OCE REPORT

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FM Broadcast Channel Frequency Spacing

Prepared by Research & Standards Division
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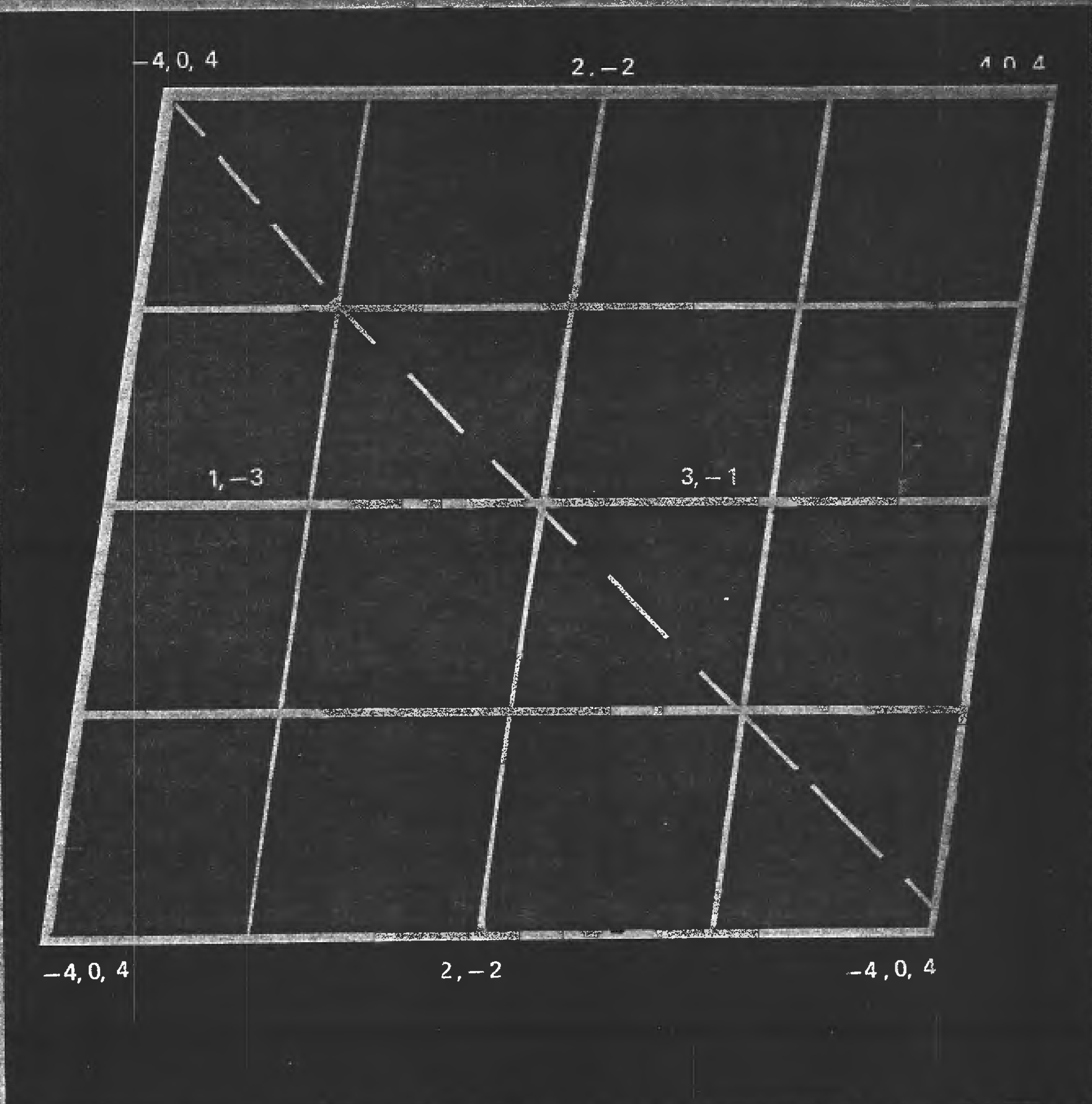

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FEDERAL COMMUNICATIONS COMMISSION

OFFICE OF CHIEF ENGINEER

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REPORT NO. RS75-08

FM BROADCAST CHANNEL FREQUENCY SPACING

By

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WASHINGTON, D. C. 20554
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SUMMARY

This report studies the effect of reducing the adjacent channel frequency offset from the presently used 200 kHz to 150 kHz and to 100 kHz. The analysis shows quite conclusively that both the 100 kHz offset, with a receiver filter, and the 150 kHz offset (no filter) are more efficient in population and area coverage efficiency than the 200 kHz offset for both stereophonic and monaural operation. The 100 kHz offset, with filter, gives about twice the improvement that the 150 kHz offset offers. However, the 100 kHz offset advantage is contingent upon the use of a low pass filter following the demodulator in the stereophonic receiver, without which the 100 kHz offset is somewhat worse than the 200 kHz offset. For lack of protection criteria the effect of reducing the frequency offset upon SCA and quadraphonic operation could not be evaluated.

FM BROADCAST CHANNEL FREQUENCY SPACING

Introduction

The total spectrum bandwidth available for assignment to FM broadcast stations is limited and in some areas quite congested. It is therefore desirable that station assignments be made in the most efficient manner. The present study was undertaken to determine the relative efficiency of adjacent channel FM assignments at 100 kHz or 150 kHz separations as contrasted with the present assignment plan which uses 200 kHz separations. The area coverage efficiencies, service ranges and available number of station assignments are compared for both monaural and stereophonic operation. The technical station operating parameters, such as emission bandwidth, frequency deviation, etc., are assumed to be unchanged. The study does not include the effects of Subsidiary Communications Authorizations (SCA) and quadraphonic operations.

A simplified equilateral triangular cochannel lattice assignment plan has been assumed for this study as the most efficient station assignment configuration.[1,4] Admittedly, such a regular configuration is not representative of the true physical distribution of the distances between population centers, nor are the transmitting antenna heights uniform nor the radiated powers all the same. In effect, all the station parameters, as well as the physical and propagation parameters, are statistically variable. The net effect is to increase substantially the overall standard deviations in the results, which means that because of this variability, the actual performance could differ greatly from what these idealized computations predict. Nevertheless, the comparisons and trends indicated in this study should be sufficient for the determination of station assignment policy. Thus, the Ad Hoc Committee[1] used substantially the same techniques for its TV studies and noted (P 5 of Vol. II), "Even though the present data may be inadequate for making an accurate prediction of the eventual total service, it should be noted that comparisons of national services which differ because of different allocation policies can, nevertheless, be made with a high degree of accuracy. For example, useful comparisons can be made between the results to be expected with different antenna heights, powers, station separations, etc."

Service Concepts and Criteria

Since the wanted and interfering signals in the FM frequency range (88-108 MHz) vary both in time and from location to location, it is useful to describe the service in statistical terminology, using the same concepts of service that have been developed for TV broadcasting.[1] Thus, the service at any location is considered to be

Should the 100 kHz adjacent channel offset operation be adopted in the U.S., there would then be the economic incentive to mass-produce such filters at a reasonable cost especially in view of the increasing use of integrated circuits. Therefore, the emphasis in this report has been upon the use of such low pass filters in the stereophonic receivers for the 100 kHz offset. The problem of retrofitting existing stereo receivers which do not have filters, is beyond the scope of this report.

For this study the following values of minimum usable field strength levels were assumed to compute service in the presence of noise only:

Monaural	:	24 dBu
Stereophonic	:	36 dBu.

The monophonic value was derived by applying a 10 dB fading factor[7/] to the 50 µv/m median field strength which has often been used by the F.C.C. for rural service. And, the stereophonic value was then obtained by adding 12 dB to the monophonic value, as suggested by CCIR[2/]. Other numbers may be substituted for the above but the computed trends will not be changed, except perhaps at the greater cochannel spacings. Because of the multiple interference for a full lattice, the noise is relatively unimportant except for a combination of wide spacings and low radiated power.

The receiving antenna discrimination pattern of Fig. 2 was used for service computations. It is similar to that of CCIR Recommendation 419,[3/] except that the discrimination increases with the square of the secant of the angle from the main beam rather than the logarithmic trend of CCIR. The secant squared variation is believed to be more typical for receiving antennas.

A triangular lattice network of cochannel stations with stations located at the vertices of the equilateral triangles provides the most efficient area coverage for a channel, as outlined in Reference 4. Consequently, equilateral triangle cochannel networks were employed in this study. The adjacent channel stations were located as efficiently as possible within the equilateral cochannel triangles, using the assignment techniques developed in References 5 and 6. The assignment method is described in more detail in Annex A.

Figs. 3, 4 and 5 illustrate the most efficient regular assignment plans for FM broadcast stations with minimum adjacent channel carrier offsets of 200, 150 and 100 kHz, respectively. Only the basic parallelograms, consisting of two adjacent equilateral cochannel triangles, are shown. The numbers at the various station locations denote the multiples of the minimum permissible adjacent channel frequency offset. The negative numbers indicate that the station carrier frequency is lower than the reference carrier frequency. Thus, in Fig. 4 the station at

The number of station assignments available, compared to that at a 200 kHz offset, is computed from

(3) $$N_{\Delta f} / N_{200} = (S_{200} / S_{\Delta f})^2 (200/\Delta f)$$

where

(4)
- Δf = the minimum frequency offset, in kHz
- $N_{\Delta f}$ = the number of frequency offsets before a channel may be repeated at a given location, for a frequency offset of Δf
- $S_{\Delta f}$ = the cochannel spacing for a frequency offset of Δf, in km

The service ranges and lattice efficiencies were computed under the assumed lattice configurations of Figs. 3, 4 and 5, using the multiple interference computation techniques of Annex 2 for the combinations of transmitting antenna height and radiated power given below in Table 1.

Table 1

Curve	Power, kw	Transmitting Antenna Height, ft
A	50	2000
B	50	1000
C	50	500
D	10	500
E	3	300

Discussion

Using the parameters listed in Table 1, service contours and efficiencies were computed for 200 kHz, 150 kHz, and 100 kHz, without filter, offsets for both monaural and stereophonic operations. In addition, the service contours and efficiencies were also computed for the 100 kHz stereophonic operation, with filter. These are plotted versus a single criterion but rather on a joint weighted comparison of the several criteria. So long as the service radius per station is great enough to cover the required area and to provide for economic viability, it becomes a relatively unimportant parameter to the allocation engineer. Thus, the main attention should be focussed upon the overall area efficiency and the relative number of station assignments - i.e. the area and the population coverage. No attempt will be made here to assess the relative importance of the overall area efficiency and the relative number of available station assignments, other than to note that they are both quite important. Further, it is believed that stereophonic coverage for FM is much more important than monaural coverage.

For purposes of comparison, Table 2 was derived from Fig. 6 through 19. At the cochannel spacings for which the maximum area efficiencies, the cochannel spacings at which they occur, the station service radii for these spacings, and the relative number of station assignments available both for monaural and stereophonic operation. It is noted that both the relative number of assignments and the relative efficiency of operation increase as the frequency offset is decreased, except that the 100 kHz operation, without filter, is the least efficient mode of operation. On the other hand, the station service range decreases somewhat as the offset is reduced. Thus, for a full lattice of Class B FM stations - 50kw at 500 ft.the stereo area efficiency at 100 kHz offset, with filter, is 23% greater than with the 200 kHz offset and the available number of station assignments is 51% greater. The improvement for 150 kHz offset as compared to the 200 kHz offset runs about half that for the 100 kHz offset, with filter. A comparable improvement is available for all height-power combinations used in the study. Unquestionably, the improvement available in reducing the offset below 200 kHz is substantial. For monaural operation the trends are similar but the improvements in "overall area" efficiency and available number of assignments, as the frequency offset is reduced, are even greater than for stereo operation.

The comparisons between the different offsets are made from a somewhat different point of view in Table 3, which was also compiled from Figs. 6 through 19. In this table, the stereophonic service radius is kept constant, the cochannel spacings being varied to provide the desired service radius. Thus, if the service radius is set to provide a given service area per station on the basis that such a service radius is required to provide station economic viability, the comparison still shows that the 100 kHz offset, with receiver filter, is the most efficient operation and that the 100 kHz offset, without filter, is the least efficient. Again, the 150 kHz offset

It should also be emphasized that our cities and towns are not arranged geographically in nice regular lattices, so that the full efficiencies of the reduced offsets could not be realized in practise. However, the relative trends and comparative advantages would be realizeable, so that the results of this report should be useful in assessing the costs for continuing with the present 200 kHz offset.

Conclusions

The analysis shows conclusively that from a technical point of view both the 100 kHz offset, with a low pass receiver filter after the second demodulator, and the 150 kHz offset are more efficient than the presently used 200 kHz offset, both in overall area coverage efficiency and in the available number of station assignments - i.e. in area and population coverage. The 100 kHz offset, with filter, shows about twice the improvement that the 150 kHz offset offers. However, the 100 kHz offset advantage would be contingent upon the use of receiver filters, without which the efficiency would be a little worse than that for the 200 kHz plan. Also, since there already exists a viable FM system with a 200 kHz offset,any reassessment would have to consider other factors, such as the costs of changing station frequencies, the costs for incorporating the receiver filters for 100 kHz offset, reduced SCA service range, and reduced quadraphonic service range.

Annex A

REGULAR EFFICIENT ASSIGNMENT PLANS

The assignment plans were designed along the concepts developed in References 5 and 6 for the efficient distribution of adjacent channel stations within the cochannel lattice. The technique not only provides an efficient assignment plan but also gives a systematic method of locating the stations in a regular order, with each station receiving equal cochannel and adjacent channel interference protection. The practical application of the technique for locating the adjacent channel stations within the basic cochannel parallelogram of two adjacent equilateral cochannel triangles is relatively simple. The basic cochannel parallelogram is subdivided into N^2 equal smaller parallelograms, as shown in Figs. 3, 4 and 5, by dividing the sides of the basic parallelogram into N equal parts and drawing a grid of parallel lines through the dividing points. N-1 is the number of adjacent channel stations. And, N is also the number of frequency offsets before a channel may be repeated at a given location. The stations are ordered in multiples of the minimum offset frequency Δf, so that $m \Delta f$ represents the carrier frequency offset. Using the lower left corner of the basic cochannel parallelogram as the zero of a graph plot, the adjacent channel stations are located in regular order at points

(A1) $(X, Y) = (mA, mB)$; $m = 1, 2, \ldots N$

$m\Delta f$ = carrier frequency offset, in kHz

Δf = minimum frequency offset, in kHz

When mA or mB exceeds N or a multiple of N, the remainder is used for plotting the stations within the basic parallelogram. Thus, for plotting purposes

(A2) $mA - aN = mA - bN$ $a; b = 0, 1, 2 \ldots$
$m = 1, 2, \ldots, N$

In the above, a may be different from b.

Various values of A and B are tried and the best combination with respect to interference is selected by observation. The choice is not difficult and can usually be made quite readily, since those adjacent channel combinations are known, which are the most susceptible to interference. Further, a number of combinations of parameters A and B give essentially the same lattice, rotated about the center axis.

Annex B

COMPUTATION OF SERVICE AND INTERFERENCE

The method used for the computation of station service in the presence of both single and multiple sources of interference will be developed in this Annex. It is a combination of two methods described in Volume II of the Ad Hoc Report.[1]

The field strength from a station may be described, approximately as a two dimensional lognormal (in μv/m) or normal (in dBu) distribution, in order to account for the variability with time and from location to location. Thus, the field strength may be described by:

(B1) $$F(L,T) = F(50,50) + X(T)\sigma_T + Y(L)\sigma_L \quad \text{dBu}$$

where

(B2)

- $F(L,T)$ = the level of field strength exceeded for T percent of the time in at least L percent of the locations, in dBu
- $F(50,50)$ = field strength median in both time and location, in dBu
- σ_T = standard deviation for time variability, in dB
- σ_L = standard deviation for location variability, in dB
- $X(T)$, $Y(L)$ = standard variates for the normal distribution

In (B1), F(50,50) and σ_T may be obtained from FCC Report R6602,[7] where

(B3) $$\sigma_T = \frac{F(50,10) - F(50,50)}{1.282} \quad \text{dB}$$

From Volume I of the Ad Hoc Report[1] is obtained the value of

(B4) $$\sigma_L = 8.3 \text{ dB}$$

And the standard Gaussian variate, X(T) or Y(L), is tabulated in many statistical textbooks. It is also plotted in Figure 30 of Reference 8.

are added powerwise statistically to give a resultant required wanted field which is also constant with time and has a variabilility with location which is assumed to be lognormal. This technique for combining multiple interferences is good so long as the F_{dri} have about the same standard deviations for their location distributions. It is therefore used to combine all the interferences except noise which is assumed not to vary from location to location. To compute the resultant lognormal distribution from the various interference sources (except noise), the first two central moments for the individual location distributions F_{dri} are added.

$$\text{(B8)} \begin{cases} \alpha = \exp(\sigma_i^2/2) \sum_i P_i & \text{watts} \\ \mu = \left[\exp(\sigma_i^2) - 1\right] \exp(\sigma_i^2) \sum_i P_i^2 & \text{watts}^2 \\ \sigma_i = 0.23026\,\sigma_L = 1.90655 & \text{nepers} \\ P_i = 10^{F_{dri}/10} & \text{watts} \\ \sigma_L = 8.3 & \text{dB} \end{cases}$$

The resultant median and normal standard deviation are then computed from:

$$\text{(B9)} \begin{cases} \sigma_{dr}^2 = \ln\left[1 + \mu k/\alpha^2\right] & \text{nepers}^2 \\ P_{dr} = \alpha \exp(-\sigma_{dr}^2/2) & \text{watts} \\ k = 0.468 & \text{(for zero correlation)} \end{cases}$$

The factor k was found empirically to improve the lognormal approximation for the resultant. More details on this lognormal approximation for the resultant distribution of the required wanted signal may be found in Volume II of Reference 1. The values of (B9) may be converted to the more useful units:

$$\text{(B10)} \begin{cases} \sigma_{Ldr} = 4.3429\,\sigma_{dr} & \text{dB} \\ F_{dr}(50,50) = 10 \log P_{dr} & \text{dBu} \end{cases}$$

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Table 2

Comparison Under Conditions of Maximum Efficiency

Monaural	2000 ft. 50 kw	1000 ft. 50 kw	500 ft. 50 kw	500 ft. 10 kw	300 ft. 3 kw
S100 (mi)	230	200	205	200	195
E100 (%)	22.8	21.5	19.6	19.5	16.7
R100 (mi)	41.0	34.5	33.3	32.7	29.3
N100/N200	1.91	2.00	2.10	1.90	1.70
E100/E200	1.25	1.28	1.32	1.32	1.37
S150 (mi)	190	200	205	200	185
E150 (%)	20.8	20.0	18.2	18.2	15.2
R150 (mi)	39.5	38.7	39.6	38.7	32.7
N150/N200	1.87	1.33	1.40	1.27	1.26
E150/E200	1.14	1.19	1.22	1.23	1.25
S200 (mi)	225	200	210	195	180
E200 (%)	18.2	16.8	14.9	14.8	12.2
R200 (mi)	50.5	43.0	42.5	39.5	33.0
Stereophonic					
S100f (mi)	285	265	265	245	245
E100f (%)	18.9	16.7	14.5	13.5	10.2
R100f (mi)	46.0	40.1	37.3	33.5	25.4
N100f/N200	1.42	1.51	1.51	1.40	1.33
E100f/E200	1.19	1.33	1.23	1.24	1.34
S100u (mi)	350	345	345	305	280
E100u (%)	14.7	12.6	10.6	9.5	6.9
R100u (mi)	50.0	45.0	41.0	35.0	27.2
N100u/N200	0.94	0.89	0.89	0.90	1.02
E100u/E200	0.92	0.91	0.90	0.87	0.91
S150 (mi)	250	240	245	215	205
E150 (%)	16.9	15.3	13.0	12.1	8.9
R150 (mi)	47.0	42.8	40.0	34.0	27.2
N150/N200	1.23	1.22	1.18	1.21	1.27
E150/E200	1.06	1.10	1.10	1.11	1.17
S200 (mi)	240	230	230	205	200
E200 (%)	15.9	13.9	11.8	10.9	7.6
R200 (mi)	50.5	45.0	41.3	35.5	29.0

Table 3 (Continued)

Comparison Under Conditions of Constant Service Radius

		Stereophonic				Monaural		
Rstereo (mi)	Δf (kHz)	Sst (mi)	Est (%)	$\frac{N_{\Delta f}}{N_{200}}$	$\frac{E_{\Delta f}}{E_{200}}$	Emono (%)	Rmono (mi)	$\frac{E_{\Delta f}}{E_{200}}$
				50 kw, 500 ft.				
50	100f	390	11.9	1.08	1.12	15.5	57.0	1.15
	100u	442	9.0	0.84	0.85	14.0	61.5	1.04
	150	330	11.2	1.01	1.06	15.1	58.2	1.12
	200	287	10.6	--	--	13.5	55.0	--
40	100f	287	14.2	1.20	1.20	18.3	45.7	1.24
	100u	337	10.5	0.87	0.90	17.1	51.8	1.16
	150	243	13.0	1.11	1.10	17.7	46.5	1.20
	200	222	11.8	--	--	14.8	45.0	--
30	100f	218	13.9	1.30	1.37	19.5	35.5	1.34
	100u	264	9.4	0.89	0.90	18.8	42.5	1.29
	150	188	12.0	1.17	1.15	18.2	36.3	1.25
	200	176	10.4	--	--	14.6	35.0	--
20	100f	160	11.0	1.49	1.47	18.7	26.0	1.43
	100u	202	7.2	0.93	0.96	19.5	33.0	1.49
	150	145	9.0	1.21	1.20	16.5	26.5	1.26
	200	138	7.5	--	--	13.1	26.0	--
				10 kw, 500 ft.				
40	100f	303	12.7	1.20	1.21	17.7	47.0	1.25
	100u	353	9.3	0.89	0.89	15.6	51.7	1.10
	150	257	11.7	1.11	1.11	16.7	47.8	1.18
	200	235	10.5	--	--	14.2	46.5	--
30	100f	220	13.9	1.31	1.37	19.6	36.0	1.34
	100u	267	9.2	0.89	0.88	18.5	42.5	1.27
	150	192	11.8	1.15	1.13	18.1	37.2	1.24
	200	178	10.4	--	--	14.6	35.7	--
20	100f	162	11.2	1.45	1.47	18.7	26.0	1.43
	100u	202	7.2	0.93	0.95	19.5	33.0	1.49
	150	146	9.2	1.19	1.21	16.5	27.0	1.26
	200	138	7.6	--	--	13.1	27.0	--
				3 kw, 300 ft.				
30	100f	258	9.8	1.30	1.29	15.4	37.8	1.29
	100u	312	6.8	0.89	0.89	13.5	42.7	1.13
	150	224	8.6	1.15	1.13	14.5	39.0	1.22
	200	208	7.6	--	--	11.9	37.7	--
20	100f	177	9.5	1.42	1.48	16.4	26.5	1.44
	100u	220	6.0	0.92	0.94	16.4	33.0	1.44
	150	157	7.6	1.20	1.19	14.6	27.3	1.28
	200	149	6.4	--	--	11.4	26.8	--
10	100f	113	5.8	1.57	1.61	12.7	14.5	1.63
	100u	142	3.7	0.99	1.03	14.8	19.8	1.90
	150	103	4.4	1.26	1.22	10.2	14.3	1.31
	200	100	3.6	--	--	7.8	14.7	--

co-channel and nearest adj channel

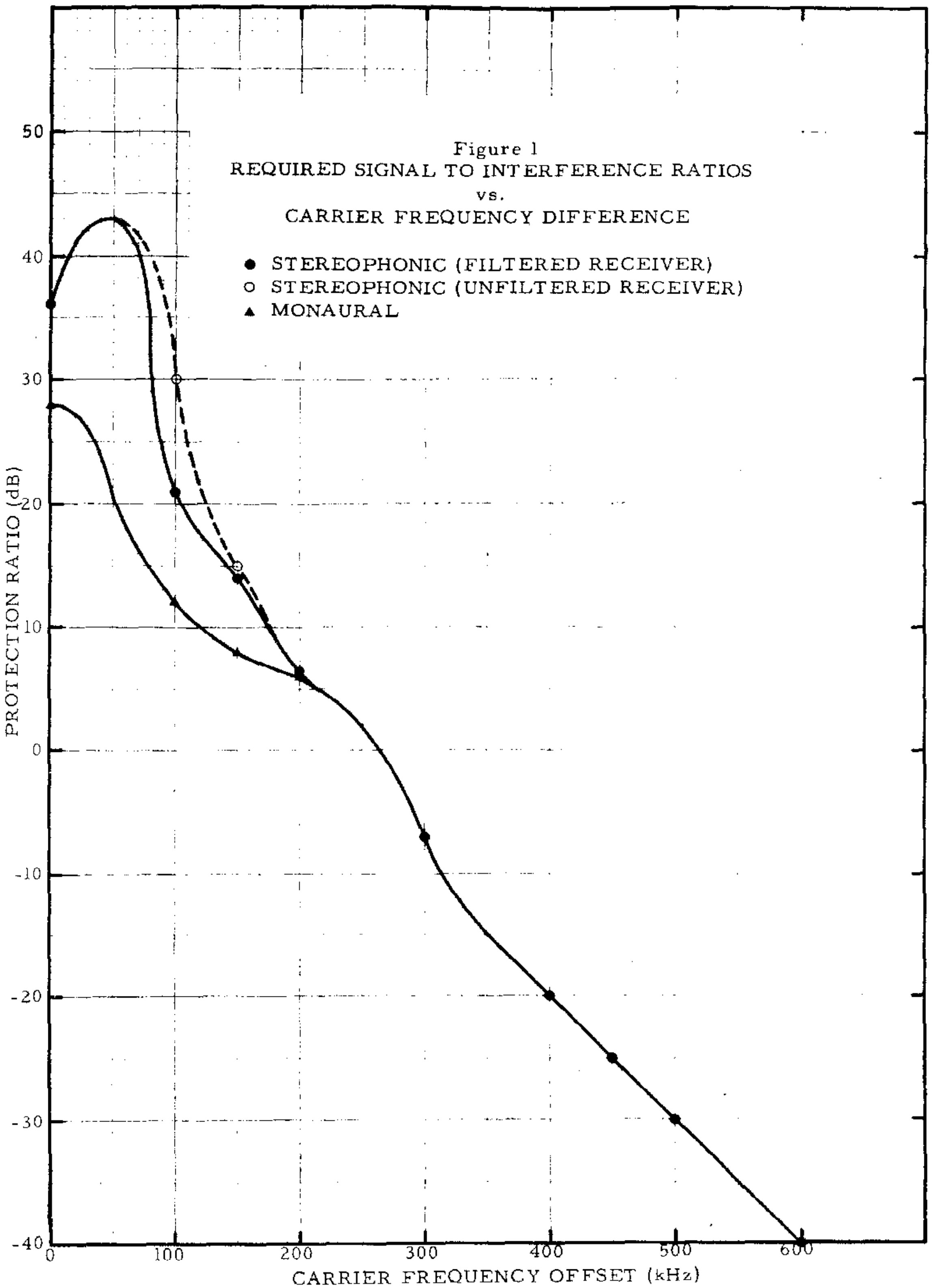
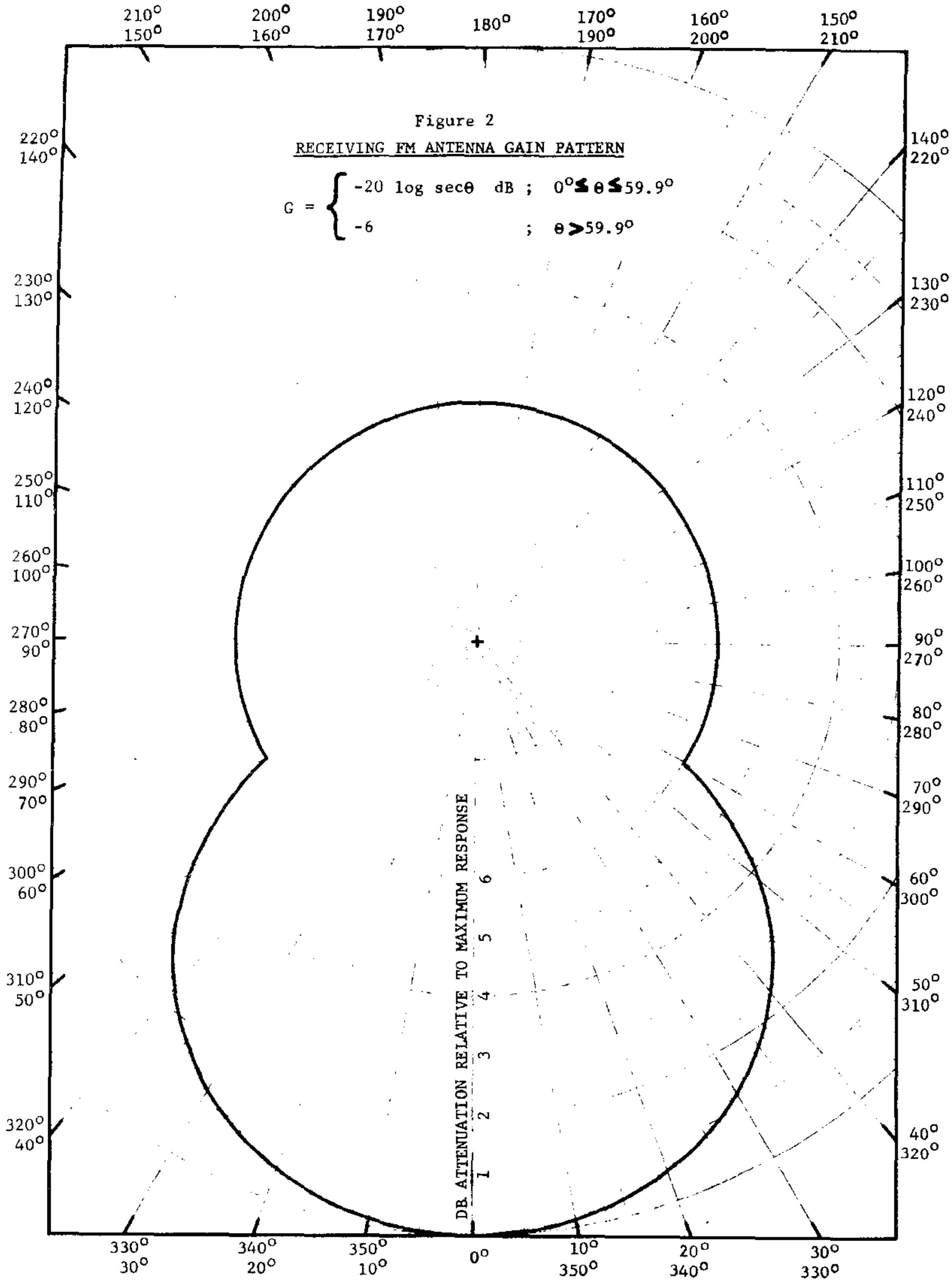


Figure 1
REQUIRED SIGNAL TO INTERFERENCE RATIOS
vs.
CARRIER FREQUENCY DIFFERENCE

Figure 2

RECEIVING FM ANTENNA GAIN PATTERN

$$G = \begin{cases} -20 \log \sec\theta \ \text{dB} ; & 0^\circ \leq \theta \leq 59.9^\circ \\ -6 ; & \theta > 59.9^\circ \end{cases}$$



FM STATION NETWORK LATTICE
(150 kHz Minimum Difference Between Channels)

Numbers 0-5 refer to Frequency Difference in 150 kHz multiples, positive being above the desired channel and negative being below the desired channel. Equilateral triangles are formed by any 3 co-channel stations.

Carrier Difference		S/I Protection Ratio in dB	
m Multiple	in kHz	Monaural	Stereophonic Unfiltered
0	0	28	36
1	150	8	15
2	300	-7	-7
3	450	-25	-25
4	600	-40	-40
5	750	-	-

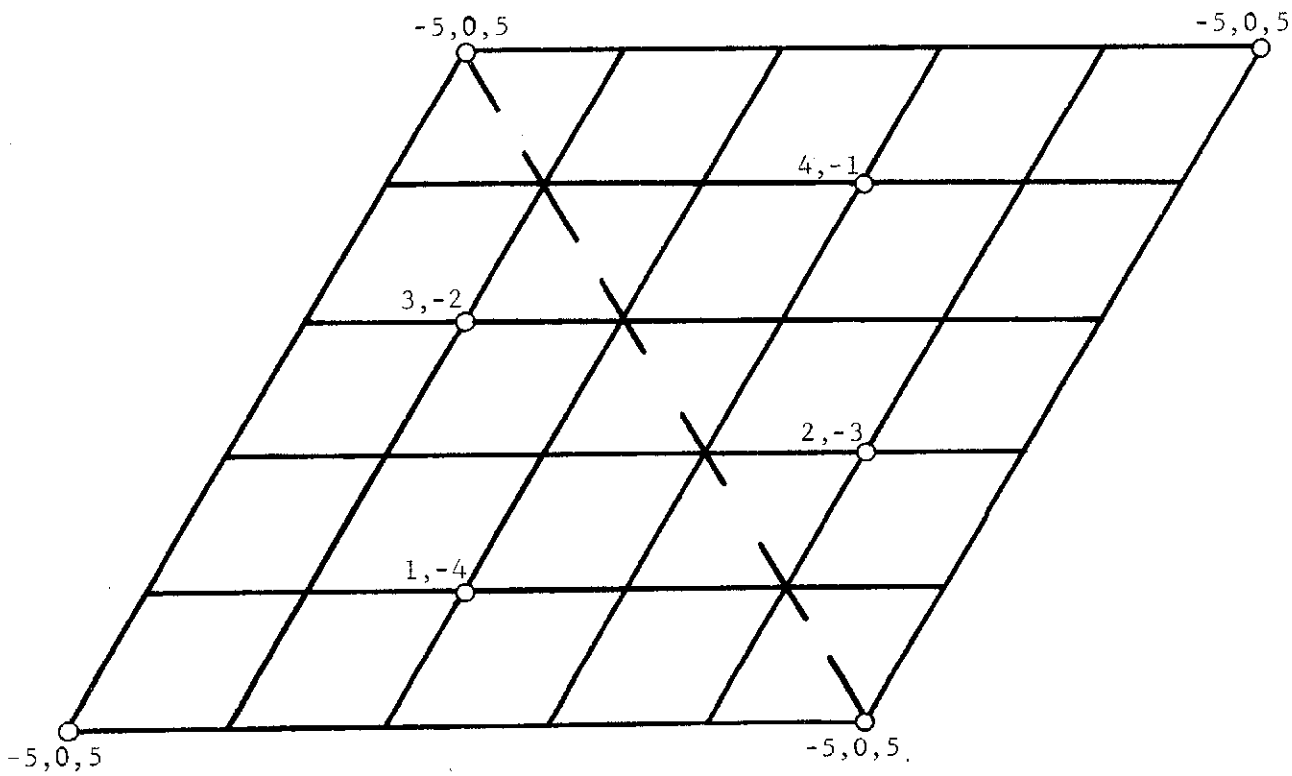


Figure 4

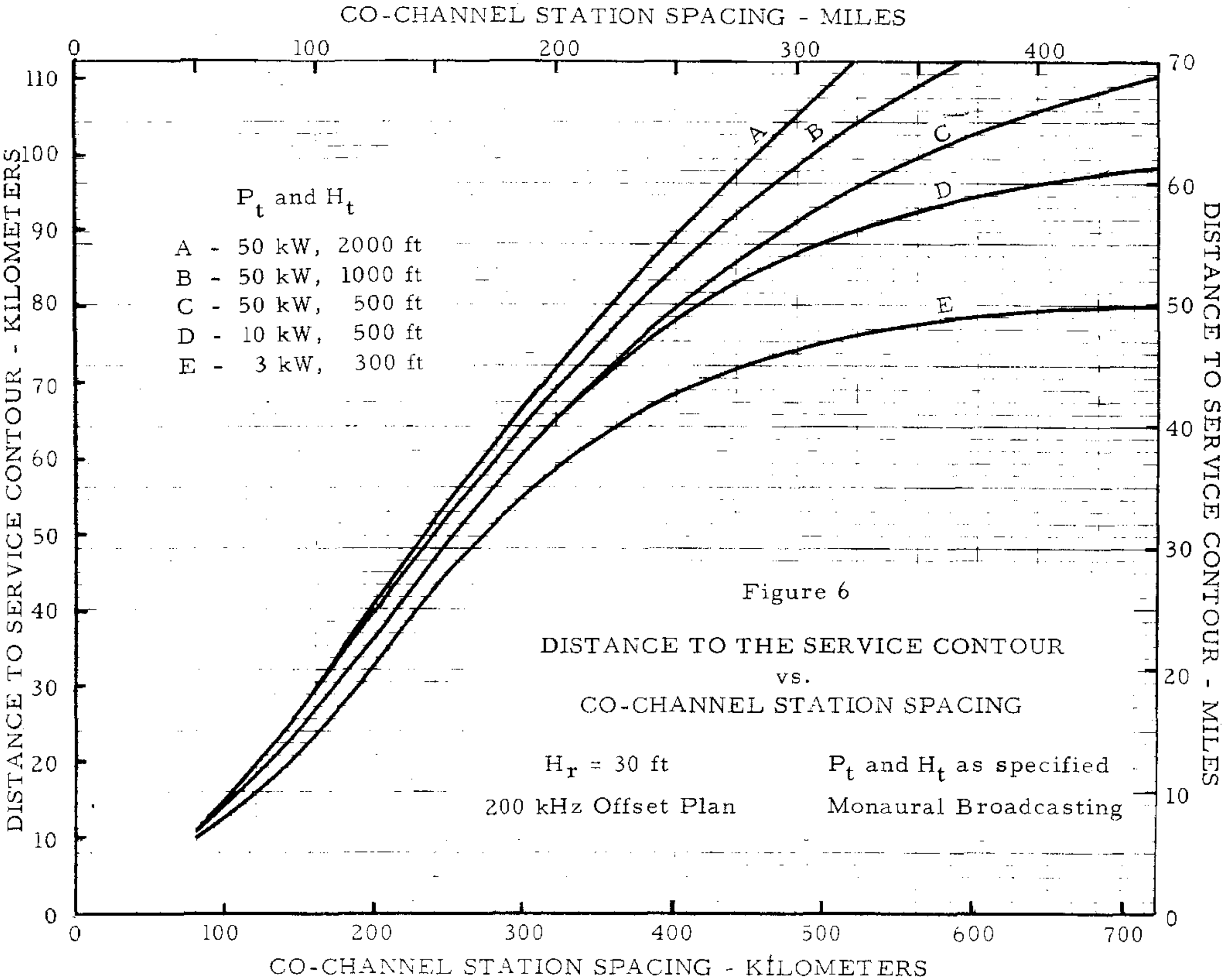


Figure 6

DISTANCE TO THE SERVICE CONTOUR
vs.
CO-CHANNEL STATION SPACING

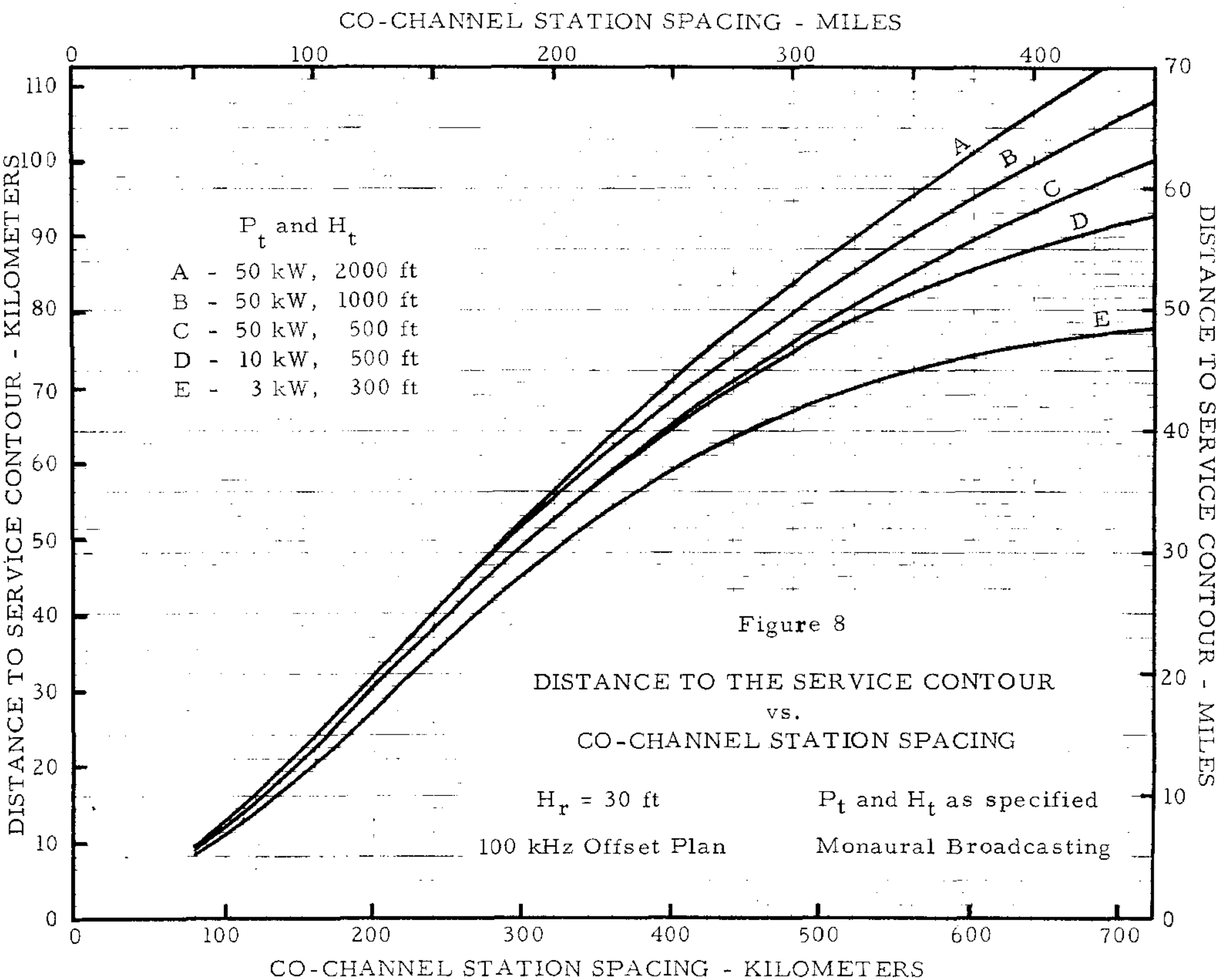


Figure 8

DISTANCE TO THE SERVICE CONTOUR
vs.
CO-CHANNEL STATION SPACING

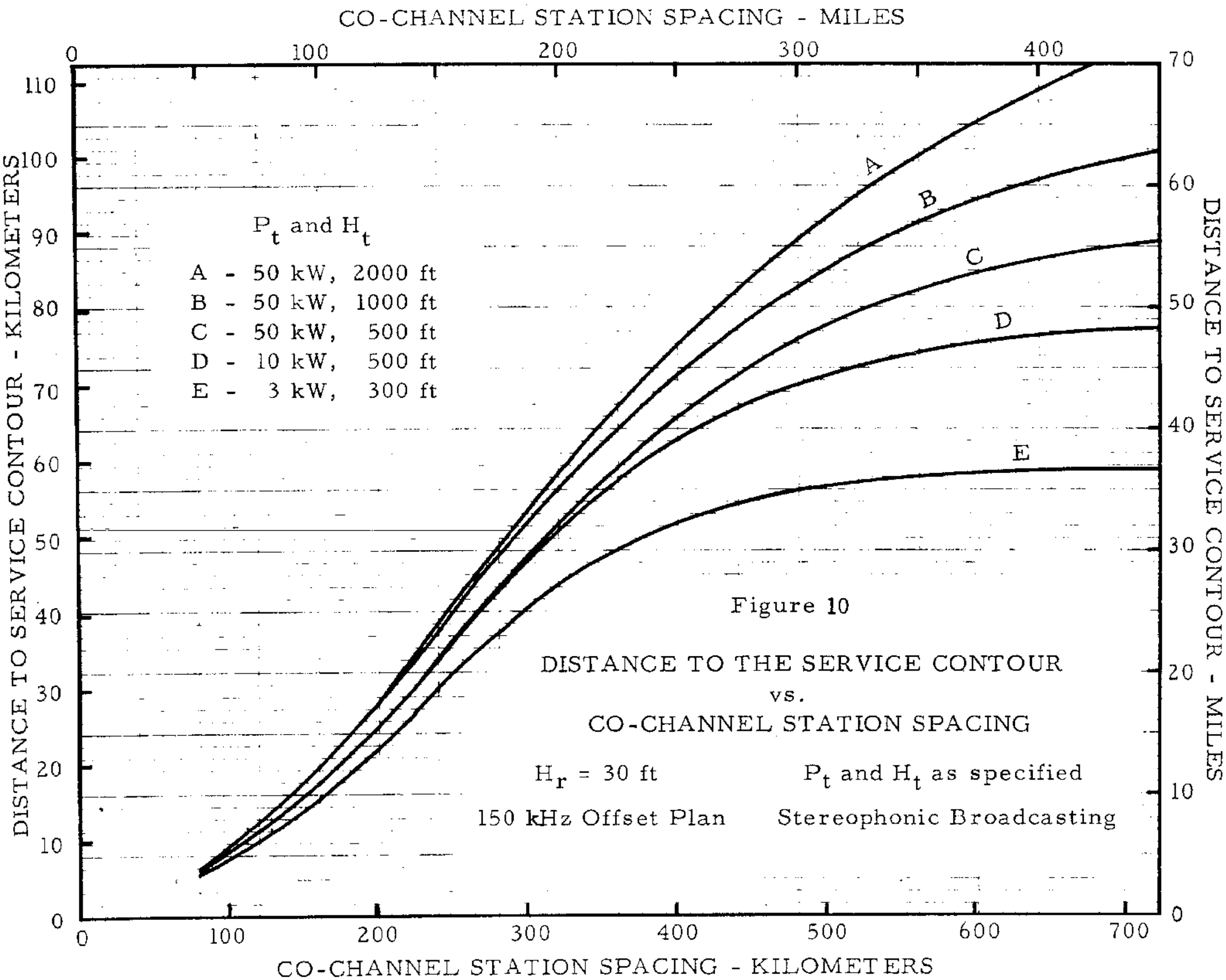


Figure 10

DISTANCE TO THE SERVICE CONTOUR
vs.
CO-CHANNEL STATION SPACING

H_r = 30 ft — P_t and H_t as specified

150 kHz Offset Plan — Stereophonic Broadcasting

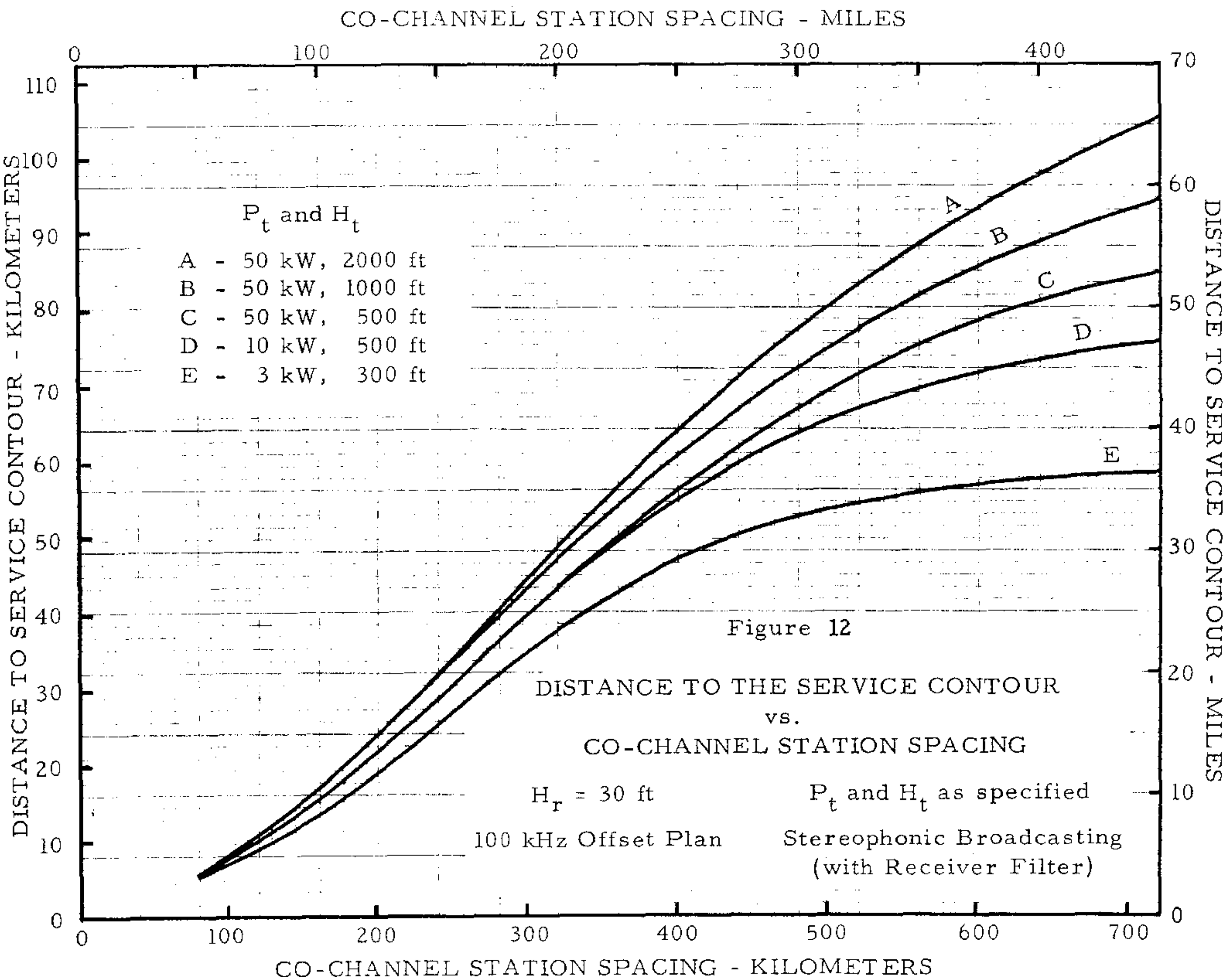
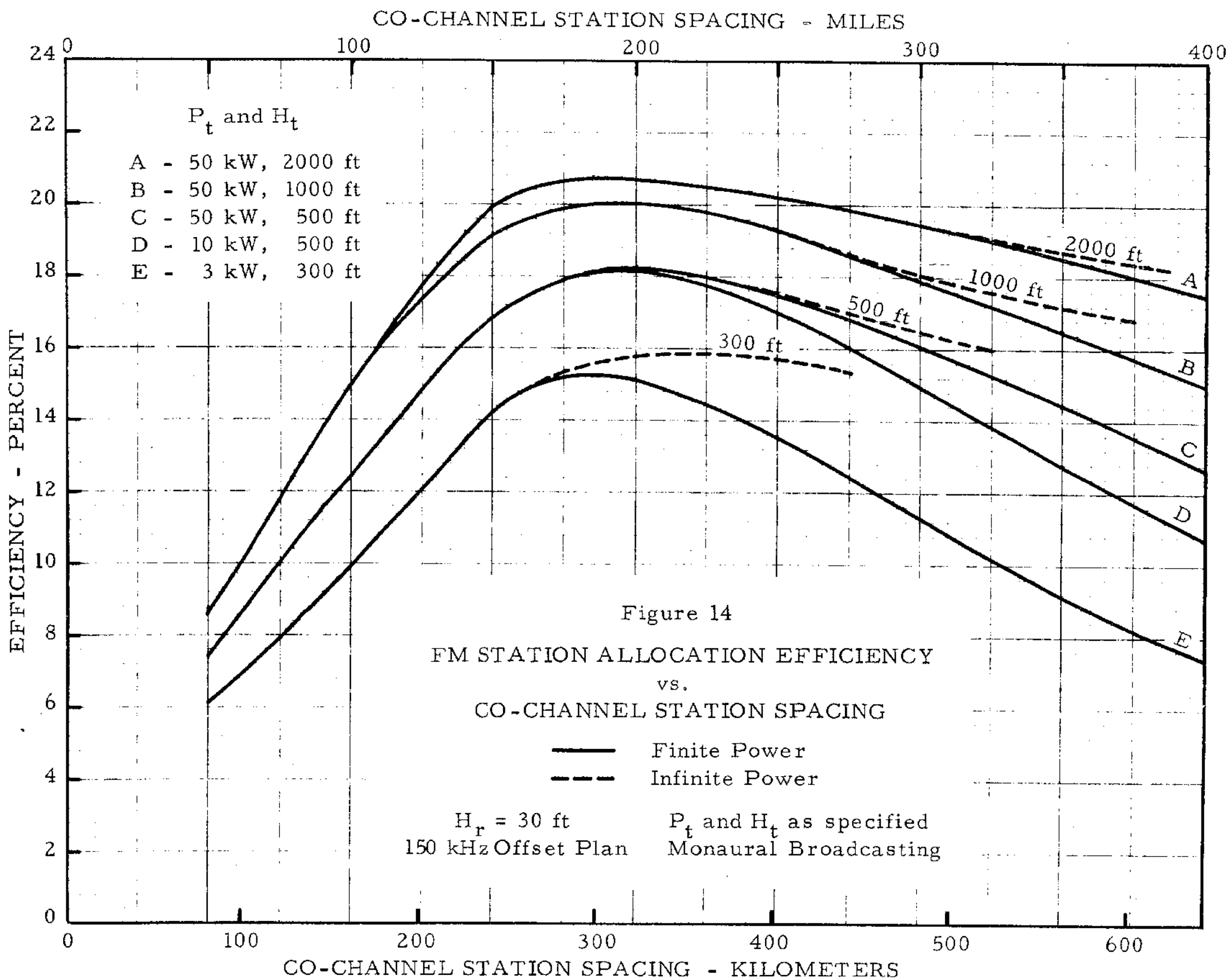


Figure 12

DISTANCE TO THE SERVICE CONTOUR vs. CO-CHANNEL STATION SPACING


CO-CHANNEL STATION SPACING - MILES
0
100
200
300
400
24
22
20
18
16
14
12
10
8
6
4
2
0
EFFICIENCY - PERCENT
P_t and H_t
A - 50 kW, 2000 ft
B - 50 kW, 1000 ft
C - 50 kW, 500 ft
D - 10 kW, 500 ft
E - 3 kW, 300 ft
2000 ft
1000 ft
500 ft
300 ft
A
B
C
D
E
Figure 14
FM STATION ALLOCATION EFFICIENCY
vs.
CO-CHANNEL STATION SPACING
Finite Power
Infinite Power
H_r = 30 ft
150 kHz Offset Plan
P_t and H_t as specified
Monaural Broadcasting
0
100
200
300
400
500
600
CO-CHANNEL STATION SPACING - KILOMETERS

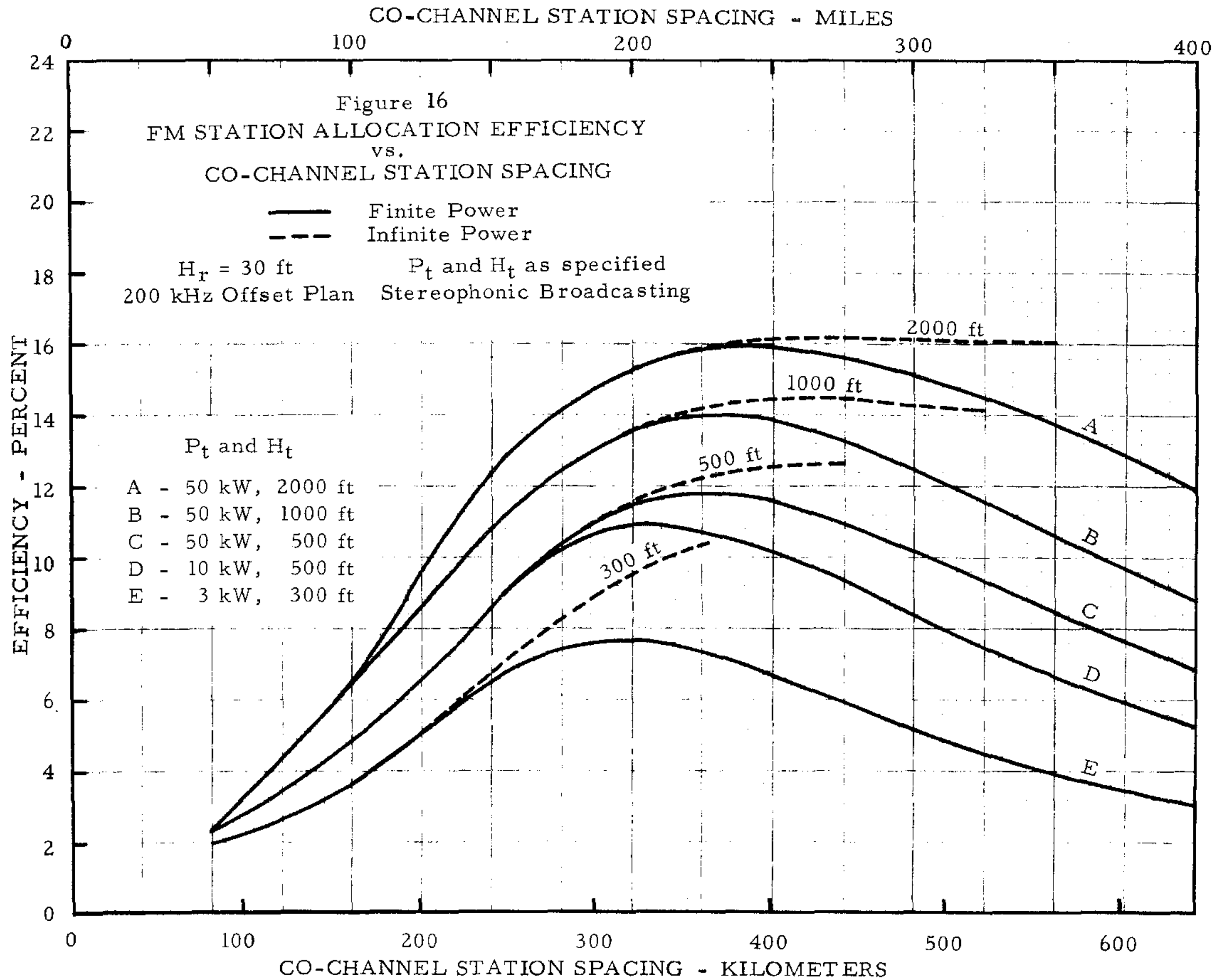


Figure 16
FM STATION ALLOCATION EFFICIENCY
vs.
CO-CHANNEL STATION SPACING

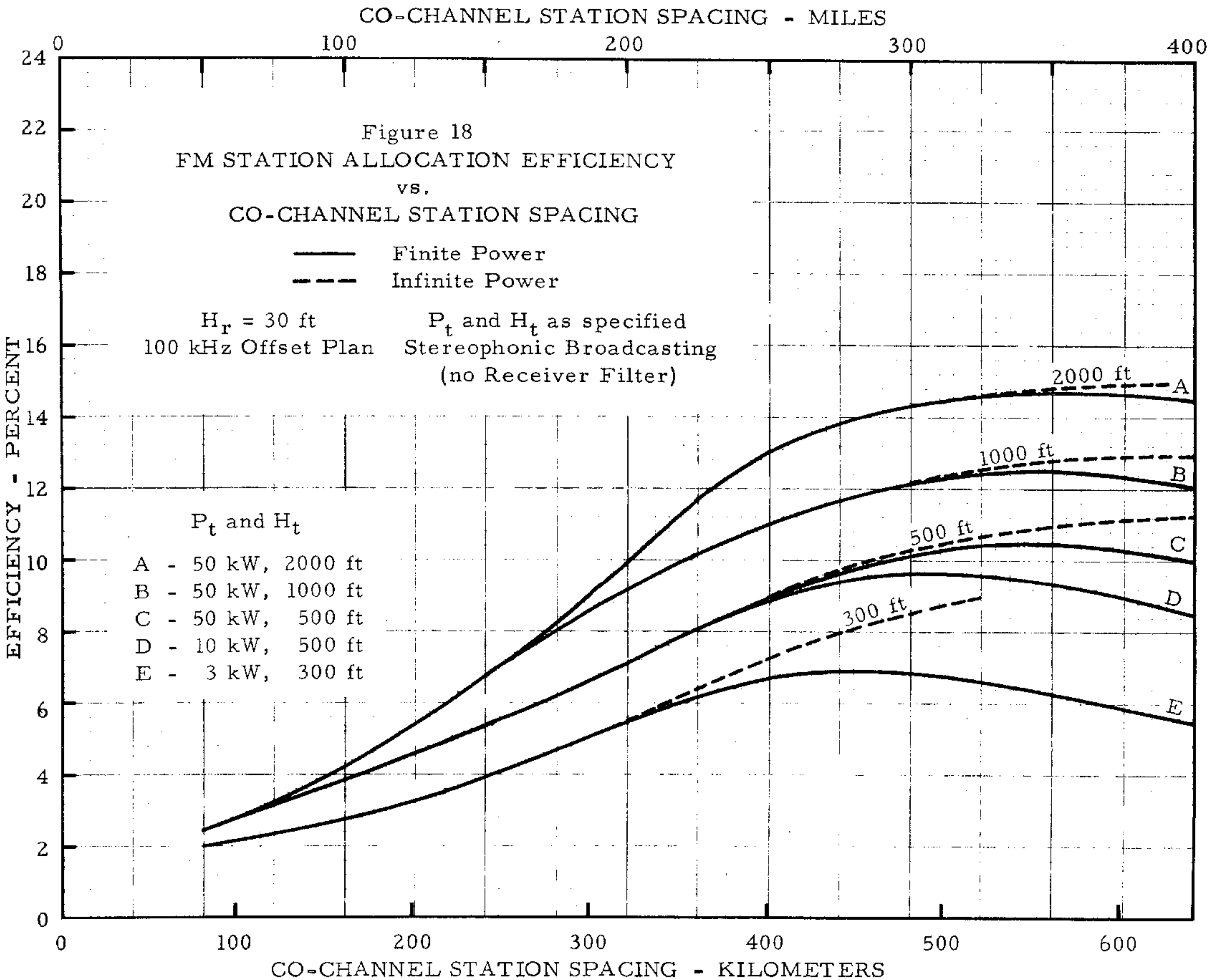
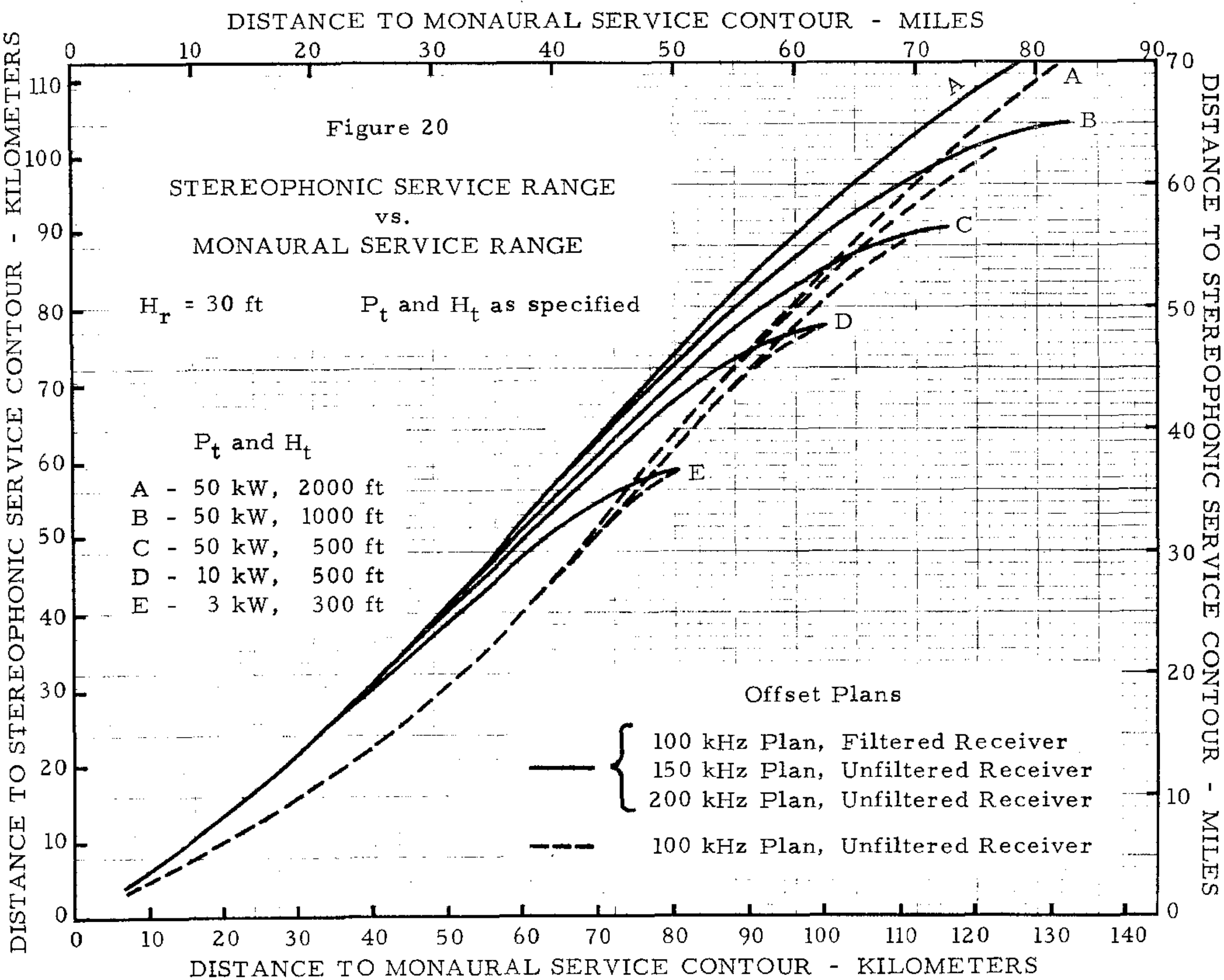


Figure 18
FM STATION ALLOCATION EFFICIENCY
vs.
CO-CHANNEL STATION SPACING


DISTANCE TO MONAURAL SERVICE CONTOUR - MILES
0
10
20
30
40
50
60
70
80
90
DISTANCE TO STEREOPHONIC SERVICE CONTOUR - KILOMETERS
110
100
90
80
70
60
50
40
30
20
10
0
DISTANCE TO STEREOPHONIC SERVICE CONTOUR - MILES
70
60
50
40
30
20
10
0
Figure 20
STEREOPHONIC SERVICE RANGE
vs.
MONAURAL SERVICE RANGE
H_r = 30 ft
P_t and H_t as specified
P_t and H_t
A - 50 kW, 2000 ft
B - 50 kW, 1000 ft
C - 50 kW, 500 ft
D - 10 kW, 500 ft
E - 3 kW, 300 ft
A
A
B
C
D
E
Offset Plans
100 kHz Plan, Filtered Receiver
150 kHz Plan, Unfiltered Receiver
200 kHz Plan, Unfiltered Receiver
100 kHz Plan, Unfiltered Receiver
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
DISTANCE TO MONAURAL SERVICE CONTOUR - KILOMETERS