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The HF Broadcasting Planning Model: A Comparison of Two Versions

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A COMPARISON OF TWO VERSIONS

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The First Session of the World Administrative Radio Conference for the planning of the high frequency (HF) bands allocated exclusively to the broadcasting service held in Geneva, Switzerland, in January and February of 1984, established the technical criteria, planning principles, and methods to be tested for the HF broadcast services during the period between the First and Second Sessions of the Conference. The International Frequency Registration Board (IFRB) implemented these planning principles and methods on a computer and prepared broadcasting plans using test sets of requirements for the Second Session of the World Administration Radio Conference. The Institute for Telecommunication Sciences (ITS) adopted a parallel activity to assist the United States' preparations for the Second Session of the Conference.

This report discusses the IFRB computer system and the ITS computer model and their results for the December 1985 set of HF broadcasting requirements. These results are further analyzed in terms of usage factor, tendencies in the planning process, and alternatives to the IFRB planning process.

Key words: broadcast requirements; HF broadcast planning model; HF propagation prediction; IFRB; World Administration Radio Conference for HF broadcasting; usage factor

1. INTRODUCTION

Decisions taken at the 1979 World Administrative Radio Conference (WARC) extended the exclusive allocations of the frequency bands for the high frequency (HF) broadcasting service by 780 kHz and called for a two-session HF WARC to plan the exclusive HF broadcasting bands. (Table 1 provides the HF broadcasting bands for the pre- and post-WARC 1979 band allocation.) These Conferences are referred to here as the First, or Second, Session of the HFBC. The First Session of the HFBC was held in Geneva, Switzerland, January 10 to February 12, 1984. This Session specified the planning principles and methods, decided the technical criteria, and outlined the intersessional activity to be undertaken between the First and Second Sessions of the HFBC

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held in Geneva, February-March 1987. The Report to the Second Session of the Conference (ITU, 1984) contains the decisions taken at the First Session of the HFBC and provides the technical criteria and planning principles that were agreed to at the First Session of the HFBC. It will be referred to as the Report (ITU, 1984).

Table 1. Exclusive Allocations to the HF Broadcasting Service

Band (MHz)	Pre-WARC 1979 (kHz)	Width (kHz)	Post-WARC 1979 (kHz)	Width (kHz)	Variation (kHz)
6	5950-6200	250	5950-6200	250	+ 0
7	7100-7300	200	7100-7300	200	+ 0
9	9500-9775	275	9500-9900	400	+ 125
11	11700-11975	275	11650-12050	400	+ 125
13	none	---	13600-13800	200	+ 200
15	15100-15450	350	15100-15600	500	+ 150
17	17700-17900	200	17550-17900	350	+ 150
21	21450-21750	300	21450-21850	400	+ 100
26	25600-26100	500	25670-26100	430	- 70
		2350		3130	+ 780

The International Frequency Registration Board (IFRB) was tasked to develop seasonal plans demonstrating the capabilities of the planning method. As many as five seasonal plans (shown in Table 2) were to be developed for the Second Session of the HFBC. Each plan was to show variations in the following parameters: 1) the percentile of test points to represent the coverage area, 2) the presence or absence of the new maritime zones, 3) the amount of additional protection in the application of proportional reduced protection, 4) the values of minimum usable field strength, and 5) the presence or absence of preset frequencies. These seasonal plans (IFRB, 1986, Chapter 6) were developed and were presented to the Second Session of the HFBC using the broadcasting requirements submitted by administrations in accordance with Resolution COM 5/3 of the First Session of the HFBC (ITU, 1984, p. 88). The Second Session of the HFBC viewed the results of the IFRB and adopted changes to the planning method decided by the First Session. The results described in this report pertain to the planning principles and methods agreed to by the First Session of the HFBC.

Table 2. Seasonal Plans

Season	Sunspot Number
December 1985 (D85)	5
December 1985 (D85 2)	120
June 1986 (J86)	5
March 1988 (M88)	60
June 1988 (J88)	60

Shortly after the end of the First Session of the HFBC, the uncertainties in the planning method and time constraints on the IFRB prompted the Institute for Telecommunication Sciences (ITS) to undertake a task similar to that of the IFRB in implementing the planning principles and methods. The results of this implementation are described in Washburn et al. (1985) along with a concise description of the differences between the ITS effort and that of the IFRB. The IFRB effort will be referred to as the System (IFRB, 1986); the ITS effort will be referred to as the Model.

The broadcasting requirements for each season change according to the objectives of the individual broadcasters. For the most part, the number of programs that are broadcast varies little from season to season. The frequencies used for broadcasting can change from season to season, however. The IFRB collected the broadcast requirements from the member administrations of the International Telecommunication Union (ITU) as specified. These requirements of the Report (ITU, 1984) were compiled, collated, and assigned unique identification numbers. They were distributed to member administrations upon request and formed the basis for the processing of the planning method by the IFRB and by ITS.

The progress made since publication of the Model, as contained in Washburn et al. (1985), built upon the preparations made during the previous year. The Model was completed to the extent possible and exercised for selected hours and radio-frequency protection ratios (PR) for the December 1985 (D85) requirements. The results and tendencies of the execution of the Model were reported routinely to IRAC Ad Hoc Committee 176 and the WARC-HFBC(2) Working Group formed by the U. S. Department of State. The basis of this report is formed from the D85 Model and System results (IFRB, 1986) as well as discussions of alternatives to the planning process. In addition, discussion is given to the suspected impact on the planning process that will result from the changes made at the Second Session of the HFBC.

In addition to this introduction, the six sections of this report include brief descriptions (Section 2) of the System and the Model, followed by their differences (Section 3). Section 4 provides a description of the processing of the D85 requirements and the D85 plan generation along with an analysis of the results of the planning process. A discussion of alternatives to the planning process as implemented in the System and the Model appears in Section 4.2. Section 5 summarizes the project accomplishments and possible alternatives to the planning method. In this report "hours" and "time blocks" are used interchangeably to mean the time interval from the beginning of an hour to the end of that hour in terms of universal time (UT). For example, hour 1 or time block 1 corresponds to the time interval from 0000 to 0100 UT.

2. BRIEF DESCRIPTIONS OF THE SYSTEM AND THE MODEL

The System (IFRB, 1986) follows the principles and specifications adopted at the First Session of the HFBC as interpreted by the IFRB. The guiding principles and methods for the development of the System are found in Chapter 4 of the Report (ITU, 1984). They have been followed to generate the D85 plan as well as the other plans appearing in Table 2. The planning method has four phases.

Phase 1 of the method organizes the basic data needed to drive the plan to completion. The first component of the basic data is the broadcast requirements of each administration for the seasons in Table 2. The elements of the requirements can be found in Chapter 3, Section 2, of IFRB (1986) or in Section 2 of Washburn et al. (1985) and are summarized here in Table 3 for convenience. The second component of the basic data is the transmitter and test point or reception locations. The transmitter locations are taken from the individual broadcast requirements and the test points, distributed world-wide within established CIRAF zones, can be found in Chapter 3, Section 3 of IFRB (1986). (CIRAF is an acronym for Conference Internacional Radiodiffusion des Altos Frequencies.) The third component of the basic data is the predicted nominal median field strength, which is based on the method found in Section 3.2.1 of ITU (1984). The highlights of this method are presented here in Table 4 and a description of its usage can be seen in Washburn et al. (1985, pp. 9-12). The fourth component of the first phase is the antenna specifications. Administrations could specify any of twenty-five reference antennas as inputs to their respective broadcast requirements. These reference antennas are described in Chapter 3, Section 5, of ITU (1984) and in Chapter 3, Section 4, of IFRB (1986). Table 5 lists these reference antennas.

Table 3. Elements of the Broadcast Requirements

Element	Feature
1	ITU Aministration Code
2	Administration requirement serial number
3	Season and year of operation
4	Name of transmitter location
5	Transmitter location by administration
6	Geographic location of the transmitter
7	Serial number of the requirement that provides frequency continuity
8	Serial number of the requirement that provides synchronous operations
9	Serial number of requirement that provides coverage of noncontiguous zones
10	Type of modulation
11	Required service area (up to 12 contiguous CIRAF zones and/or quadrants, or 1 service sector)
12	Hours of operation
13	Indication of one preferred frequency or one preferred frequency band
14	Number of bands that can be used simultaneously
15	Equipment availability and limits for each band [antenna type number, azimuth of main beam, maximum transmitter power (dBW), three reduced power levels (dBW), preset frequency]
16	IFRB serial number (unique for the season)

The fifth component of the basic data is the minimum field strength (Emin). This is in the form of a table indexed by test point, season, and time block, and represents the values that the predicted median field strengths must have to overcome the noise levels adopted by the First Session of the HFBC plus a radio noise protection ratio of 34 dB. The specification for Emin is in Chapter 3, Section 5 of IFRB (1986). The minimum value Emin can have in this table is 37.5 dB uV/m.

Table 4. Highlights of the Propagation Prediction Method

Method	Path Distance d (km)	Exceptions	Features	ITU (1984) Paragraph
1	≤ 7000		Sum two strongest F-layer modes with strongest E-layer mode	3.2.1.3.1.7
		1) d > 4000 km	E-layer mode ignored	3.2.1.2.2.2.2
		2) d ≤ 4000 km	F-layer mode screened by E-layer ignored	3.2.1.2.2.2.1
2	> 9000		Antenna gain calculated for fixed elevation angle of 8 degrees for all azimuths	3.2.1.3.2
3	7000 < d ≤ 9000		Median field strength based on linear interpolation between results of Methods 1 and 2	3.2.1.3.3

Phase 2 of the planning method establishes a profile for each of the requirements from information supplied by the basic data. The profile consists of attributes the planning method assigns depending upon the predictions of the propagation environment. The attributes indicate elements for the appropriate band selection, additional frequency selection, qualification for proportionally reduced protection, associated test points, the upper and lower deciles, and the median of the field strengths, Emin, basic circuit reliability (BCR), basic broadcast reliability (BBR), and basic maximum usable frequency (MUF).

In Phase 3 of the planning method the overall frequency assignment plan is generated. A description of this is found in Washburn et al. (1985, pp. 17-27). This process includes distributing the requirements to their most appropriate band, developing the signal-to-interference (S/I) and incompatibility matrices, employing methods to reduce congestion, generating frequency assignments, and determining the overall broadcast reliability (OBR).

Table 5. Reference Antennas

Antenna Number	Antenna Type	Gain (dBi)	Elevation Angle (deg)	Horizontal Beamwidth (deg)
1	HR 4/4/1	22	7	35
2	HR 4/4/0.8	22	8	35
3	HR 4/4/0.5	21	9	35
4	HR 4/3/0.5	20	12	35
5	HR 4/2/0.5	19	17	35
6	HR 4/2/0.3	18	20	35
7	HR 2/4/1	19	7	70
8	HR 2/4/0.8	19	8	70
9	HR 2/4/0.5	19	9	70
10	HR 2/3/0.5	18	12	70
11	HR 2/2/0.5	16	17	70
12	HR 2/2/0.3	15	20	70
13	HR 2/1/0.5	14	28	74
14	HR 2/1/0.3	11	44	90
15	HR 1/2/0.5	14	17	108
16	HR 1/2/0.3	13	20	110
17	HR 1/1/0.5	12	28	114
18	HR 1/1/0.3	10	44	180
19	H 2/1/0.5	11	28	78
20	H 2/1/0.3	9	47	180
21	H 1/2/0.5	11	17	112
22	H 1/2/0.3	10	20	116
23	H 1/1/0.5	9	28	126
24	H 1/1/0.3	7	47	180
25	ND	4	47	-

Phase 4 is the plan comparison and assessment part of the process and is not automated. It is the process where administrations can review the results of specific plans generated by the planning method and study the sensitivity of the results to selected parameters. These parameters include the percentiles used for overall plan acceptance, the reliability calculations, appropriate band selection, congestion reduction rules, test point selection and use, and frequency assignment algorithms.

2.1 Test Point Selection

A set of test points was determined that best suited the IFRB in its preparations for the Second Session of the HFBC. Test points are those geographic locations distributed worldwide within CIRAF zones representing wanted broadcast service areas. Chapter 3, Section 3, of IFRB (1986) provides the authority and rationale for their selection. The actual set of 911 test points used in the planning process was presented at the Second HFBC Information Meeting held in Geneva from February 5-7, 1986. This set provides at most, five test points per CIRAF zone quadrant where reception was most probable. It provides fewer in zones that are less populated (e. g., the polar regions) and only one point per quadrant in the 10 new maritime zones. It is this number of test points times the active transmitters in a given plan that determines the number of circuits computed for the propagation data base.

The IFRB has a dedicated computer system to use in its plan generation. Its only constraint is time. ITS shares computer resources on a faster computer but also has to pay for all system resources used. Therefore, in the interest of economy, ITS used a subset of test points in its application of the Model because of the cost constraints. Based on the study "Sensitivity of HF Broadcast Planning to Selected Parameters," by G. W. Haydon, D. L. Lucas, and J. S. Washburn, (NTIA-TM-84-104, limited distribution), this approach of reducing the test point number would not significantly affect the outcome in terms of numbers of requirements assigned to channels, but would lead to disparities in the detailed results of the two applications.

2.2 Appropriate Band Selection

Early in the implementation of the planning method it became obvious that the optimum band selection based upon median signal-to-noise (S/N) ratios would lead to paradoxical selections of the optimum band (e.g., the optimum band could be above the basic MUF where noise levels could be much lower relative to the signal value). The IFRB decided to define the concept of appropriate band based on basic broadcast reliability (BBR) where account is taken of the availability and limitations of transmitting equipment, best coverage, and continuity of the utilization of a band over a period of time exceeding 1 hour. The IFRB staff outlined the rules to determine the appropriate band at the Second HFBC Information Meeting referred to previously. At the time of that meeting several examples were offered in an heuristic approach to show how the appropriate band is selected. Table 6 offers a summary of this selection process.

Table 6. Rules for Determining the Appropriate Band

Case	Action
A. Requirements with a transmission period fully contained within 1 hour	
1) BBR ≥ 80% at least in one band	Select the band with BBR ≥ 80% Given the choice, select: a) preferred band b) band where BCR ≥ 80% at all test points c) band with the greatest BBR
2) 50% ≤ BBR < 80% at least in one band	Select the band that provides the greatest BBR. Also select the band that meets the criteria for an additional band.
3) BBR < 50% in all bands	For bands where BCR ≥ 80% at some test points select the one providing best signal coverage to the most test points (S ≥ Emin) For bands where the BCR ε[50%, 80%) for some test points, select the one providing best signal coverage to the most test points (Emin-Z ≤ = S < Emin).
B. Requirements with a transmission period of 2 or more consecutive hours	Given the choice, select: a) longest period of operation b) preferred band c) band providing the most bands where BCR ≥ 80% at all test points d) band with best average BBR e) band with fewest number of band changes during transmission period f) band with longest period of operation including the hourly appropriate band where the BBR < 80%

Table 6. (continued)

C. Frequency-continuous requirements (hour-to-hour)	Band continuity is permitted if the number of band changes and the number of bands for use in each requirement do not increase while selecting the appropriate band after merging
D. Concurrent requirements	Treat as one requirement where the two service areas are combined
E. Synchronous requirements	Same as case D except test points from combined service area are eliminated if field strengths from two transmitters is less than 8 dB or less than 3 dB where common oscillators are used

2.3 Resolution of Incompatibilities

Once the requirements are assigned to their appropriate band, the planning method proceeds by creating the signal-to-interference (S/I) matrix for each band. The details of the creation of the S/I matrix are in Washburn et al. (1986, pp. 17-20). Basically the interferences are calculated to each test point that is retained in the wanted-signal's service area. On a test-point-by-test-point basis the wanted signal is altered by any applicable proportional protection. The resultant S/I values at each test point are ranked and the 80th (or 90th) percentile value (op. cit., p. 20) is taken as the S/I value in the matrix. These values are used directly to develop the constraint matrix to determine co- and adjacent-channel compatibility between transmitter pairs. Values in the constraint matrix are overridden in the case of administration-declared preset frequencies for its requirements.

Analysis of the constraint matrix can indicate groups of requirements that are incompatible to the extent their total number exceeds the number of available channels. This possibility is called band congestion and the amount by which the incompatible requirements exceeds the available number of channels is an estimate of the degree of congestion. The System (IFRB, 1986) prescribes a set of rules called "N-Rules" to alleviate the congestion by suspending requirements and reducing protection ratios. These rules appear in Table 7 for convenience.

The basic steps in the System to reduce congestion are first to determine the greatest group of incompatible requirements. If the required number of channels is greater than the available number of channels, the requirements involved are considered for the congested quadrants. The radio-frequency protection-ratio (PR) for these requirements is reduced in steps of 3 dB from 27 to 17 as needed to obtain compatibility. When a 17 dB protection ratio is reached and congestion remains, suspension rules N1, N2, and N3 are applied as necessary to the requirements involved.

Table 7. Summary of Rules for Reducing Service Area Congestion

Planning Method Rule		Action
N1	- Suspension rule (Identical requirement, band)	- Suspend identical requirement from same administration with the same required service area
N2	- Suspension rule (Common unit of service area, same band)	- Suspend requirement from same administration whose service area is at least that of another in the same band
N3	- Common unit of service area, different bands	- Suspend requirement as in rule N2 but in any band
N4	- Reduction of quality (1)	- Suspend requirement from the band under consideration if the requirement is present in two or three bands
N5	- Reduction of quality (2)	- Reduce multiple interference and fading margins in steps of 3 dB (retain overall PR of 17 dB)
N6	- Reduction of transmission time	- Reduce transmission time by a maximum of 30 minutes

If congestion still exists after the rules N1 through N3 are applied, rules N4 and N5 are applied followed by the time reduction rule N6, if necessary. As a last resort to overcome congestion in the service area, the PR is further reduced in steps of 3 dB from 17 to 0, as necessary.

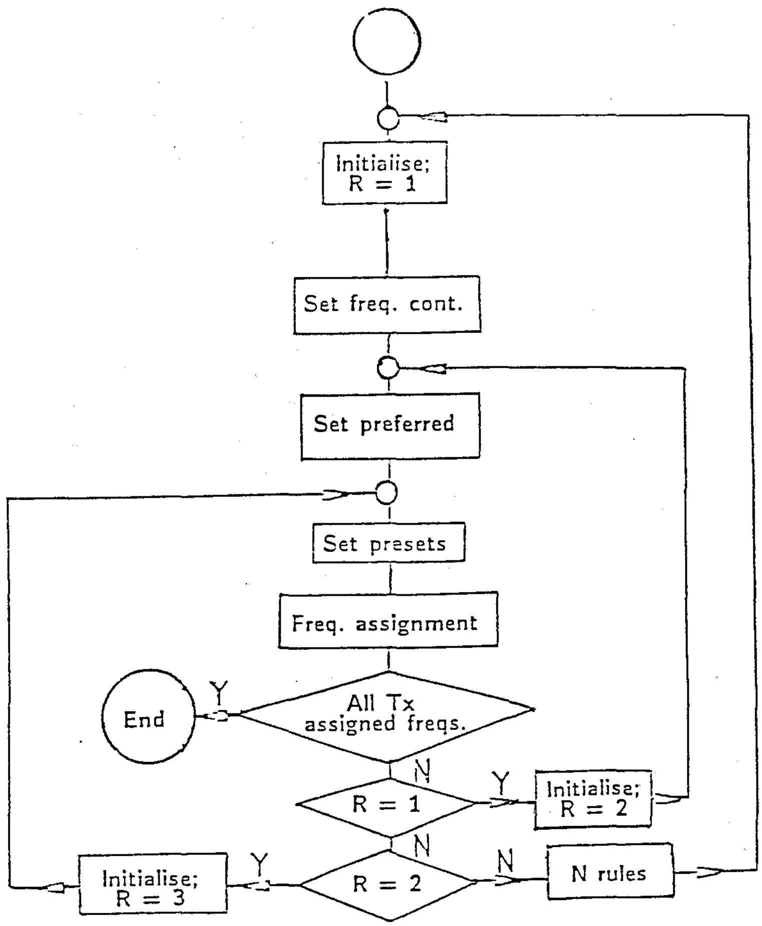
The result of all these steps to overcome congestion in various reception zones is manifested in the adjusted incompatibility matrix (IM). The IM is the data element used during the frequency assignment phase of the planning method.

2.4 Frequency Assignment

The frequency assignment process is complex. The System (IFRB, 1986) prescribes methods designed to provide the most assignments under the constraints that a given band may have. The theoretical details applicable to the frequency assignment problem can be found in Hale (1980, 1981); Berry and Cronin (1982); and Garey and Johnson (1979). The actual frequency assignment procedure chosen is outlined in the System (IFRB, 1986, Annex 1 to Chapter. 5, Sec. 7). Basically, this outline describes how the transmitters indexed in the IM were subjected to a specific number of ordering schemes. Once the transmitters are ordered, frequency selection is made using a specific number of selection schemes. The combination of a specific ordering scheme with the specific frequency selection scheme providing the greatest number of frequency assignments is the one selected for the band, regardless of the constraints posed by preset frequencies, preferred frequencies, and frequency continuity. Figure 1 provides the flow diagram associated with incorporating the constraints. Note that the suspension rules are applied until all transmitters that can be assigned a frequency are given one. Suspended requirements are the unfortunate outcome of this process.

The Report (ITU, 1984, para 6.) stipulates efforts will be made to enter the suspended requirements in the plan without affecting the requirements already assigned a frequency in the plan. Table 8 provides an outline of the treatment of suspended requirements. Requirements remaining suspended after this process are stored in a file of unsatisfied requirements.

The frequency assignment methods and the treatment of suspended requirements provides the necessary information to assign frequencies to the satisfied requirements. Table 9 provides an overall flow of the frequency assignment process.



Key

For a specified band and time block:
R - index representing specified groups of requirements
R=1 - group of requirements with preset frequencies
R=2 - group of requirements with preferred frequencies
R=3 - group of requirements with frequency continuity designated
Tx - group of nonsuspended requirements including the above groups
Initialise - find the nonsuspended R group of requirements
Set - Assign frequencies to the specified group of requirements

Figure 1. General frequency assignment flow diagram.
(Second HFBC Information Meeting, February 5-7, 1986, Geneva.)

Table 8. Treatment of Suspended Requirements

Order of Treatment	Comments
Treat N4-Rule standby file first, then N3-Rule standby file, then N2-rule standby file, then N1-rule standby file.	Within each standby file the requirements are organized by the band they were suspended from. For each N-rule suspension treat the standby file in ascending order of the number of suspensions by band. Within each band treat the suspended requirements on a last-in-first-out basis.
Criteria for Insertion	
Usable bands Each suspended requirement reinserted in the plan on a noninterference basis	Probable solution lies in other bands. This includes those previously suspended requirements already reinserted.

Table 9. Frequency Assignment

Step	Comments
1) Set preset, preferred, and continuous frequencies	For each band in the hour under consideration
2) Assign frequencies to the satisfied requirements taking into account the ordering of the transmitters and the frequency selection process	See IFRB (1986), paragraph 5 in Annex 1 to Chap. 5, Sec. 7
3) If all requirements are not satisfied, return to N-rule and repeat steps 1 to 3 as often as necessary	Reiterate the N-rule processing to suspend requirements interfering with the overall plan.
4) Repeat steps 1 to 3 for each band in the hour	Generate a plan for each hour
5) Assign frequencies to the suspended requirements taking into account their ordering, usable bands, and noninterfering criteria	Once a plan is generated try to reinsert suspended requirements
6) Establish file of unsatisfied requirements	These requirements could not be reinserted under the prevailing rules

3. DIFFERENCES BETWEEN THE SYSTEM AND THE MODEL

Table 10 shows the features of the HFBC planning method based on the decision of the First Session of the HFBC. These features appear in the Report (ITU, 1984) and the System (IFRB, 1986) either as specifications or items needed in the planning process. Corresponding to each feature in the table are two comments. The first concerns the results of the IFRB planning effort under the System heading, and the other concerns the results of the ITS planning effort under the Model heading. The features are subdivided by their respective automated phase.

Table 10. Model and System Differences

Feature	System	Model
Phase 1		
Requirements file	- Compiled as per Resolution COM5/3 of the Report (ITU, 1984)	- Used as received
Test point file	- 911 test point set, See System (IFRB, 1986, Chap. 3, Sec. 3)	- subset of 911 test point set (248 test points)
Antenna file	- 25 reference antennas	- Same
Propagation file	- All seasons (Table 2)	- D85 SSN=5 (all hours) J88 SSN=60 (selected
Emin file	- Based on method of Lucas and Harper (1965)	- Same
Phase 2		
HF frequency band typing	- Implemented, see System (IFRB, 1986, Chap. 4, Sec. 3)	- Same
Available band	- Implemented, requirement specified	- Implemented
Usable band	- Implemented, see System (IFRB, 1986, Chap. 4, Sec. 3, Para. 4.4)	- Implemented
Optimum band	- Not used	- Implemented, Report (ITU, 1984, Sec.3.2.1. 4)
Appropriate band	- Implemented, see System (IFRB, 1986, Chap. 4, Sec. 4). Implies multihour plan processing)	- Not used
Basic circuit reliability	- Implemented, see (ITU, 1984, Sec. 3.2.4.1)	- Same
Basic reception/ broadcast reliability	- Implemented, see System (IFRB, 1986, Sec. 8 para. 8, and Annex 1 to Chap. 4, Sec. 3)	- Same

Table 10 (continued)

Additional frequency band selection	- Implemented, see Report (ITU, 1984, Sec. 3.8.2) and System (IFRB, 1986, Annex 2 to Chap. 4, Sec. 3)	- Same
Proportionally reduced protection	- Implemented, see Report (ITU, 1984, Sec. 3.2.4.6) and System (IFRB, 1986, Annex 3 to Chap. 4, Sec. 3)	- Same
Treatment of synchronized requirements	- Implemented, see System (IFRB, 1986, Annex 4 to Chap. 4, Sec. 3)	- Not Implemented
Phase 3		
Congestion reduction (requirement suspension)	- Implemented, Rules N1, ... N6, see System (IFRB, 1986, Chap. 5, Sec. 1)	- Implemented, Rules N1, N2
S/I matrix	- Implemented, see System (IFRB, 1986, Chap. 5, Sec. 2)	- Same
Incompatibility matrix	- Implemented, see System (IFRB, 1986, Chap. 5, Sec. 3)	- Same
Frequency assignment	- Interpreted and implemented, see System (IFRB, 1986, Chap. 5, Sec. 8)	- 16 algorithms implemented, see Washburn et al., 1985, pp. 24-26.
ICR/OCR/OBR calculation	- Implemented, see Report (ITU, 1984, Sec. 3.2.4.2) and System (IFRB, 1986, Chap. 5, Sec. 9)	- Same
Plan generation	- All proposed plans generated, see Table 2	- D85 & J88 plans generated for selected hours

The planning method is specified by season for a sunspot number for all 24 hours (UTC) and for all HF bands. The System (IFRB, 1986) follows this specification. The Model uses the optimum band as the appropriate band. Other differences between the System (IFRB, 1986) and the Model are the use of the N-rules, frequency assignments, and the reinsertion of suspended requirements.

In Phase 3 the Model uses only rules N1 and N2 for suspending requirements and makes no attempt to reinsert these in the planning process. Also, the reduction of broadcast quality is not affected in the Model but rather held constant for the entire plan-hour. Necessarily, the frequency assignment process is different as only one attempt to assign frequencies to satisfy the remaining requirements is represented in the final IM. The details of the procedures used in the Model can be found in Washburn et al. (1985).

The IFRB used the algorithm described in the System (IFRB, 1986, Annex 1 to Chapter 5, Section 7). As discussed above the System selected the best combination of transmitter ordering (seven schemes) and frequency selection (five schemes) in terms of most requirements satisfied. The Model uses 16 different algorithms and selects the algorithm satisfying the most requirements.

4. PREPARING THE D85 PLAN

Table 3 provides a list of elements found in the broadcast requirements. Table 11 provides a summary of these elements for the requirements submitted for the December 1985 season (D85). The distributions of the requirements are shown by enumerated feature. Distributions by band and hour appear as appropriate and the numbers are in terms of requirements or requirement-hours.

Table 11. D85 Requirements Profile

	Feature	
1.	Requirement-hours	
	No. of Requirements	6909
	No. of Administrations	95
	No. of Requirement-Hours	30779
	Av. Hours/Requirement	4.45
2.	Related Requirements	
	Frequency Continuity	697
	Synchronous	84
	Concurrency (noncontiguous service area)	31
3.	Requirements with Service Sector	
	No. of Requirements with Service Sectors	429
	No. of Administrations	20
	No. of Requirement-Hours	3763
	Av. Hours/Requirement	8.77
4.	Requirements with at Least One Maritime Area	
	No. of Requirements	38
	No. of Administrations	9

Table 11 (continued)

5. No. of Requirements with Preferred Band or Preferred Frequency

6	7	9	11	13	15	17	21	26	(MHz)
920	688	935	750	19	535	302	120	3	(Total 4272)

6. No. of Requirements that can use 1, 2, or 3 bands simultaneously

1	2	3	Bands
4712	1482	715	(Total 6909)

7. No. of Requirements by Available Band

6	7	9	11	13	15	17	21	26	(MHz)
3294	2781	3928	3380	2678	1973	1064	300	1405	(Total 20803)

8. No. of Requirements by Antenna Type Season D85

Antenna Number	6	7	9	11	13	15	17	21	26 MHz
1	265	255	591	586	242	582	522	371	64
2	196	203	307	382	202	372	251	110	8
3	488	453	770	641	259	478	355	170	72
4	269	216	331	268	145	228	172	129	41
5	223	140	178	166	46	84	50	13	5
6	111	84	99	49	17	29	10	5	-
7	190	254	267	165	90	105	101	39	40
8	10	11	30	20	3	19	18	10	-
9	48	72	77	86	30	73	48	38	1
10	74	51	109	134	75	133	81	21	31
11	368	312	417	314	94	205	123	25	8
12	78	82	79	64	22	59	46	30	-
13	141	100	115	76	23	45	38	13	-
14	96	77	57	41	16	14	4	4	-
15	17	25	30	31	19	26	15	10	-
16	20	4	4	13	8	9	10	-	-
17	64	29	30	39	5	25	17	17	-
18	19	21	16	16	-	6	2	2	-
19	30	32	36	34	17	31	26	15	2
20	8	1	1	-	-	-	-	-	-
21	30	30	41	43	24	22	23	5	-
22	8	7	12	3	-	1	-	-	-

Table 11 (continued)

23	61	66	71	50	9	42	30	10	3
24	56	36	22	13	-	1	-	-	-
25	424	220	238	146	59	89	31	25	25

9. No. of Requirements by Available Band and Maximum Transmitter Power

6	7	9	11	13	15	17	21	26(MHz)	- Level (kW)
11	-	2	1	-	-	-	-	-	
12	-	-	-	-	-	-	-	-	1
16	5	21	21	-	15	7	1	-	
74	31	92	42	9	38	3	3	3	10
522	365	450	371	124	289	175	89	59	
1060	997	1302	1044	350	801	559	224	49	100
125	173	223	172	70	82	61	19	-	
780	697	1017	963	414	815	662	360	61	250
91	59	83	74	6	46	36	25	4	
602	454	737	686	428	570	458	337	124	500
1	-	1	6	4	11	12	6	-	

10. No. of Requirements with Modulation Types A, B, or C.

Double Sideband (Type A)	6897
Single Sideband with Reduced Carrier (Type B)	1
Single Sideband with Suppressed Carrier (Type C)	11

11. Requirement-Hours by Hour for Selected Hours

Time block	Number
1	1112
7	1141
13	1559
19	1369
TOTAL	5181

The main items worth noting from Table 11 are the number of requirements and the number of requirement-hours. The number of requirements divided by the total number of channels available provides a loading factor of approximately 22 requirements per channel. The average hours/requirement of 4.45 is especially significant since 697 requirements called for frequency continuity with other requirements. In general, it appears that administrations want many programs spanning more than 1 hour where frequency continuity is preferred.

The remaining features show the distribution of national service broadcasts (service sector requirements), the usage of maritime service areas (less than 1 percent of the requirements), the distributions of the types and availability of equipment by band, and distribution of requirement-hours by hour. This information is useful in assessing the success of the planning method for the D85 season.

Once the Phase 1 data bases are in place, the generation of the HF broadcast plan starts with Phase 2 processing of the requirements. This processing of the D85 requirements provided the information found in Tables 12, 13, and 14. Table 12 shows the distribution of the requirements in qualified frequency bands for selected hours. The F=0 column indicates the number of requirements for that time block qualifying for no frequency band, i.e., field strength below Emin less a margin of 5 dB. Table 13 shows the result of the appropriate band assignments for selected hours.

Table 12. Total Number of Requirements with 0, 1, 2, or 3 Frequencies for Selected Hours--D85

Time block	F=0	F=1	F=2	F=3	Total Frequency Hours	Total Requirements
1	37	1014	50	1	1117	1065
7	76	1012	39	1	1093	1052
13	47	1416	67	1	1553	1484
19	54	1248	60	0	1368	1308
TOTAL	214	4690	216	3	5131	4909

Table 13. Requirements Assigned to Appropriate Bands for Selected Hours--D85

Time block	Appropriate Band (MHz)								
	6	7	9	11	13	15	17	21	26
1	431	149	282	144	26	55	25	5	-
7	293	164	260	149	31	116	57	22	1
13	343	174	355	245	65	191	120	53	7
19	446	285	312	167	24	86	43	5	-

Table 14 shows the distribution of the requirements in ranges of their basic broadcast reliabilities (BBR) for selected hours as well as the distribution of requirements qualifying for proportionally reduced protection

(PRP). The BBR is the basic circuit reliability (BCR) at a service area test point whose value is exceeded at 80 percent of the other service area test points. The definition of BBR can be found in the Report (ITU, 1984). The BCR computed at each service area test point represents the probability that the computed Emin will be exceeded.

Table 14. BBR and PRP Requirement Distributions for Selected Hours--D85

Time block	BBR Ranges					PRP	
	0	(0,50)	[50,80)	[80,90)	(90,100]	YES	NO
1	91	268	213	202	291	429	636
7	100	198	207	202	345	380	672
13	113	288	276	271	536	509	975
19	158	312	309	227	302	528	780
TOTAL	462	1066	1005	902	1474	1846	3063

Once the requirements have been screened through Phase 2, they are subjected to Phase 3. This part of the plan first puts them through the appropriate band process then creates the S/I matrix followed by the incompatibility matrix. Table 13 supplies information about the distribution of the D85 requirements in their appropriate band by time block. The result of the incompatibility analysis is shown in Table 15. This table compares the distribution of the required number of channels for selected hours and band with the available number of channels. In order to assign as many requirements as possible to channels in the appropriate bands, congested areas were identified and the N-rule analysis was applied.

Table 15. Required Number of Channels as a Function of Time Block and Band for Selected Hours--D85

Band (MHz)	Time Block				Available Number of Channels
	1	7	13	19	
6	260	156	154	276	25
7	123	71	96	221	20
9	182	123	157	177	40
11	105	87	141	96	40
13	21	26	55	12	20
15	37	77	113	59	50
17	21	44	87	31	35
21	5	17	47	5	40
26	-	1	7	-	43

The application of the N-rules in the System approach led to an iteration of the congested area analysis, suspension of requirements, and frequency assignment process until all requirements were assigned frequencies in the remaining set of requirements. The process to reinsert suspended requirements that could receive interference but could not give interference to requirements already in the plan was then performed. This application to the D85 requirements is found in Table 16 for selected plan hours.

Table 16. System Plan for Selected Hours--D85

Requirements Satisfied*

Band (MHz)	Time block 1	7	13	19
6	202.0	161.8	161.8	223.0
7	82.5	91.0	97.5	164.8
9	111.3	170.8	215.5	166.5
11	142.3	127.5	165.3	128.5
13	37.3	40.5	44.0	32.3
15	79.5	105.3	147.0	105.3
17	34.0	59.5	109.8	59.5
21	9.8	34.5	72.0	11.3
26	-	1.0	10.3	-
% Rqs Satisfied	65.2	71.7	68.9	67.7

* Note: results from using all features of the planning method including such features as the N-rules and reinsertion of suspended requirements

The application of the N-rules for the Model was limited to rules N1 and N2. The suspended requirements were not reinserted after the frequency assignment process. And there was no iteration to reapply rules N1 and N2 after channel assignment. This application to the D85 requirements is found in Table 17 for selected plan hours and PR's.

Table 17. Model Plan for Selected Hours--D85

Requirements Satisfied*

Band (MHz)	Time block 1		7		13			19		
	17	27	17	27	7	17	27	17	27	PRs (dB)
6	157	98	160	123	224	197	154	165	127	
7	72	54	111	93	132	104	88	77	49	
9	160	114	199	147	302	241	185	168	134	
11	131	94	142	100	253	186	147	128	104	
13	14	14	30	30	52	47	41	23	23	
15	103	103	124	96	251	198	143	134	105	
17	48	48	95	68	183	131	93	67	63	
21	11	11	36	36	92	89	65	16	16	
26	-	-	-	-	11	11	11	-	-	
%Rqs Satisfied	55.5	42.7	71.4	55.1	87.0	69.9	53.8	51.4	44.1	

* Note: This result is for "optimum band" as the "appropriate band", fixed protection ratios, application of rules N1 and N2 only, and no reinsertion of suspended requirements

The summary statistics from Tables 16 and 17 can be compared directly, bearing in mind the different application of the PR's and the reinsertion process. The Model is a process performing some, but not all, of the System processes and of those, as in the case of appropriate band selection, performing some of these differently. One would expect the Model results to be similar to the System results, however. This observation is verified by examining the percentage of requirements satisfied between the two plan results in Tables 16 and 17. As an example, one can observe from the hour 13 column for Table 17 as the fixed protection ratios decline more requirements are satisfied. The similar column for Table 16 shows 68.9 percent satisfied requirements. A look at Table 18 for hour 13 shows over half the requirements were satisfied with a protection ratio between 17 dB and 23 dB while 93 percent of these satisfied requirements had protection ratios of 17 dB or greater. The distribution is skewed favorably for a 17 dB ratio explaining the similar summary statistics for hour 13 from Tables 16 and 17.

Table 18. Lowest Value of Protection Ratio for Selected Hours--D85

Protection Ratio (dB)/ Time block	≤0	(0,17)	[17,23)	[23,27)	≥ 27	Total
	Number of Requirements					
1	109	214	69	53	146	591
7	43	41	169	20	389	662
13	0	63	447	33	282	825
19	200	280	53	9	249	791
Totals	352	598	738	115	1066	2869

One can observe from Table 18 that most of the requirements for hour 1 were satisfied by the System with protection ratios below 17 dB. The Model would consider these as unsatisfiable and therefore one would expect a lower percentage of satisfied requirements than within the System. This is precisely the case as seen from Tables 16 and 17 for hour 1. Again for hours 7 and 19 one can make a similar analysis to show the Model's results support the System's results.

Table 19, part A, shows a comparison between the two methods in terms of band loading factor and usage factor for selected hours in the D85 plan generation. The band loading factor is the number of requirements per channel in the band after the appropriate band designation process. The usage factor is defined to be the number of requirements per channel satisfied by the planning method. Loading factor and usage factor can refer to one or more bands. From Table 19 one observes the loading factors for two methods are approximately the same while the usage factor for the Model is not as great as for the System. A breakout of these data by band is given in Figures 2 through 5.

Table 19. Band Loading Factors and Usage Factors for Selected Hours--D85

	System		Model	
Time block	Loading Factor	Usage Factor	Loading Factor	Usage Factor
		A. All Bands		
1	4.3	2.7	4.3	2.3
7	4.2	3.0	4.2	2.4
13	5.8	3.4	5.7	3.0
19	5.3	3.4	5.4	2.9
		B. Bands 6, 7, and 9 MHz		
1	10.5	5.0	11.0	4.6
7	8.8	5.1	9.1	5.7
13	10.4	5.6	10.1	6.4
19	13.3	7.1	12.3	4.9

For D85 the sunspot number of 5 dictated better propagation conditions in the lower HF broadcast bands than in the higher bands. From the figures given above one observes the loading factors for the 6, 7, and 9 MHz bands are approximately twice the usage factor for their respective hour in both methods. At 11 MHz the usage factor approaches the loading factor; i.e., there are fewer demands on the band. The bands 13 MHz and up have relatively low loading factors. Sometimes the usage factor is greater than the loading factor for System results. This was due to reinserting requirements suspended from the lower bands into the higher bands.

Table 19, part B, makes a similar comparison for the 6, 7, and 9 MHz bands only. The loading factors and subsequent usage factors are expectedly greater where the demand is greater.

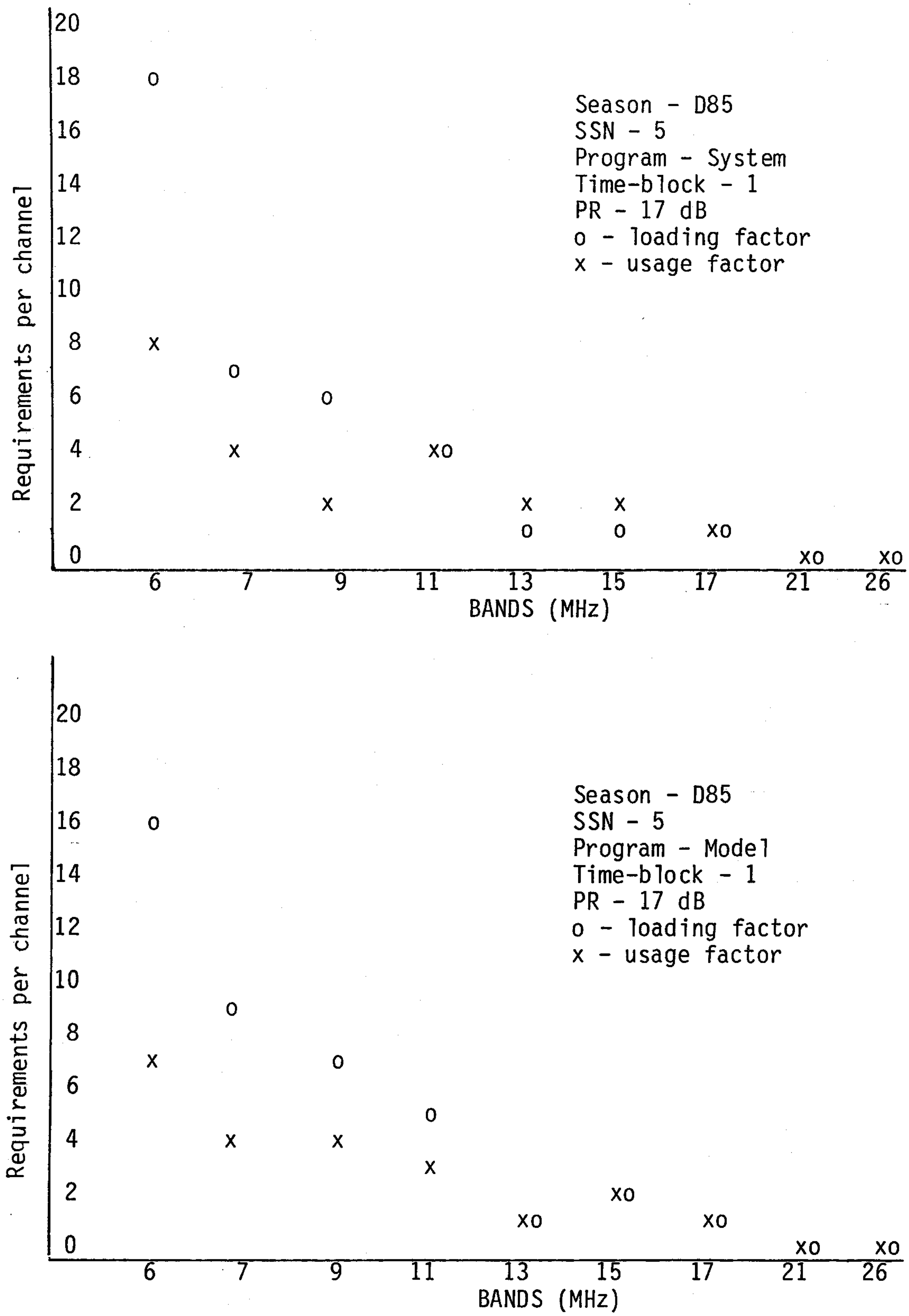
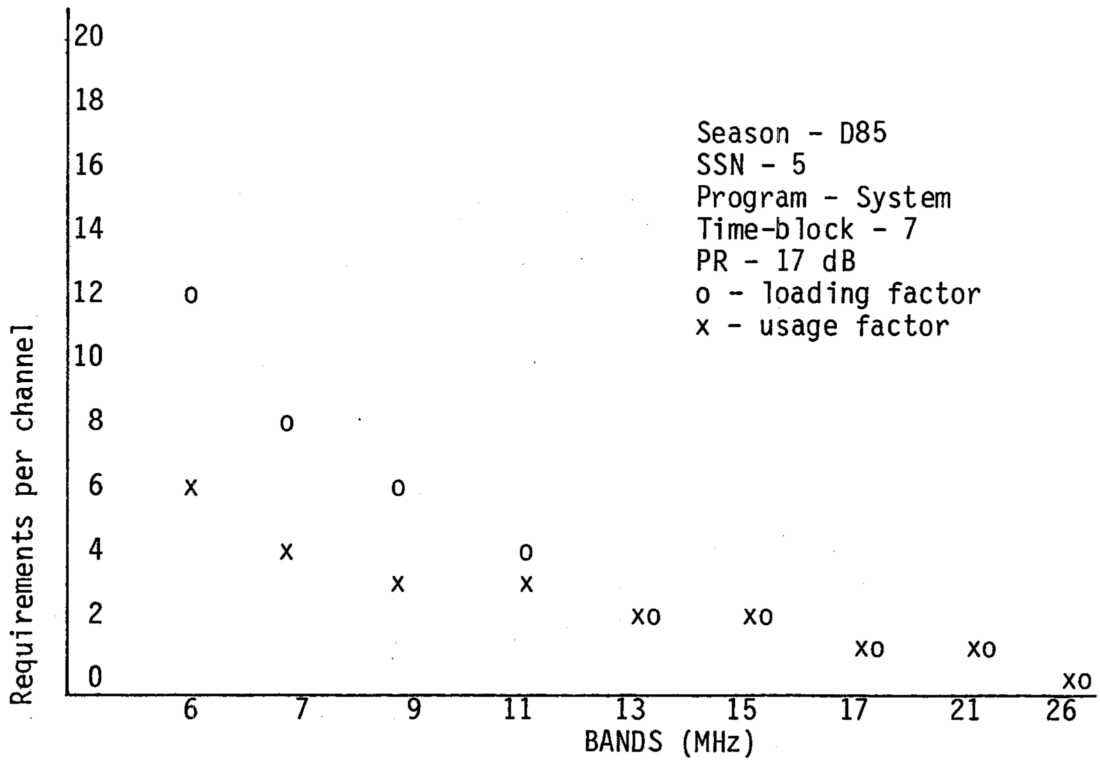


Figure 2. Model vs System--loading factor/usage factor for time block 1.



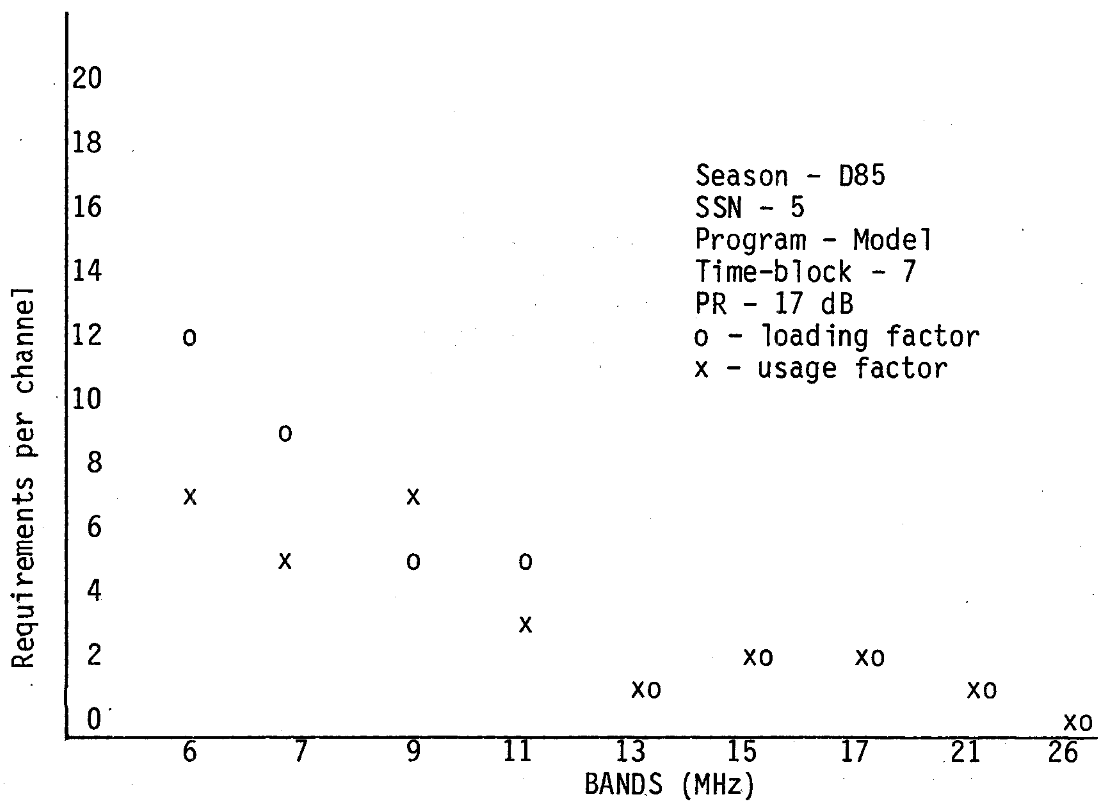
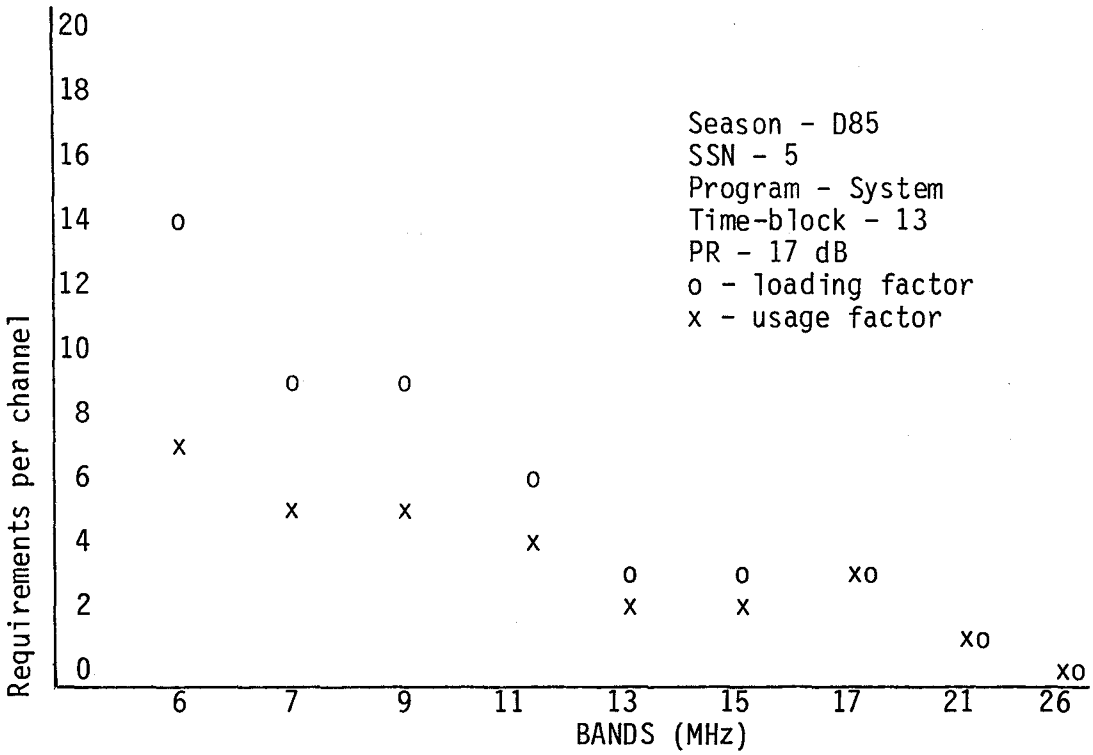


Figure 3. Model vs System--loading factor/usage factor for time block 7.



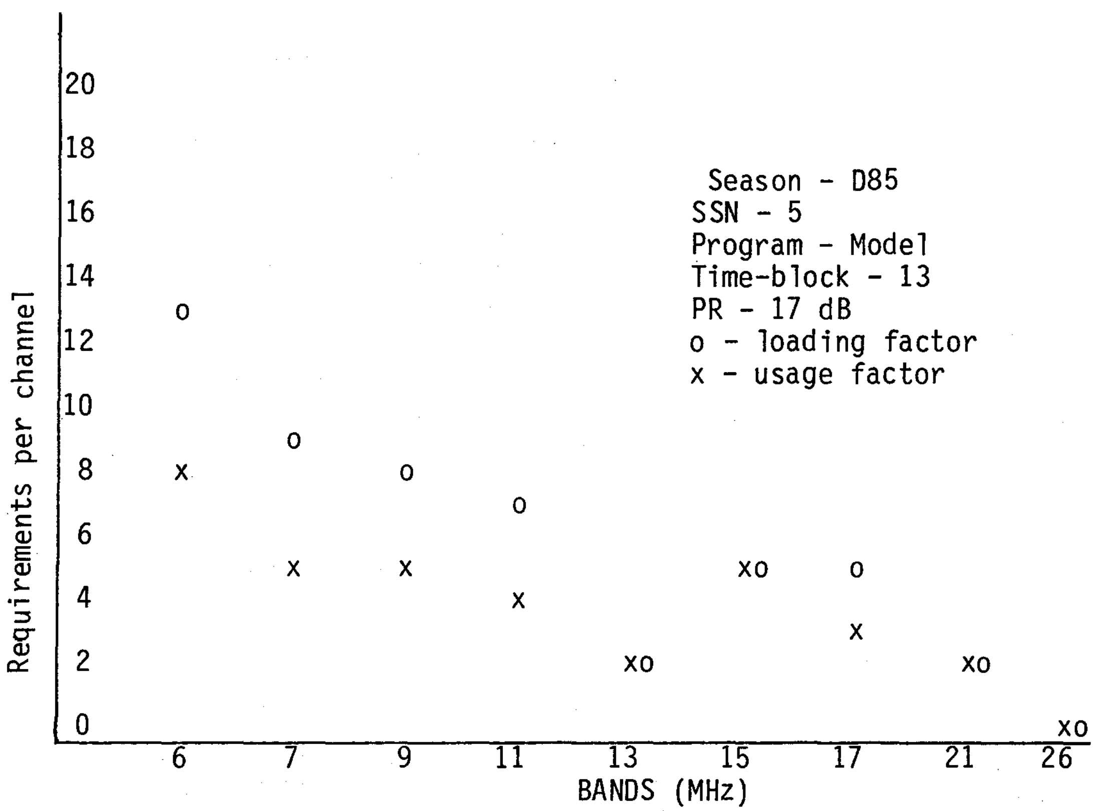


Figure 4. Model vs System--loading factor/usage factor for time block 13.

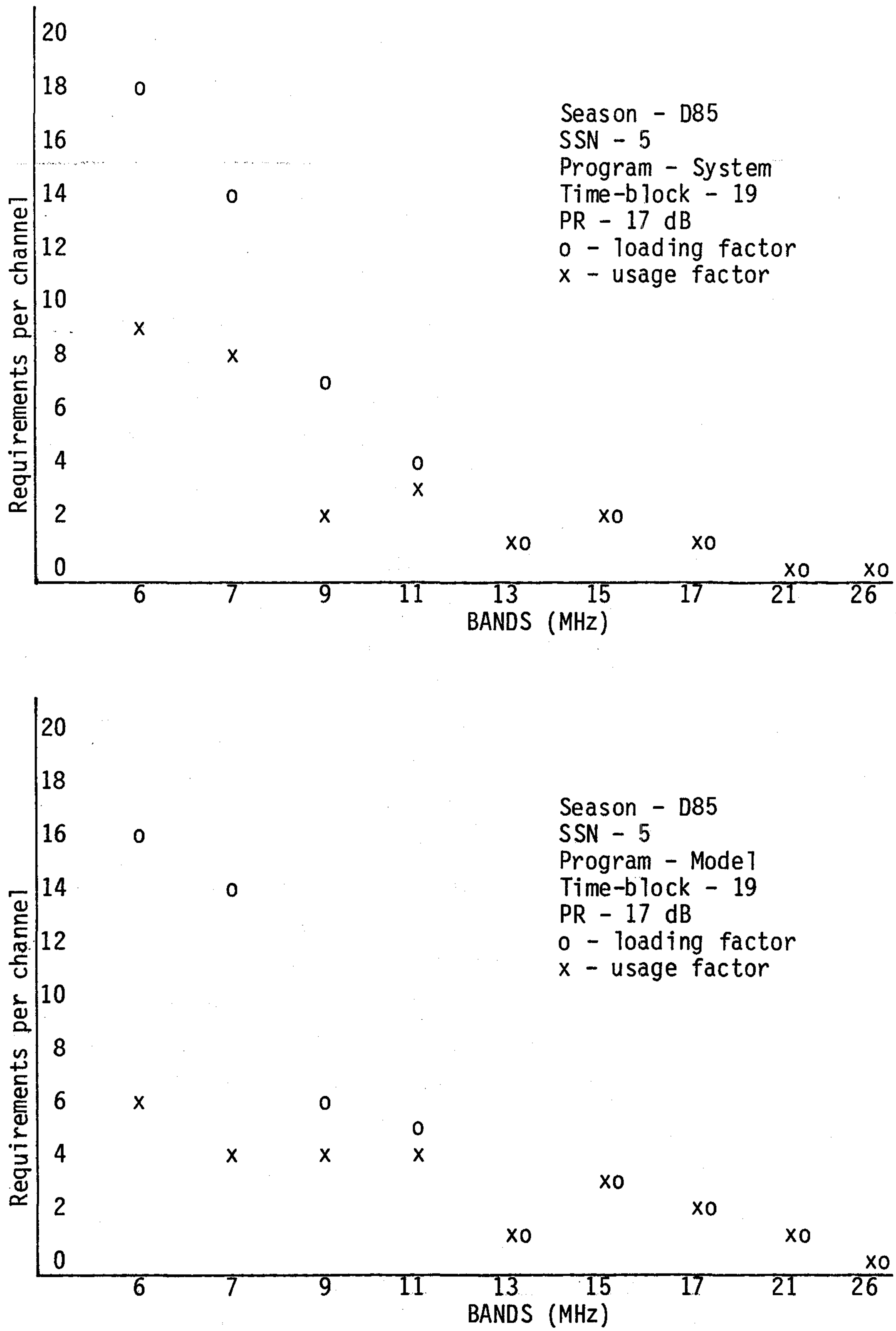


Figure 5. Model vs System--loading factor/usage factor for time block 19.

4.1 Discussion

The requirements submitted for the D85 plan showed a great demand for channel space in the HF broadcast bands. The Model and the System generated results satisfying up to 68 percent of the requirements. The results of the two methods cannot be compared directly because the Model uses a fixed PR while the System will, with the N-rules, reduce the starting PR as necessary to satisfy as many requirements as possible in congested areas. However, an analysis for selected hours in Table 18 proves instructive in studying the distribution of the satisfied requirements by PR for the System results. For the representative hours it can be shown that 67 percent of the satisfied requirements had PR's of 17 dB or greater. Using the representative hours for the Model-generated results, fixed PR of 17 dB, it can be shown from Table 17 that only 62 percent of the requirements were satisfied. The fixed PR implies all satisfied requirements had at least a PR of 17 dB (some of these that needed proportionally reduced protection were included with margins of up to 5 dB less than 17 dB). The grade of service that can be expected for a PR of 17 dB is termed "marginally commercial" (see "Sensitivity of HF broadcast planning to selected parameters," NTIA-TM-84-104, limited distribution, p. 25). Using Tables 17 and 18 it can be shown for the selected hours and a PR of 27 dB that only 37 percent of the requirements were satisfied by the System and 49 percent for the Model. A PR of 27 dB is considered "Good Commercial" grade of service (op. cit.). The examples given above showed that an increased usage factor caused a decrease in the grade of service when the band loading factors were high. In fact, as usage factors go up the quality of service drops because requirements are satisfied at lower PR's and some requirements, like the reinserted ones, are not protected at all. The planning method following the decisions of the First Session of the HFBC is not acceptable to successfully plan the HF broadcast service because of the resultant low grade of service. Other methods have to be considered as possible alternatives to the planning method of the System.

4.2 Alternatives to the Planning Method

Given that the First Session planning method (the System) was acceptable in its original configuration, there is a need to identify and test alternatives to the planning method. The Second Session of the HFBC has adopted changes to the planning method decided by the First Session (ITU, 1987). The changes included forcing continuity of requirements under certain conditions. This constraint coupled with other decisions of WARC-HFBC (2) are likely to yield results that are even more unacceptable than those obtained from the System. As a result, studies have been undertaken to identify a few alternative possibilities for planning and testing them. This description follows.

4.2.1 Leinwoll Method

The first possible alternative was proposed by S. Leinwoll (1986, private communication). The proposal called for using the System only for the expanded portion of the post-WARC 1979 HF broadcast bands. This would include the expanded portions of the 9, 11, 15, 17, and 21 MHz bands and all of the 13 MHz band. Table 1 shows the variation in kilohertz to these bands. These variations will be referred to as the "expanded portions of the bands" or the "expanded bands." The requirements are planned in the expanded portions of the bands in order of some hierarchy assigned by the administrations and in order of increasing number of frequency hours requested within this hierarchy. A requirement would not be assigned a frequency if it were incompatible with a previously assigned requirement. Requirements not assigned in the expanded portion of the bands would be designated for coordination as is the current procedure (ITU, 1985, Article 17).

An ITS version of this proposal was implemented using the Model. It was tested for D85 requirements and the representative hours 1, 7, 13, and 19. The method called for a priority assignment of each requirement within an administration, and within each priority the requirements were listed in increasing order of the total number of frequency hours requested by the administration by band within the given hour. For purposes of this test, the order in which the administration submitted its requirements was taken as the given priority and a simple sorting by hour for each band into like priorities provided the second constraint of the proposal.

Frequencies were then assigned to the requirements in the order described. If a requirement was found to be incompatible with a previously assigned requirement, it was not assigned a frequency but was designated for coordination. If a requirement qualified for additional frequencies in other bands, the additional frequencies were counted as requirements and treated independently. Because of different conditions in different bands, a frequency may be assigned to a requirement in one band, but the associated frequency in another band may be designated for coordination. Note the expanded portions of the 11 MHz band are above and below the pre-WARC 1979 band allocation. For our purposes the number of requirements assigned in this band may be slightly smaller than would be possible with the two bands separated because of adjacent channel constraints. This discrepancy is believed to be small.

An extension of the proposal eliminated all transmitters with powers greater than 100 kW from consideration. The extension of the proposal was to exclude from planning transmitters with powers greater than 100 kW.

Table 20 shows the number of administrations that had all their requests assigned frequencies in the expanded bands for the representative hours and a PR of 17 dB. The results of the tests showed about 28 percent of all requirements were assigned in the new bands; the remainder were designated for coordination. About 18 percent of the administrations requesting frequencies had all their requirements planned in the new bands. In general, the administrations with the most requirements had the most assignments in the new bands, probably because there were more opportunities to fit them in without interference.

Table 20. Leinwoll Proposal--Number of Administrations with All Requirements Planned

Time block	(1)	(2)	Percent	Specifications:
1	11	61	18.0	Selected Hours
7	18	76	23.7	D85
13	12	83	14.5	PR - 17 dB
19	12	72	16.7	
Totals	53	292	18.2	

Note: (1) Number of administrations with requirements in the hour and in the planned bands that had all their requirements planned
(2) Number of administrations with requirements in the hour and in the planned bands

Table 21 shows the distribution of the planned requirements. The entries in the four columns under the hours are the number of administrations that had N requirements planned, where N is the number in the left column. Some administrations had more than 10 requirements planned; this is noted at the bottom of the table. Table 22 shows the total number of requirements, the number of assigned frequencies in the new bands, and the percentage assigned, for each hour.

Table 21. Leinwoll Proposal--Number of Administrations and Planned Frequency Hours

Frequency Hours Planned	Time block 1	7	13	19	Specifications
0	9	16	3	9	PR - 17 dB
1	14	16	12	17	D85
2	18	14	20	23	
3	2	8	13	4	
4	4	5	7	12	
5	5	4	10	2	
6	2	4	4	3	
7	1	1	5	0	
8	2	3	1	0	
9	1	0	2	0	
10	0	2	2	0	

Notes: Time block 1 - Other administrations had 12, 16, and 23 frequency hours planned
Time block 7 - Two administrations had 18 and 31 frequency hours planned
Time block 13 - Four administrations had 11, 11, 15, and 28 frequency hours planned
Time block 19 - Two adminstrations had 13 and 23 frequency hours planned

Table 22. Leinwoll Proposal--Assigned Requirements

	Time block 1	7	13	19	Totals	Specifications
Requirements	671	788	1205	725	3389	PR - 17 dB
Assigned	193	236	338	186	953	D85
Percent Assigned	29	30	28	26	28	

Tables 23, 24, and 25 show similar results for the extended proposal. Table 23 shows fewer administrations had their requirements planned under the this extension than the original; i.e., 15 percent as opposed to 18 percent. Table 24 shows many more administrations failed to receive assignments under the extension. Table 25 showed fewer requirements were planned than under the original proposal, i.e., 22 percent instead of 28 percent. It is pointed out no attempt was made to assign frequencies to the high powered transmitters after all the low powered ones had been considered. It is possible some of the high powered transmitters could have been assigned frequencies in the expanded bands without interfering with previous assignments. If so, the total number of requirements planned would be no greater than the number planned under the original proposal.

Table 23. Extended Proposal--Number of Administrations with All Requirements Planned

Time block	(1)	(2)	Percent
1	9	61	14.8
7	19	77	24.7
13	8	83	9.6
19	7	72	9.7
Totals	43	293	14.7

Note: (1) Number of administrations with requirements in the hour and in expanded bands that had all their requirements planned
(2) Number of administrations with requirements in the hour and in expanded bands

Table 24. Extended Proposal--Number of Administrations and Planned Frequency Hours

Frequency Hours Planned	Time block 1	7	13	19	Specifications
0	25	17	16	25	PR - 17 dB
1	5	22	14	12	D85
2	11	15	13	11	
3	8	8	11	10	
4	2	2	9	5	
5	4	5	9	1	
6	2	3	3	0	
7	1	1	2	2	
8	0	0	3	1	
9	0	0	0	1	
10	0	1	1	1	

Notes: Time block 1 - Three administrations had 11, 12, 13 frequency hours planned
Time block 7 - Three administrations had 14, 22, and 25 frequency hours planned
Time block 13 - Two administrations had 13 and 14 frequency hours planned
Time block 19 - Two adminstrations had 13 and 19 frequency hours planned

Table 25. Extended Proposal--Assigned Requirements

	Time block 1	7	13	19	Totals	Specifications
Requirements	671	788	1205	725	3389	PR - 17 dB
Assigned	140	200	257	156	753	D85
Percent Assigned	21	25	21	22	22	

4.2.2 Planning Only the Expanded Bands

A variation on the Leinwoll proposal was to use the Model to plan the expanded portion of the HF broadcast bands without any strategy for setting the priority of administrations based on the number of frequency hours requested. To test, the expanded portions of the bands were chosen for hour 13 from D85 at a protection ratio of 17 dB. The test results are displayed in Table 26. In this case it can be seen that 35.5 percent of the requirements were satisfied in the expanded portion of the bands compared with 28 percent for the Leinwoll proposal (see Table 22) for this same hour.

Table 26. An Example of Planning in the Expanded Portions of the Bands

Band (MHz) Specifications	Channels	Number of Requirements	Number of Requirements Satisfied		Specifications
9	12	330	105		D85
11	12	288	78		Time block 13
13	20	53	53		
15	15	251	82		
17	15	191	72		
21	10	92	38		
Totals	84	1205	428	(35.5%)	

Power Discrimination

In addition to planning the expanded portions of the bands, it was thought to limit the plan to requirements that had transmitted powers less than some specified amount. The effect on one band-hour was enough to make decisions as to the usefulness of this approach. The 15 MHz band was chosen as the band to test for the D85 season, hour 13, and PR of 17 dB. Table 27 shows the effect of limiting the frequency assignments to those requirements that have transmitter power no greater than 100 kW and then again for 50 kW. The results when no power limitation is imposed is also shown.

Table 27. Power Limitation in the 15 MHz Expanded Band

Power Limited to Transmission of	Number of Requirements Not Satisfied	Number of Requirements Satisfied	Percent	Specifications
none	169	82	32.7	D85
100 kW	182	69	27.5	15 Channels
50 kW	204	47	18.7	251 Requirements

The table shows requirement assignments decline when the requirements power discrimination is imposed. In this case one sees 13 additional requirements were eliminated when the 100 kW limitation was imposed, and 35 additional requirements for the 50 kW. In these cases the results imply high powered transmitters not causing interference under the protection ratio of 17 dB were eliminated from receiving frequency assignments. Clearly, discriminating solely on power appears to yield results that are unjustified in the planning process.

4.2.3 Interleaving

One of the possibilities to increase the usage factor is to reduce the channel spacing from 10 kHz to 5 kHz. The earlier work of Haydon et al. ("Sensitivity of HF Broadcast Planning to Selected Parameters," op. cit.) showed there was no advantage in terms of increased usage factor of 5 kHz over 10 kHz channel spacing using the adjacent channel PR relative to the co-channel S/I requirement as found in CCIR Recommendation 560-1. In this case the PR for the 5 kHz offset frequency was 3 dB below that of the co-channel value. However, by using interleaving, the expected usage factor may increase by using 5-kHz channel spacing plus assigning only those frequencies with a 0 kHz in the units place to qualifying requirements having reception zones in the northern hemisphere, and assigning a 5 kHz in the units place to all others.

This hypothesis was tested using the Model for the D85 season and hour 19. The first-adjacent-channel PR was varied using values that were 3, 8, and 17 dB down from the co-channel PR of 17 dB. The results are presented in Table 28 in terms of requirements satisfied. One observes, in general, as the first-adjacent-channel PR decreases the number of satisfied requirements increases in the congested bands. One interpretation is that interleaving, used prudently along with the hemispheric constraint, could increase the usage factor from between 5 to 15 percent.

Table 28. Results of the Interleaving Tests

Band(MHz)	Requirements Assigned to Band	Requirements Satisfied Using Selected First Adjacent Channel PR's of 14dB (%)	9dB (%)	0dB (%)
6	400	174 (43.5)	179 (44.8)	181 (45.2)
7	283	74 (26.1)	79 (27.9)	85 (30.0)
9	273	142 (52.0)	159 (58.2)	175 (64.1)
11	195	114 (58.5)	128 (65.6)	143 (73.3)
13	23	23 (100.)	23 (100.)	23 (100.)
15	151	120 (79.5)	131 (86.7)	144 (95.4)
17	67	64 (95.5)	65 (97.0)	67 (100.)
21	16	16 (100.)	16 (100.)	16 (100.)
26	-	-	-	-

4.2.4 Double Sideband vs Single Sideband Transmissions

The prospect of increasing the usage factor using single side band (SSB) transmissions in place of double sideband (DSB) transmissions was also investigated. A study was designed to address the total bandwidth needed to satisfy all requirements when some requirements are DSB and some are SSB. The requirements used are from the D85, 15 MHz band.

A total of 251 requirements were considered from the 15 MHz band of time block 13 for D85. Some were randomly designated as SSB. Five cases were considered with the ratio of SSB transmissions to DBS transmissions of 0, 25, 50, 75, and 100 percent. The cases with 25, 50, and 75 percent were nominal since the random procedure does not generate exact percentages. The exact numbers of transmitters in each category are shown in Table 29.

Table 29. DSB vs SSB--Transmitter Distribution

Number of Transmitters with Each Modulation for the Nominal Percentages of SSB Transmitters

25%		50%		75%	
DSB	SSB	DSB	SSB	DSB	SSB
193	58	126	125	61	190

The protection ratios at different separation frequencies were derived from Section 3.9.1.13 of the Report (ITU, 1984) except the Model requires the protection ratios must be the same above and below the center frequency.

Table 30 shows the protection ratios (dB) provided at different frequency separations for different combinations of DSB and SSB signals. The nominal co-channel protection ratio is 17 dB but some of the transmissions have proportionally reduced protection.

Table 30. DSB vs SSB--Protection Ratios

Protection Ratio (dB) Provided at Different Frequency Separations for Different Combinations of DSB and SSB Signals

Wanted Transmitter	Unwanted Transmitter	Frequency separation (kHz) 0	5	10
DSB	DSB	17	--	-18
DSB	SSB	20	19	-15
SSB	DSB	17	15	-18
SSB	SSB	17	16	-15

The frequency assignment program was modified to assign all requirements in the least possible bandwidth, and the total amount of bandwidth required was recorded. Three assignment methods were used. The first used 10 kHz spacing with mixed DSB and SSB transmissions. The second mixed the transmissions as before but the DSB transmissions had 10 kHz spacing and those with SSB had 5 kHz spacing. The third method segregated the DSB and SSB transmissions into separate portions of the band, with constraints observed at the common edge.

The results are displayed in Table 31. These appear to be counter-intuitive. Assuming some requirements as SSB (with narrower emissions) increased the amount of spectrum needed to assign all requirements. The explanation is in the protection ratios in Table 30. It is the protection ratios at given frequency separations that determine the bandwidth required. As Table 30 shows, all combinations including an SSB emission have at least as much protection at each frequency separation, and sometimes more protection than DSB. This means such combinations will require more total bandwidth to assign. In addition, the SSB-SSB combination has more protection at 10 kHz than DSB-DSB, so that the SSB stations will need more bandwidth when segregated than they did when they were DSB. Finally, the third method for segregated bands required more total bandwidth, as can be seen in Table 31, because some of the SSB stations could have been assigned (would not have interfered) on DSB channels if that were allowed by the rules. Since it was not, they needed more bandwidth on already-occupied channels in the SSB segment of the band.

Table 31. DSB vs SSB--Required Bandwidth

Total Bandwidth Needed to Assign all Requirements (kHz)

Percent SSB	Method 1	2	3
0	790	790	790
25	810	815	855
50	820	825	925
75	800	825	890
100	810	805	805

The test with more realistic protection ratios for SSB vs SSB transmissions was conducted. The benefits of grouping SSB transmitters in a separate portion of the band were calculated when SSB receivers are designed with narrow passbands to receive only SSB transmissions. Table 32 shows the protection ratios used. As before, the nominal co-channel protection is 17 dB but some transmitters may have proportionally reduced protection.

Table 32. SSB vs SSB--Protection Ratios

Protection Ratios (dB) Provided at Different Frequency Separations when SSB Receivers are Designed for SSB Signals

Wanted Transmitter	Unwanted Transmitter	Frequency Separation (kHz) 0	5	10
DSB	DSB	17	--	-18
DSB	SSB	20	19	-15
SSB	DSB	17	15	-18
SSB	SSB	17	-3	-31

The first three lines of Table 32 are identical to Table 30; only the SSB-SSB protection ratios are different. The SSB-SSB protection ratios are taken from Figure 3-15 of the Report (ITU, 1984). The Model must have ratios symmetric around the center frequency, so the worst-case values were used. The results of the test are shown in Table 33 in terms of the total bandwidth needed to assign all requirements. The third method described above was used for the protection ratios shown in Table 32.

Table 33. SSB vs SSB--Required Bandwidth
Total Bandwidth Needed to Assign all Requirements (kHz)

Percent SSB	Total bandwidth
0	790
25	780
50	735
75	635
100	495

The results showed, as expected, a 38 percent decrease in bandwidth when all emissions were SSB. Recall that this is a worst case. If the program could allow for the smaller protection ratio required when the interferer is below the wanted signal, even less bandwidth would be required to satisfy all requirements.

5. SUMMARY

The First Session of the HFBC tasked the IFRB to develop seasonal plans demonstrating the capabilities of those decisions established during the First Session of the HFBC and subsequent intersessional meetings. Due to uncertainties in the planning method, ITS proceeded to parallel the development of the planning method by the IFRB. Subsequent seasonal plans were computed using the ITS Model and the IFRB System. Portions of the plans were compared to show the consistencies of both approaches.

The seasonal plans showed several inadequacies in the planning results that were noted by the Second Session of the HFBC (ITU, 1987). As a result ITS pursued studies of alternatives to the planning method to determine if these inadequacies could be overcome and if so what the impact on band use would be. The alternatives included a method of frequency assignment, proposed by S. Leinwoll, that called for planning the expanded portions of the bands only giving round-by-round priority to those administrations with the least number of frequency-hours requested. Under the Leinwoll method, all requirements not assigned frequencies would be coordinated as they are using current practices. The result of the Leinwoll plan showed that the administrations with the most requirements had the most assignments in the expanded bands probably because there were opportunities to fit them in without interference.

A variation of the Leinwoll proposal was to study the outcome of planning the expanded portions of the bands using the Model. More requirements were satisfied with this variation than with the Leinwoll proposal. Power limitations were imposed using both the Leinwoll approach and the Model. Discriminating solely on the basis of transmitted power appears to be unjustified because the number of requirements satisfied declined when transmitter power was limited.

Another alternative studied was reducing the channel spacing between assignments from 10 kHz to 5 kHz. Earlier work showed there was no advantage in doing this alone, so an additional constraint was imposed. This constraint allowed only 0-suffix frequencies for requirements to the Northern Hemisphere and five-suffix frequencies everywhere else. In general, these test results showed that prudent use of interleaving with the hemispheric constraint could increase the usage factor from 5 to 15 percent.

A further study was directed at the alternative of using more SSB transmissions to test its impact on the usage factor. This test was designed to address the total bandwidth needed to satisfy all requirements when some requirements are DSB and some are SSB. Using protection ratios at different separation frequencies derived from the Report, all requirements were assigned using the Model in the least possible bandwidth. The results showed SSB transmissions actually increased the amount of spectrum needed to assign all requirements. The explanation is in the protection ratios used. Single sideband emissions need at least as much protection at each frequency separation and sometimes more than DSB. Another test was conducted by modifying the SSB vs SSB transmissions to protection ratios that would be indicative of the environment when only SSB is operating. The benefits of grouping SSB transmitters in a separate portion of the band were shown when SSB receivers are designed with narrow passbands to receive only SSB transmissions. The results showed, as expected, a 38 percent decrease in bandwidth needed to satisfy all requirements when all emissions were SSB.

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14. SUPPLEMENTARY NOTES

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

The First Session of the World Administrative Radio Conference for the planning of the HF bands allocated to the broadcasting service held in Geneva, Switzerland, in January and February of 1984, established the technical criteria to be used in testing planning principles for the HF Broadcast services during the period between the First and Second Sessions of the Conference. The Internatinal Frequency Registration Board (IFRB) implemented these planning principles on a computer and reported the results at the Second Session of the World Administration Radio Conference. The Institute for Telecommunication Sciences (ITS) adopted a parallel activity to assist the United States' preparations for the Second Session of the Conference.

This report discusses the IFRB computer system and the ITS computer model and their results for the December 1985 HF broadcast plan. The results are further analyzed in terms of usage factor, tendencies in the planning process, etc.

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

broadcast requirements; HF broadcast planning model; HF propagation prediction; IFRB; World Administration Radio Conference for HF broadcasting; usage factor

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