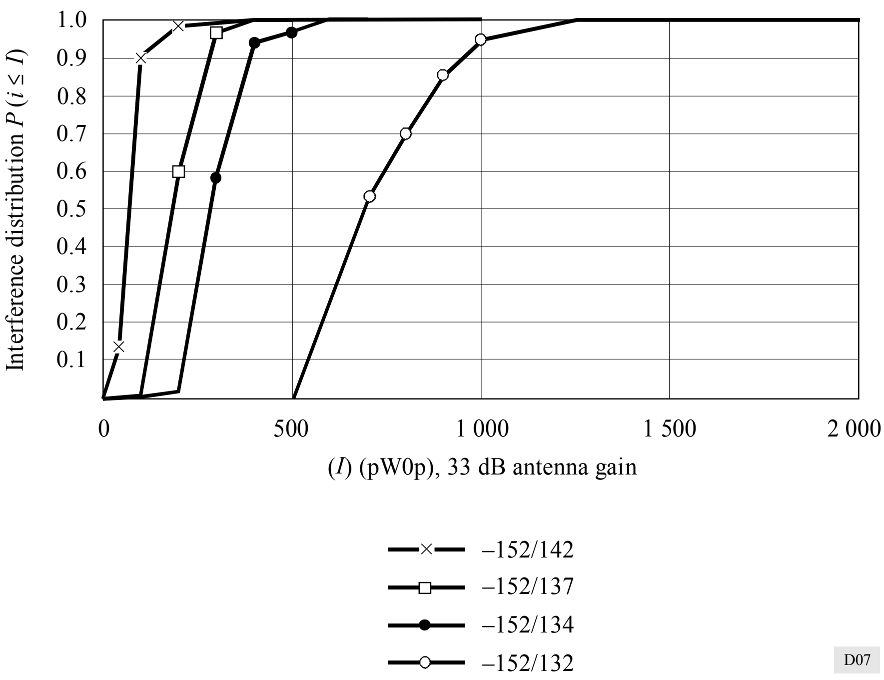


FIGURE 7

2.5 GHz, satellite/FS interference study
40° lat, satellite separation = 45°, pfd = dB(W/(m²/4 kHz))



5. Listing OF RAD_REL.BAS

The following listing has been successfully compiled with a commercial compiler (Microsoft QuickBasic versions 4 and 4.5). Other compilers may require some modification of the code for proper operation. As indicated in § 1 of this Appendix, network parameters can be adjusted for both the radio-relay and satellite networks so that a variety of sharing situations can be analysed.

Care should be taken that the below numbered statements having more than one line of code be entered without control characters i.e. no “carriage return” or “line feed”.

REFERENCE: A.S. MAY AND M.J. PAGONES. MODEL FOR COMPUTATION OF INTERFERENCE FROM GEOSTATIONARY SATELLITES. BSTJ, VOL. 50, NO. 1, JANUARY 1971, PP81-102.

```
'       MAINPROGRAM

100     CLS : SCREEN 9

155     RANDOMIZE TIMER: RTS = 49:
        STS = 50'RTS=# RR ROUTES, STS=# STATION SITES PER ROUTE

160     CLS : PI = 3.141593: RA = .01745329#:
        DE = 57.29578: T = 22.48309
'       T = MAXIMUM GREAT CIRCLE LENGTH (DEG) OF ONE 50 HOP ROUTE

162     K = 6.629957: K2 = K * K: K4 = 1 / (K2 - 1) ^ .5:
        K2I = 1 / K2: PI2 = PI / 2

165     GOSUB 1650'ENTER LATITUDE OF SYSTEMS

170     GOSUB 1700'ENTER FREQUENCY

175     GOSUB 1750'ENTER RR RECEIVER NOISE TEMP

180     GOSUB 1800'ENTER RR RECEIVE MAXIMUM ANTENNA GAIN

185     GOSUB 3000'ENTER # OF RR ROUTES

190     GOSUB 4000'ENTER AMOUNT OF ORBIT AVOIDANCE

195     GOSUB 5000'ENTER SATELLITE ORBIT SEPARATION

200     GOSUB 6000'ENTER LOW/HIGH ANGLE PFD LIMIT VALUES

210     GOSUB 7000'MAKE REVISIONS OF ABOVE ENTRIES

215     PF = .005 * (PFH - PFL): PFDL = 10 ^ (.1 * PFL):
        PFDH = 10 ^ (.1 * PFH)

220     CLS : DIM A!(RTS, STS): DIM B!(1 + 2 * RTS): DIM C!(RTS, STS)

225     FOR Q = 0 TO RTS: FOR V = 0 TO STS: A(Q, V) = 0: C(Q, V) = 0:
        NEXT: NEXT

227     FOR Q = 0 TO (1 + 2 * RTS): B(Q) = 0: NEXT

230     MU = 1.6212E+18 / (FREQ ^ 2 * NTEMP)

235     MU1 = kTbl/Nc

'       MU=Nc((c/FREQ)^2/4Pi)/kTbl, MU1 = kTbl/Nc

'       Where:

'                       Nc=voice channel noise power

'                       = 25 picowatts

'                       c/FREQ=transmission wavelength

'                       k=Boltzmann's constant, 1.3805E-23
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```
'                         T=receiver noise temp. in Kelvin s
'                         b=channel bw, 4KHz
'                         l=feeder loss,3dB
'       START ROUTE CALCULATIONS
240     FOR M = 0 TO RTS
243     LOCATE 13, 1: PRINT STRING$(30, 0)
244     LOCATE 13, 1: PRINT "CALCULATING ROUTE"; M
245     LONGREF = T * (2 * RND - 1)
'       LONGREF is longitude of middle of reference
250     TAU = 90 * RND: TAURA = TAU * RA
'       TAU is the direction of RR network trendline
260     LATR0 = (((T / 2) * COS(TAURA)) + LATREF)
265     LONGR0 = -((T / 2) * SIN(TAURA) + LONGREF)
'       LATRO, LONGRO is latitude, longitude of the 1st RR site.
275     'X = 319.5 + ((LONGR0 * 319.5) / (1.5 * T)):
        'Y = (1 - COS(TAURA)) * 77.5
'       X, Y= SCREEN COORDINATES FOR PLOTTTING THE SITES. REMOVE "'"
'       FROM 275, 530 - 550 FOR GRAPHIC REPRESENTATION OF ROUTES.
'       Find satellite horizon from 1st RR site
300     A = K4 * TAN(LATR0 * RA): A2 = ((1 - A * A) ^ .5) / A
305     AZMUTH = ATN(A2)
'       Azmuth= angle to horizon from south at RR point
310     AZ = SIN(AZMUTH) * ((1 - K2I) ^ .5)
315     LONGHOR = ATN(AZ / ((1 - AZ * AZ) ^ .5))
'       LONGHOR is the longitude difference between the RR and
'       horizon/orbit intercept
320     LONHOR = LONGHOR * DE
'       Calculate interference from all visible sats into a RR site
'       on a route.
330     LONGR = LONGR0: LATR = LATR0: LONS = 0
'       LONGR=Longitude of RR, LATR=Latitude of RR, LONS=longitude of
'       next visible sat.
'       Do the interference calculation for each site
335     FOR N = 0 TO STS
340     RR = (TAU + 25) - (50 * RND): RRD = RR * RA
'       RR, RRD is the pointing direction to the next site
'       Calculate location of next RR site
'       Find most easterly visible satellite.
350     DO WHILE LONS <= LONHOR + LONGR
360     LONS = LONS + SEP: LOOP
364     LONS = LONS - SEP
370     'Do the interference calculation per site.
380     DO WHILE LONS >= LONGR - LONHOR
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```
390     GOSUB 2360

395     IF GAMMAW < AVOID OR GAMMAE < AVOID
        THEN A(M, N) = 0: C(M, N) = 0: GOTO 340

400     LONS = LONS - SEP: LOOP

'       Calculate location of next RR site

411     J = LONGR: L = LATR

420     P =  (SIN(LATR * RA)) * COS(.4496 * RA) -
             (COS(LATR * RA)) * (SIN(.4496 * RA)) * (COS(RRD))

430     Q = P / (1 - P * P) ^ .5

435     LATR = DE * ATN(Q) 'LATITUDE OF THE NEXT RR SITE

440     R = SIN(.4496 * RA) * SIN(RRD) / (1 - P * P) ^ .5:
        S = R / (1 - R * R) ^ .5: DELLONGR = ATN(S) * DE

450     LONGR = LONGR + DELLONGR 'LONGITUDE OF NEXT RR SITE

'       Calculate satellite horizon for the new RR site

470     A = K4 * TAN(LATR * RA): A2 = ((1 - A * A) ^ .5) / A

480     AZMUTH = ATN(A2)
        'Azmuth= angle to horizon from south at RR point, South reference

490     AZ = SIN(AZMUTH) * ((1 - K2I) ^ .5)

500     LONGHOR = ATN(AZ / ((1 - AZ * AZ) ^ .5))

'       LONGHOR is the longitude of the RR horizon/orbit intercept

520     LONHOR = LONGHOR * DE

'       Print RR route on screen

530     'Y1 = ((L - LATR) / T) * 155: X1 = (DELLONGR / (3 * T)) * 480

540     'LINE (X, Y)-(X + X1, Y + Y1)

550     'X = X + X1: Y = Y + Y1

555     NEXT ' Do next RR site

560     NEXT ' Do next RR route

'       Calculate the output files

600     FOR M = 0 TO RTS

610        FOR N = 1 TO STS

620              B(M) = B(M) + A(M, N)

630        NEXT N

640     NEXT M

650     FOR G = 0 TO RTS

660       FOR H = 0 TO STS - 1

670             B(RTS + 1 + G) = B(RTS + 1 + G) + C(G, H)

680       NEXT H

690     NEXT G

700     OPEN "RAD_RTS.DAT" FOR APPEND AS #1

710     FOR M = 0 TO 1 + (2 * RTS)
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720     'PRINT "ROUTE"; M; : PRINT "="; B(M)
725     PRINT #1, B(M)
730     NEXT
735     CLOSE #1
740     OPEN "RAD_STE.DAT" FOR APPEND AS #2
750     FOR M = 0 TO RTS: FOR N = 0 TO STS
755     A(M, N) = A(M, N) * MU1
760     PRINT #2, A(M, N): NEXT: NEXT
765     PRINT #2, 0
770     FOR M = 0 TO RTS: FOR N = 0 TO STS
775     C(M, N) = C(M, N) * MU1
780     PRINT #2, C(M, N): NEXT: NEXT
790     CLOSE #2
830     'PRINT "PROGRAM COMPLETED, PRESS ANY KEY TO END"
840     A$ = INKEY$: IF A$ = " " THEN 840
850     IF A$ = "r" OR A$ = "R" THEN LOCATE 14, 1:
        PRINT STRING$(70, 0): GOTO 225 'REPEAT DATA BASE CALC.
860     IF A$ = "e" OR A$ = "E" THEN CLS : GOTO 1000
870     GOTO 830
1000    END ' END OF RAD_REL.BAS

'Subroutine for entering RR route latitude

1650    LOCATE 4, 1: PRINT STRING$(78, 0): LOCATE 5, 1:
        PRINT STRING$(20, 0)
1660    LOCATE 4, 1: PRINT "1) ENTER NETWORK LATITUDE (15 to 70) "
1670    INLEN% = 6: GOSUB 14000
1680    LATREF = VAL(BUFF$)
        'LATREF is the latitude at the centre of the trend line
1690    IF (LATREF > 70! OR LATREF < 15!) THEN LOCATE 22, 1:
        PRINT "Out of Range, RE-ENTER, ": FOR C = 1 TO 100000:
        NEXT: LOCATE 22, 1: PRINT STRING$(40, 0): GOTO 1650
1695    RETURN

'Subroutine for entering frequency of operation

1700    LOCATE 6, 1: PRINT STRING$(78, 0): LOCATE 7, 1:
        PRINT STRING$(20, 0)
1710    LOCATE 6, 1: PRINT "2) ENTER TRANSMIT CARRIER FREQUENCY <GHz>"
1720    INLEN% = 6: GOSUB 14000
1730    FREQ = VAL(BUFF$)'FREQ = FREQUENCY OF SHARING SCENARIO IN GHZ
1740    IF FREQ <= 0! OR FREQ > 100! THEN LOCATE 22, 1:
        PRINT "OUT OF RANGE, RE-ENTER,": FOR C = 1 TO 100000: NEXT:
        LOCATE 22, 1: PRINT STRING$(78, 0): GOTO 1700
1745    RETURN
```

```
'Subroutine - enter RR receiver noise temp.

1750    LOCATE 8, 1: PRINT STRING$(78, 0): LOCATE 9, 1:
        PRINT STRING$(20, 0)

1760    LOCATE 8, 1:
        PRINT "3) ENTER AVE. VALUE OF RR RECEIVER NOISE TEMP <DEG
        KELVIN>"

1770    INLEN% = 6: GOSUB 14000

1780    NTEMP = VAL(BUFF$)'NTEMP=NOISE TEMP OF RR RECEIVERS

1790    IF NTEMP <= 0 THEN LOCATE 22, 1:
        PRINT "OUT OF RANGE, RE-ENTER,": FOR C = 1 TO 100000: NEXT:
        LOCATE 22, 1: PRINT STRING$(78, 0): GOTO 1750

1795    RETURN

'Subroutine - enter RR receive antenna gain and calculate
              intermediate parms.

1800    LOCATE 10, 1: PRINT STRING$(78, 0): LOCATE 11, 1:
        PRINT STRING$(20, 0)

1805    LOCATE 10, 1:
        PRINT "4) ENTER MAX RADIO-RELAY RECEIVE ANTENNA DB GAIN"

1810    INLEN% = 6: GOSUB 14000

1820    GMAX = VAL(BUFF$)'GMAX is MAX RR rec. Antenna gain

1830    IF GMAX < 0 OR GMAX > 99 THEN LOCATE 22, 1:
        PRINT "OUT OF RANGE, RE-ENTER": FOR C = 1 TO 100000: NEXT:
        LOCATE 22, 1: PRINT STRING$(40, 0): GOTO 1800

1840    DLAMBDA = 10 ^ ((GMAX - 7.7) / 20)
        'DLAMBDA=RATIO OF REC. ANT DIA./ WAVELENGTH

1850    G1 = 2 + 15 * (LOG(DLAMBDA) / LOG(10))
        'PRINT "DLAMBDA="; DLAMBDA

1860    PHYM = (20 / DLAMBDA) * (GMAX - G1) ^ .5

1870    RETURN

'       This Subroutine to calculate RR/sat elevation and
        separation angles and interference

2360    W = (LONS - LONGR):
        ASAT = ATN((TAN(W * RA)) / SIN(LATR * RA)): ASAT1 = ASAT

'       ASAT=AZMUTH ANGLE TO SUBSAT REFERENCED TO SOUTH

2370    U = COS(LATR * RA) * COS(W * RA):
        BETA = ATN((1 - U * U) ^ .5 / U)

2380    OMEGA = ATN(SIN(BETA) / (K - COS(BETA)))

2390    THETAR = PI2 - (BETA + OMEGA): THETA = THETAR * DE
        THETA=ELEVATION ANGLE TO SAT FROM RR

2400    VW = (COS(THETAR)) * COS(ASAT - RRD):
        GAMMAW = (PI2 - ATN(VW/SQR (1 - VW * VW)) * DE
'       GAMMAW = ANGLE BETWEEN SATELLITE AND WEST POINTING RECEIVER

2415    GAMMAE = 180 - GAMMAW
'       GAMMAE = ANGLE BETWEEN SATELLITE AND EAST POINTING RECEIVER

2420    IF GAMMAW < 0 THEN GAMMAW = 180 + GAMMAW

2425    IF GAMMAE < 0 THEN GAMMAE = 180 + GAMMAE
```

```
2430    IF (GAMMAW <= AVOID) OR (GAMMAE <= AVOID) THEN RETURN

2440    IF THETA >= 0 AND THETA < 5 THEN PFD = PFDL: GOTO 2500

2450    IF THETA >= 5 AND THETA < 25 THEN
        PFD = (10 ^ (PFL * .1 + PF * (THETA - 5))): GOTO 2500

2460    IF THETA >= 25 THEN PFD = PFDH

2500    IF GAMMAW >= 0 AND GAMMAW <= PHYM THEN GTHETAW
        = 10 ^ (.1 * (GMAX - .0025 * (DLAMBDA * GAMMAW) ^ 2)):
        GOTO 2540

2510    IF GAMMAW >= PHYM AND GAMMAW < (100 / DLAMBDA) THEN
        GTHETAW = 10 ^ (.1 * G1): GOTO 2540

2520    IF GAMMAW >= (100 / DLAMBDA) AND GAMMAW < 48 THEN
        GTHETAW = 10 ^ (.1 * (52 - 10 * (LOG(DLAMBDA)) / LOG(10) -
        25 * (LOG(GAMMAW)) / LOG(10))): GOTO 2540

2530    IF GAMMAW >= 48 AND GAMMAW ≤ 180 THEN
        GTHETAW = 10 ^ (1 - (LOG(DLAMBDA)) / LOG(10))

2540    SINTW = MU * PFD * GTHETAW:
        IF N > 0 THEN A(M, N) = A(M, N) + SINTW
'       SINTW = INTEFERENCE INTO WEST POINTING RECEIVERS

2550    IF GAMMAE >= 0 AND GAMMAE <= PHYM THEN GTHETAE
        = 10 ^ (.1 * (GMAX - .0025 * (DLAMBDA * GAMMAE) ^ 2)):
        GOTO 2590

2560    IF GAMMAE >= PHYM AND GAMMAE < (100 / DLAMBDA) THEN
        GTHETAE = 10 ^ (.1 * G1): GOTO 2590

2570    IF GAMMAE >= (100 / DLAMBDA) AND GAMMAE < 48 THEN
        GTHETAE = 10 ^ (.1 * (52 - 10 * (LOG(DLAMBDA)) / LOG(10) -
        25 * (LOG(GAMMAE)) / LOG(10))): GOTO 2590

2580    IF GAMMAE >= 48 AND GAMMAE ≤ 180 THEN
        GTHETAE = 10 ^ (1 - (LOG(DLAMBDA)) / LOG(10))

2590    SINTE = MU * PFD * GTHETAE: IF N < 50 THEN
        C(M, N) = C(M, N) + SINTE
'       SINTE = INTERFERENCE INTO EAST POINTING RECEIVERS

2600    RETURN


'Subroutine - ALLOWS ENTRY OF # RR ROUTES (RTS)

3000    LOCATE 12, 1: PRINT STRING$(78, 0): LOCATE 13, 1:
        PRINT STRING$(20, 0)

3010    LOCATE 12, 1:
        PRINT "5) ENTER NUMBER OF RADIO-RELAY ROUTES <300 MAX>"

3020    INLEN% = 3: GOSUB 14000

3030    RTS = VAL(BUFF$)

3033    IF RTS > 300 OR RTS < 1 THEN LOCATE 22, 1:
        PRINT "Out of Range, RE-ENTER": FOR C = 1 TO 100000: NEXT:
        LOCATE 22, 1: PRINT STRING$(40, 0): GOTO 3000

3035    IF RTS <= 300 THEN RTS = RTS - 1: RETURN
```

```
'Subroutine to specify orbit avoidance

4000    LOCATE 14, 1: PRINT STRING$(78, 0): LOCATE 15, 1:
        PRINT STRING$(20, 0)

4040    LOCATE 14, 1:
        PRINT "6) ENTER ORBIT AVOIDANCE ANGLE, DEG. <ENTER>"

4050    INLEN% = 4: GOSUB 14000

4060    AVOID = VAL(BUFF$)

4070    IF AVOID < 0 THEN LOCATE 22, 1:
        PRINT "Out of Range, RE-ENTER": FOR C = 1 TO 100000: NEXT:
        LOCATE 22, 1: PRINT STRING$(40, 0): GOTO 4000

4080    RETURN

'Subroutine to determine satellite orbit separation

5000    LOCATE 16, 1: PRINT STRING$(78, 0): LOCATE 17, 1:
        PRINT STRING$(20, 0)

5010    LOCATE 16, 1:
        PRINT "7) ENTER SATELLITE ORBIT SEPARATION (2 MIN), DEG.
        <ENTER>"

5060    INLEN% = 5: GOSUB 14000

5070    SEP = VAL(BUFF$)

5080    IF SEP < 2 THEN LOCATE 22, 1: PRINT "Out of Range, RE-ENTER":
        FOR C = 1 TO 100000: NEXT: LOCATE 22, 1: PRINT STRING$(40, 0):
        GOTO 5000

5090    RETURN

'Subroutine - Enter low/high angle pfd value

6000    LOCATE 18, 1: PRINT STRING$(78, 0): LOCATE 19, 1:
        PRINT STRING$(20, 0): LOCATE 20, 1: PRINT STRING$(78, 0):
        LOCATE 21, 1: PRINT STRING$(20, 0)

6010    LOCATE 18, 1:
        PRINT "8A) ENTER MAXIMUM LOW ANGLE (0 <= THETA < 5°) PFD
        LEVEL"

6020    INLEN% = 5: GOSUB 14000

6030    PFL = VAL(BUFF$)

6040    IF PFL > 0 THEN LOCATE 22, 1:
        PRINT "OUT OF RANGE, ENTER NEGATIVE VALUE":
        FOR C = 1 TO 100000: NEXT: LOCATE 22, 1: PRINT STRING$(50, 0):
        GOTO 6000

' - Enter high angle pfd value

6500    LOCATE 20, 1: PRINT STRING$(78, 0): LOCATE 21, 1:
        PRINT STRING$(20, 0)

6510    LOCATE 20, 1:
        PRINT "8B) ENTER MAXIMUM HIGH ANGLE ( THETA >= 25°)
        PFD LEVEL"

6520    INLEN% = 5: GOSUB 14000

6530    PFH = VAL(BUFF$)
```

```
6540   IF PFH > 0 THEN LOCATE 22, 1:
       PRINT "OUT OF RANGE, ENTER NEGATIVE VALUE":
       FOR C = 1 TO 100000: NEXT: LOCATE 22, 1: PRINT STRING$(50, 0):
       GOTO 6500

6545   PF = .005 * (PFH - PFL): PFDL = 10 ^ (.1 * PFL):
       PFDH = 10 ^ (.1 * PFH)

6550   RETURN

7000   LOCATE 22, 1: PRINT STRING$(78, 0): LOCATE 23, 1:
       PRINT STRING$(20, 0)

7010   LOCATE 22, 1:
       PRINT "REVISIONS? ENTER '1 - 8' OR '0' IF  NONE "

7020   A$ = INKEY$: IF A$ = "" THEN 7020

7030   IF A$ = "0" OR A$ = CHR$(13) THEN RETURN

7040   IF A$ = "1" THEN GOSUB 1650: GOTO 7000

7050   IF A$ = "2" THEN GOSUB 1700: GOTO 7000

7060   IF A$ = "3" THEN GOSUB 1750: GOTO 7000

7070   IF A$ = "4" THEN GOSUB 1800: GOTO 7000

7080   IF A$ = "5" THEN GOSUB 3000: GOTO 7000

7090   IF A$ = "6" THEN GOSUB 4000: GOTO 7000

7100   IF A$ = "7" THEN GOSUB 5000: GOTO 7000

7110   IF A$ = "8" THEN GOSUB 6000: GOTO 7000

7200   GOTO 7000

'Subroutine for entering numeric data

14000  TRUE = -1: FALSE = 0'Formated numeric input subroutine

14005  POINT. = FALSE: DEC.CNT = 0: BUFF$ = " ":
       ERA$ = CHR$(29) + CHR$(95) + CHR$(29):
       PRINT STRING$(INLEN%, CHR$(95)); STRING$(INLEN%, CHR$(29));

14010  W$ = INPUT$(1): IF W$ >= "0" AND W$ <= "9" THEN 14100

14020  IF W$ <> CHR$(8) THEN 14040

14030  IF BUFF$ = "" THEN 14010 ELSE W$ = RIGHT$(BUFF$, 1):
       BUFF$ = LEFT$(BUFF$, LEN(BUFF$) - 1): PRINT ERA$; :
       IF W$ = "." THEN POINT. = FALSE: DEC.CNT = 0

14035  IF POINT. THEN DEC.CNT = DEC.CNT - 1: GOTO 14010 ELSE 14010

14040  IF W$ = CHR$(13) THEN RETURN

14070  IF W$ = "." THEN IF POINT. THEN 14010 ELSE IF
       LEN(BUFF$) = INLEN% THEN 14010 ELSE POINT. = TRUE: GOTO 14100

14080  IF W$ = "-" OR W$ = "+" THEN IF BUFF$ > " " THEN
       14010 ELSE 14100

14090  GOTO 14010

14100  IF LEN(BUFF$) = INLEN% OR DEC.CNT = 3 THEN
       14010 ELSE PRINT W$; :  BUFF$ = BUFF$ + W$:
       IF POINT. THEN DEC.CNT = DEC.CNT + 1: GOTO 14010 ELSE 14010
```

'Subroutine - Enter alphanumeric data (not used)

```
14300   BKSPC$ = CHR$(8): CR.RET$ = CHR$(13):
        ERA$ = CHR$(29) + " " + CHR$(29) 'String input routine

14305   BUFF$ = " "

14310   W$ = INPUT$(1): IF W$ >= "a" AND W$ <= "z" THEN
        W$ = CHR$(ASC(W$) - 32): GOTO 14350

14315   IF W$ >= " " AND W$ <= CHR$(127) THEN 14350

14320   IF W$ = BKSPC$ THEN IF BUFF$ = " " THEN 14310 ELSE
        BUFF$ = LEFT$(BUFF$, LEN(BUFF$) - 1): PRINT ERA$; :
        GOTO 14310

14340   IF W$ = CR.RET$ THEN RETURN ELSE 14310

14350   IF LEN(BUFF$) = INLEN% THEN 14310 ELSE PRINT W$; :
        BUFF$ = BUFF$ + W$: GOTO 14310
```