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FACTORS AFFECTING FREQUENCY AND ORBIT UTILIZATION BY HIGH POWER TRANSMISSION SATELLITE SYSTEMS

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SUMMARY

The factors affecting the sharing of the geostationary orbit by high power (primarily television) satellite systems having the same or adjacent coverage areas and by satellites occupying the same orbit segment are examined and examples using the results of computer computations are given. The factors considered include: required protection ratio, receiver antenna patterns, relative transmitter power, transmitter antenna patterns, satellite grouping, and coverage pattern overlap.

The results presented indicate the limits of system characteristics and orbit deployment which can result from mixing systems.

INTRODUCTION

It has become increasingly apparent in recent years that there is a necessity for further broadening the base of the world's communications systems to include a greater proportion of nations and their populations. There is a need to improve the systems inward to maintain communications between different segments of our communities and there is a need to improve communications outward to areas which are technologically, geographically, or economically remote. The technology of inward growth is that of CATV, cable systems and the "wired city." The technology of the outward growth is that of High Power Communications Satellites transmitting primarily FM television to a multitude of low cost receivers. The technologies necessary for such satellite systems in the major areas of low cost receivers (MILLER, E.F., 1971), narrow beam transmitting antennas (DION, A.R., 1971, SAVIDES, J. 1970), highly efficient high power transmitters (RAMINS, P., 1970, KUHNS, P.W., 1971) and large solar arrays (WOLFF, G., 1971) are under development and will be demonstrated in the 1970's by the United States Air Force, NASA-ATS, and U.S.-Canadian CTS satellites.

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The questions now being asked no longer concern the technological feasibility of such satellites but rather concern the feasibility of frequency sharing between high power space transmissions and terrestrial communications systems, and the optimum use of the geostationary orbit by the satellites. The problem of sharing with terrestrial systems was a prominent subject for discussion at the CCIR Special Joint Meeting in February 1971 (CCIR, 1971) and at the interim CCIR meetings of April-May 1972. The problem of orbit sharing of high power satellites was also discussed at these meetings (Japan, 1971a, U.S.A., 1971a, Italy, 1971a) but in less detail. This paper will be concerned with the latter of these two problems. Since there is very little probability of AM-VSB television transmission from space, only FM television transmission will be discussed.

The work reported in this paper is the result of computations made of orbit sharing problems and deployment arrangements which may be more applicable to the Western Hemisphere. Sharing between satellites deployed such that each coverage area is serviced by a single or a multiple number of satellites is discussed. The deployment of individual satellites for each coverage area which is considered in this paper fulfills the requirements of potential users who desire to transmit a large number of programs to a limited number of areas. The converse may be desirable in Europe. It is believed that the trends shown and the conclusions reached are applicable to both situations.

Optimizing the use of a segment of the geostationary orbit by satellites using the same frequency band is a problem of orbit spacing which must consider: required protection ratios, receiver and satellite antenna patterns, relative power levels, satellite and coverage area groupings and channel isolation.

Pattern Plan and Relative Transmitter Powers

In order to calculate the effects of the various factors it is necessary to assume some coverage pattern plan. In this paper it will be assumed that the coverage pattern plan is as shown in figure 1. This particular plan was chosen because it indicates a possible scheme of coverages for the North American continent. It was further assumed that the receiving antennas would be fixed pointing and all desired transmissions to a given coverage area would emanate from a single satellite. The resulting ten satellites are assumed to be equally spaced. The sharing between these satellites will be called <u>single satellite sharing</u> in the text that follows.

It is also of interest to consider the sharing between multiple satellites transmitting to the same coverage area. This is a more complex problem and all the possible methods of deployment have not been fully explored. However, some preliminary results will be given and trends indicated. Sharing between multiple satellites transmitting to the same area will be called <u>multiple satellite sharing</u> in the text that follows.

Since it cannot be expected that all high power satellites will have the same output power, it will be assumed when calculating single satellite sharing that there are two administrations who wish to transmit to different parts of the plan shown in figure 1. The two are shown as shaded and unshaded portions in figure 1. A parameter used in further discussions of single satellite sharing will be the ratio, P_C/P_D, which is the ratio of satellite transmitter power levels of the two administrations: P_C being the transmission power level of the satellites of the wanted signal administration, and P_D the transmission power level of the satellites of the other administration.

When computations are made of sharing between multiple satellites transmitting to the same area it will be assumed that both administrations wish to transmit to all the coverage areas shown in figure 1. Administration "A" will transmit from single satellites of higher power while administration "B" transmits to the same area using lower powered single or grouped multiple satellites. The parameter used will be P_A/P_B which is the transmitter power ratio of the two respective administrations.

For the computation of interference in the single satellite sharing case seven different receiver locations on the coverage pattern edges were assumed as shown for typical locations by the triangles in figure 1. The worst interference at these locations was used to determine the effects of factors upon orbit sharing. In computing the interference for multiple satellite orbit sharing one location at the intersection of three beams (fig. 1) was used.

Protection Ratios

The protection ratio is a major factor in determining satellite spacing. The protection ratio, P_R, is the ratio of wanted to interfering power needed to protect the wanted signal from a certain degree of interference determined by subjective measurements or analytically. While the degree of interference used in tests ranges from just perceptible to annoying, just perceptible interference seems to be the maximum that most administrations will tolerate. Thus only values of P_R for just perceptible interference will be considered here. For FM television the value of P_R lies between 20 and 40 dB depending primarily upon modulation index, signal-to-noise ratio of the wanted signal, and the interference free percentile desired.

Shown in figure 2 is a summary of measured values of P_R at high signal-to-noise ratio (CCIR weighted $S/N_w > 49$ dB) as a function of the FM peak-to-peak deviation. These values are the result of a number of inputs from many nations (U.S.A., 1971b, Japan, 1971b, Italy, 1971b, France, 1971, BROWN, A., 1971) having different television formats and different approaches toward interference measurement.

At the time of writing the only way in which the relationship between the required protection ratio and wanted signal interference percentile can be estimated is by the use of data taken for FM television interference upon AM-VSB television (U.S.A., 1971b, MILLER, E.F. and MYHRE, R.W., 1970). More data which will clarify this relationship hopefully will be presented at the CCIR meetings in July of this year. The data available is summarized in figure 3. This data was taken primarily using daytime off-the-air programs for both wanted and unwanted signals. Commercials and cartoons were excluded from the tests. In making the tests for the data in figure 3 it was noted that a fairly high percentage of the daytime programming in the United States consists of interview shows whose simple backgrounds are fairly susceptible to interference. When the background is more complicated, or moving, as in outdoor scenes, lower protection ratios are required for just perceptible interference. The data in figure 3 indicates that an AM-VSB protection ratio of 49 dB would protect AM-VSB reception more than 90 percent of the time. Since this protection ratio is equal to that obtained using interferences upon color bars (Japan, 1971b) we can reasonably extrapolate this percentile to the FM protection ratios which were obtained also using this or similar test signals.

At the time of writing there is some confusion as to the relationship between wanted transmission signal-to-noise ratio and required protection ratio. The results of tests taken of FM on FM interference (Italy, 1971b) and FM on AM-VSB interference (U.S.A., 1971b) are summarized in figure 4. The divergence in the dependence upon signal-to-noise ratio of the two sets of data may be due to differences in the testing approach; however, two other possibilities are also suggested.

1. The constant difference between AM and FM noise weighting is incorrect. Some preliminary subjective testing indicates the difference in weighting for system "M" may be as little as 1 dB at high signal-to-noise ratios or as much as 6 dB for low signal-to-noise ratios. These results would suggest a divergence even larger than shown.

2. There is a functional difference in the susceptibility to interference of the United States NTSC color television and the European PAL and SECAM color television systems.

What is indicated is that caution should be exercised in equating AM-VSB quality standards such as TASO to FM reception quality simply by equating weighted signal-to-noise ratios. Since in this paper it will be assumed that high signal-to-noise ratios are desired the values of the "CCIR" curve in figure 2 will be used for the most part.

The data from subjective testing has to date been taken with one interfering entry. If two or more entries are present there is a finite probability that at some time all the signals will add in amplitude. The magnitude of the change in the protection is dependent upon the relative strengths of the entries and the programming of the different sources. In order to ascertain the magnitude of change, computations were made assuming the satellite deployment groupings which will be discussed later in the text. The results of the computations indicated that if the optimum sharing deployment scheme were used the maximum increase in interference to be expected by entries adding as amplitude, rather than power, is 2.8 dB if all satellites have equal transmitter power and 3.5 dB if some differ by 10 dB. For less optimum deployments of satellites these values would be increased to 3.5 and 5.0 dB, respectively. In this paper interference entries will be added as power.

An attractive technique which can be applied to FM television signals to lower the interference upon narrow bandwidth telephony signals is to add a very low frequency triangular wave to the modulating television signal. Measurements have indicated that for a FM signal with strong spectral component (all black, etc.) the increase in allowable power is approximately equal to the reciprocal of the fraction of time within the 4 KHz telephony band. The limit to the improvement by this method (26 to 30 dB referred to the unmodulated carrier) is set by the fact that for typical pictures with many components, dispersion deviations much beyond 1 MHz will bring other components into the wanted bandwidth.

Preliminary measurements of FM transmissions interfering with VSB-TV reception indicate that this technique is not as effective when applied to television interference. Improvements are limited to 0 to 6 dB, depending upon the FM television signal spectrum content. Further tests will have to be made to assess the full value of the dispersion technique and its applicability to the reduction of interference on FM television reception.

Receiving Antenna Patterns

The next major factor affecting the orbit utilization is the receiving antenna pattern. If the satellites deployed within an orbit segment are assumed to be equally spaced then the angular separation between satellites, ϕ, can be determined from the equation:

$$G(0) - G(\phi) = P_R + F, \text{ in dB} \tag{1}$$

where

$G(0) - G(\phi)$ is the difference between centerline gain and the gain at angle ϕ

P_R is the required protection ratio

F is an orbit spacing factor which is the margin over the protection ratio due to multisatellite interference

In a sense F is a catchall of all the other factors which determine satellite spacing and is typically between +5 and -5 dB.

Usually (CCIR, 1971) for planning purposes the maximum pattern level beyond the 3 dB point is expressed in a form similar to:

$$G(0) - G(\phi) = 3 + 10N \log 2\phi/\phi_o, \text{ in dB} \tag{2}$$

where $2 \le N \le 3$ and ϕ_o is the half power beamwidth. It is also usually assumed that for individual reception $N \cong 2$, while for community reception $N \cong 2.5$, or in the case of a more expensive shielded parabolic antenna or cornucopia $N \cong 3$.

While this formulation is adequate for the description of far side lobes it is inadequate for describing the main lobe and near side lobes (U.S.A., 1972b). For this reason an additional "improved" formulation is also used in this paper.

$$G(0) - G(\phi) = 10 \log\left[1 + (2\phi/\phi_o)^{6N-9}\right], \text{ in dB} \tag{3}$$

for the main lobe and

$$G(0) - G(\phi) = 3 + 10 \log\left[80N + (2\phi/\phi_o)^{N}\right], \text{ in dB} \tag{4}$$

for the side lobes.

The gain functions given in equations (2), (3), and (4) for $N = 2.5$ are shown in figure 5.

While studies have indicated that side lobe levels lower than those given in equation (4) are possible using auxiliary radiators to compensate for feed blockage and edge radiation (SAVIDES, J., 1971, THOMAS, R.K., 1971), these techniques require considerable testing of individual antennas. This will probably price the receiving antennas out of the range of all but the more richly endowed ground systems.

The effect of N and $P_R + F$ on the relative spacing ϕ/ϕ_o is shown in figure 6. In determining the curves of this figure certain assumptions were made as to satellite deployment grouping which will be discussed in further detail below.

In computing these curves and most of the curves in the text that follows it was assumed that the decrease in side lobe level was limited to 45 dB below centerline gain (fig. 5). This is within 5 dB of the isotropic gain level for antennas expected to be used for community reception at 12 GHz. At 2.5 GHz this low level will require the use of good design and fabrication techniques.

Before going further it would perhaps be instructive to discuss the factor F in some detail. As was said before it is in effect a catchall which combines the effects of all the lesser factors such as satellite grouping, power ratios, transmission antenna gain curves, and coverage patterns. For the particular case of equally spaced satellites it is a useful parameter to measure effects of the various factors given above.

For the interference upon the reception of a signal at point m from the L^{th} satellite deployed within an orbit segment, F may be calculated from

$$F_{mL} = 10 \log \sum_{\ell \neq L} \frac{g(x_{m\ell}) \cdot G[(L-\ell)\phi]}{G(\phi)} \frac{P_\ell}{P_C} K_\ell, \text{ in dB} \tag{5}$$

where $g(x_{m\ell})$ is the relative gain of the transmission antenna of satellite ℓ at the point m. P_ℓ/P_C is the relative transmission power of satellite "ℓ" and is equal to 1 or P_D/P_C, and K_ℓ is a constant *whose value depends upon the isolation of transmission channels obtained by the use of cross polarization* or by using adjacent channels. For the particular type of antenna pattern given in equation (2) without a lower limit to the far side lobes this reduces to:

$$F_{mL} = 10 \log \sum_{\ell \neq L} \frac{g(x_{m\ell}) \cdot P_\ell/P_C \cdot K_\ell}{(L - \ell)^N}, \qquad (6)$$

which is independent of ϕ/ϕ_o. For the values of protection ratios considered in this paper the spacing will be such that the satellites which contribute most of the interference will lie at sighting angles such that the F determined by equation (6) is an excellent approximation of the values of F obtained from computations using equation (5) and specific values of ϕ/ϕ_o and can be extended with minimal error to other values of ϕ_o. As is shown in figure 6(b), for the grouping scheme and the antenna coverage plan used in this text, F also varies only about 3.5 dB with a variation of N from 2 to 3. F is also almost independent of ϕ/ϕ_o using equations (3) and (4) when the required protection ratio is such that $\phi/\phi_o > 4$.

The value of F can be very dependent upon the far side lobe level when this level is near the value of the required protection ratio. This is shown in figure 7 where F is plotted as function of P_C/P_D and the far side lobe level limit. For this particular set of curves antenna pattern A of figure 5 was modified for the different level limits noted. The protection ratio assumed was 30 dB. It can be seen from these curves that it is desirable to have the receiver side lobe limit with respect to the main lobe be approximately at least 3 dB below the ratio P_C/P_D minus the protection ratio.

For the more complex problem of multiple satellite sharing in which groups of lower power satellites transmit to the same coverage area as the higher power satellite, the relationships for determining F become more complicated. Each case is best handled individually. F then becomes less useful as a measure of sharing feasibility.

Satellite Grouping

To utilize orbit segments and allocated bandwidths in an orderly fashion it is necessary that the administrations concerned agreed upon some logical division of these two resources. Generally the schemes considered fall roughly into three approaches.

1. Allow the satellites to be deployed in a simple west-east sequence neglecting differences in satellite and receiver characteristics. This could be called <u>interspersed grouping</u>.

2. Physically group satellites of similar characteristics together or <u>separate grouping</u>.

3. Divide up the allocated frequency band among the prospective users. This is grouping by <u>separate frequencies</u>. In the work reported in this paper all three of these approaches were considered.

The first approach when studying single satellite sharing was assumed to be a simple "west-east" deployment in a sequence of 1 through 10 (see fig. 1). When considering multiple satellite sharing this grouping approach was studied assuming interspersing the high power satellites with groups of low power satellites placed adjacent to the high power satellite which transmits to the same area. This grouping while allowing the satellites to be at a high viewing attitude results in the possibility of very bad interference as the satellites transmitting to the same or adjacent areas are adjacent to each other in space. As will be shown this approach may also place severe restrictions upon satellite relative power levels.

The second approach, separate grouping, would result in the satellites of the different administrations being grouped about different longitudes. The sequence of single satellites providing the coverage shown in figure 1 would then be 1,3,6,8 followed by 2,5,7,9,4,10. When considering the problem of multiple satellite sharing, high power satellites are assumed to be located in the center of the segment while the low power satellites are deployed in groups at the east and west extremes. When this approach to deployment is used the result is a minimum of interference. However some satellites may be too low on the horizon for good viewing (for example, satellites 2, 4, and 8).

When considering division of the frequency band in this report it is assumed that the band is equally divided between administrations.

When considering single satellite sharing it is assumed that the satellites transmit from alternate channels in a manner which minimizes interference. When considering multiple satellite sharing it is assumed that the frequency band is divided in half, en bloc, with a suitable guard band between the two services to minimize interference.

There are, of course, other methods by which channel isolation can be obtained, the most prominent of which is polarization diversity. Today rather expensive parabolic antennas can be purchased which have a polarization isolation of 40 dB in the boresight axis and 10 dB below the wanted polarization pattern in the side lobe region. Such polarization isolation cannot be expected of high power satellite ground receiving antennas at this time. However when calculating multiple satellite sharing it will be assumed that the lower power satellites transmit two channels at the same frequency with 35 to 40 dB isolation.

Shown in figure 8 is the value of the factor F as a function of the satellite power ratio P_C/P_D and grouping scheme assuming 20 dB isolation between channels when separate frequencies are used.

Using the specific receiver characteristics given in Table I the orbit spacing for multiple satellite sharing using the different groupings was also computed. Of these, the curves delineating the feasible sharing using the interspersed group deployment scheme are the more interesting and are shown in figure 9. The optimum ratio of power for minimum separation is shown clearly. In computing these particular curves it was first necessary to optimize the spacing between the multiple low power satellites in each group before summing the interference entries. This was done by computing the separation at which the interference on the outer low power satellites in a group was equal to that of the inner ones.

TABLE I. - CHARACTERISTICS OF ASSUMED 12 GHZ RECEIVING SYSTEMS

System	P_R, dB	D/λ	ϕ_o	Antenna pattern	Polarization diversity
1A	26	35	2^o	A	-
2B	30	200	0.35^o	A	Yes - 35 dB
3A	30	70	1^o	B	-
4B	30	250	0.28^o	B	Yes - 40 dB

From curves similar to those shown in figure 9 and the computed interference levels obtained using the other grouping schemes, curves can be constructed which indicate the relative merits of the grouping schemes.

A measure of the relative merit of the method of satellite deployment is given by the number of information (television) channels which can be received within the frequency band in each coverage area. Such a comparison is shown in figures 10 and 11 where it is assumed that the bandwidth would allow for 10 separate information channels. To obtain these curves the two sets of receiver characteristics given in Table I were used. A specific value of P_A/P_B of 15 dB was assumed.

Transmitting Antenna Pattern

It is the perennial hope of those confronted with problems of orbit sharing that someone will devise an ingenious method by which the transmitted power delivered to a desired area will be uniform within the area and confined to its boundaries. This of course does not happen. Using a simple parabolic antenna with a single feed the power levels peak at the beam center and as much as 60 percent of the transmitted power may be delivered to undesired areas; adjacent coverage areas or oceans. This problem would be more amenable to partial solution if there were not certain restrictions placed upon the antenna system by the spacecraft environment. These include:

1. A limit of about 3 meters in largest dimension of a nonfolded antenna due to launch shroud size
2. Thermal control problems which restrict the losses which can be allowed in a high power space antenna system: i.e., a 3 dB power loss in the spacecraft antenna system cannot be tolerated.
3. Distortions of the antenna aperture by solar radiation which will raise side lobes and shift the pattern
4. Total spacecraft weight limits which if exceeded may result in a costly "jump" to another launch vehicle

In an effort to obtain partial solution within the above limitations there is at present a considerable effort in the development of more advanced antenna concepts.

At frequencies below 2 GHz the use of a deployable array of solid state amplifiers supported by a foldable truss structure looks promising. At higher frequencies the inefficiencies of the lower power amplifiers, the losses, and the weight make this type of antenna unattractive. At 12 GHz the side lobe levels and pointing requirements for small beams will probably necessitate the use of an antenna deployed as one piece. Luckily at this frequency the dimension of 3 meters is equivalent to a beamwidth of 2/3 degree which is close to the lower limit on beam sizes that has been determined to be required from user studies. These studies indicate beams for most uses in North America of 1-1/2 to 3 degrees thus allowing the use of beam matrices at 12 GHz.

The approaches studied at higher frequencies use a matrix feed aperture configuration such as an offset fed parabola or a lens. An example of a matrix fed lens antenna is the LES-7 antenna (DION, A.R., 1971) which would consist of a 19 horn cluster feeding a waveguide lens 75 cm in diameter. The offset fed parabola approach is exemplified by the Hughes-Canadian ANIK satellite. Both of these approaches are currently under study by NASA to determine their relative merits. Unfortunately both of these antenna approaches inherently have higher side lobes than can be obtained using a single prime focus fed antenna.

In order to ascertain the possible improvements in orbit sharing which might be obtained through the use of improved antenna techniques computations were made using transmitting antenna patterns given in figure 5 and similar patterns with lower side lobe levels and sharper main lobe falloff. A comparison of the results for the patterns of figure 5 is given in figure 12. In this figure F is shown as a function of the channel isolation: i.e., the isolation obtained in the transmission and reception pattern between two channels of information by means of polarization or separation of channel frequencies. As can be seen from this figure the effect of the change in antenna pattern is not great. Indeed further narrowing the main beam pattern or lowering the side lobes further do not lower the values of F much beyond those given for antenna pattern B. Significant improvement in F would only be accomplished by dividing the frequency band into sufficient separate channel groups so that at no location would two patterns which touch have the same frequency or would adjacent satellites use the same frequency. This would be done by dividing the frequency band into three portions for the particular pattern plan used in this exercise.

The magnitude of the interference will also depend upon the separation between patterns. Operational requirements such as common receiver systems or interlocking coverage areas may necessitate the use of transmission beams whose patterns overlap considerably. Conversely transmissions to selected members of a community such as receivers in the Rocky Mountains and Appalachia may result in considerable separation in antenna pattern coverages. The effect of antenna pattern separation is shown for 2 typical cases in figure 13. Again the factor F is given as a function of channel isolation. The upper curve is for a pattern plan similar to that of figure 1 but with the 3 dB contours touching the centers of the adjacent patterns. The lowest curve indicates the values of F when the 3 dB contours touch tangentially. This figure indicates a variation in the spacing by a factor of less than 1.5 for N = 2.5 when there is pure co-channel sharing for this wide range in pattern overlap.

Deployment of Operational Systems

The size of the orbit segment in which a system of satellites may be deployed limits the satellite separation and thus the flexibility of deployment. Shown in figure 14 are envelope curves indicating the estimated number of high power satellites transmitting for community reception which can be placed in a 100 degree orbit segment as a function of transmission frequency. In computing the curves, limits of a 3 m antenna diameter and/or a 1 degree half power beamwidth were placed upon the receiver antenna and appropriate protection ratios were used. As can be seen from this figure the number of satellites which can be deployed in a limited orbit segment is severely restricted at frequencies below 1 GHz. At 2.5 GHz a difficult but not unsolvable problem arises. In order to deploy 10 satellites it may be necessary to use co-channel operation to increase the antenna diameter to 4.5 m, or to use more sophisticated antennas such as those which are now becoming available for terrestrial microwave links.

When considering multiple satellite sharing a measure of the sharing feasibility and the optimum method of satellite grouping is obtained by expanding data such as that given in figures 10 and 11 to different values of P_A/P_B. The result of such an exercise is shown in figure 15 as a map of the domains of optimum deployment schemes for the sharing of the orbit and frequency band by multiple satellites transmitting to the same coverage areas. The restrictions imposed on satellite relative power by the interspersed deployment scheme are clearly shown in this figure.

CONCLUSIONS

Although there is still much work to be done before the problems of orbit/frequency sharing are fully assessed the results of the analyses summarized in this paper indicated the following conclusions.

1. The full usage of the 12 GHz frequency band can be obtained by satellites broadcasting to community receivers without recourse to expensive antenna systems.

2. Relatively sophisticated or large receiving antennas will be necessary at 2.5 GHz in order to fully use the frequency band and the orbit space.

3. Gathering satellites into reasonably homogeneous groups results in better orbit utilization.

4. When the orbit segment becomes small optimal orbit/frequency utilization is obtained by dividing the frequency band among satellite systems having differing power levels.

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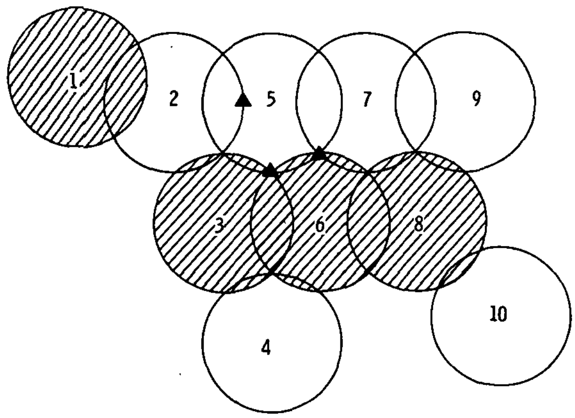


Figure 1. - Antenna Coverage Pattern Plan, cross hatching indicates signals transmitted by differing administrations when considering "single satellite" sharing.

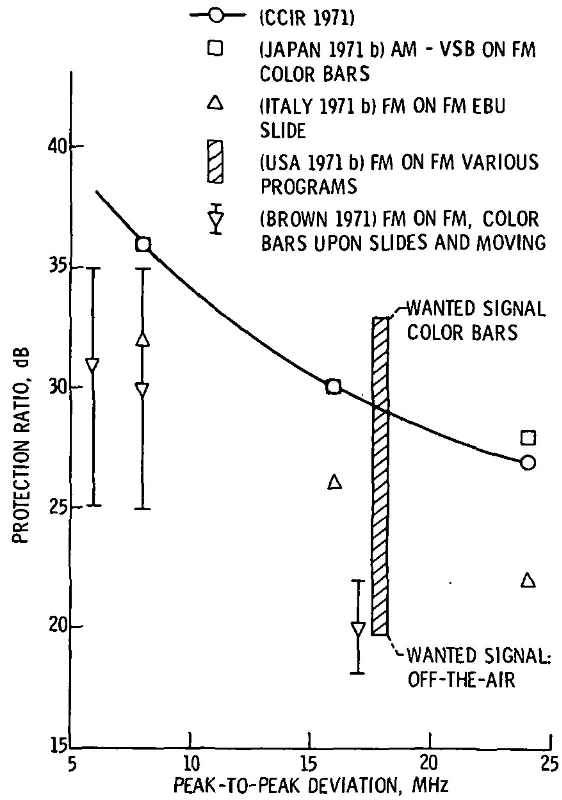


Figure 2. - FM - Television Protection Ratio for weighted signal-to-noise ratios greater than 49 dB.

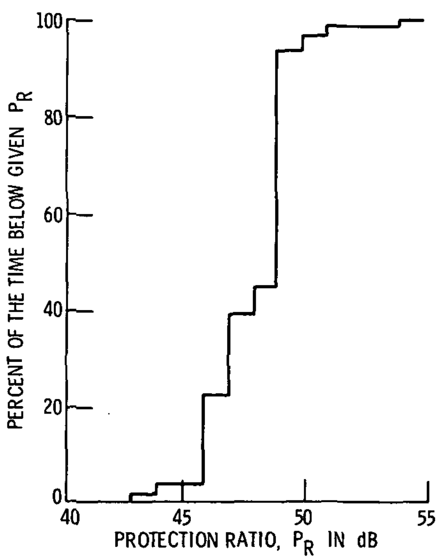


Figure 3. - AM VSB Television Protection Ratio distribution for "off-the" air programming. $46 < S/N_W < 51$, 68 data points

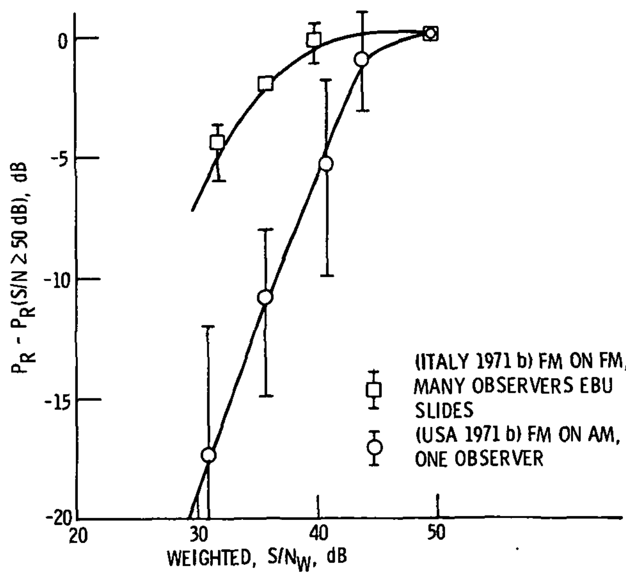


Figure 4. - Protection ratio as a function of weighted signal-to-noise ratio.

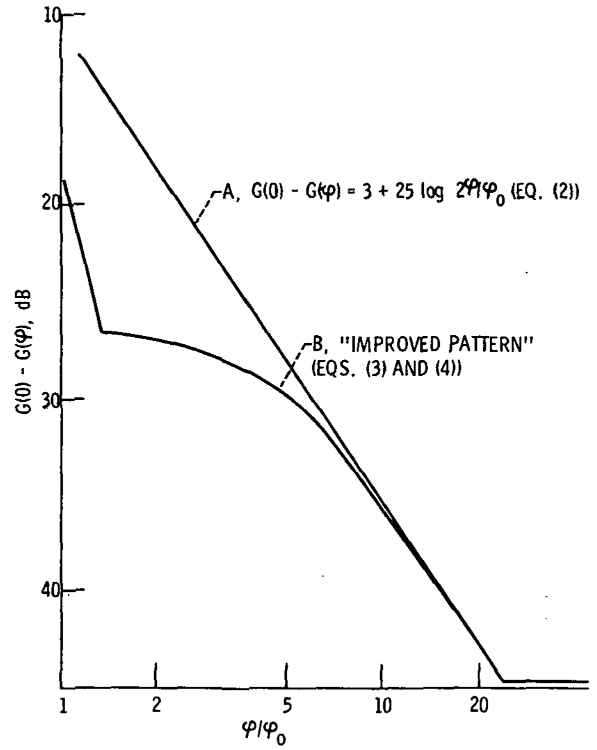
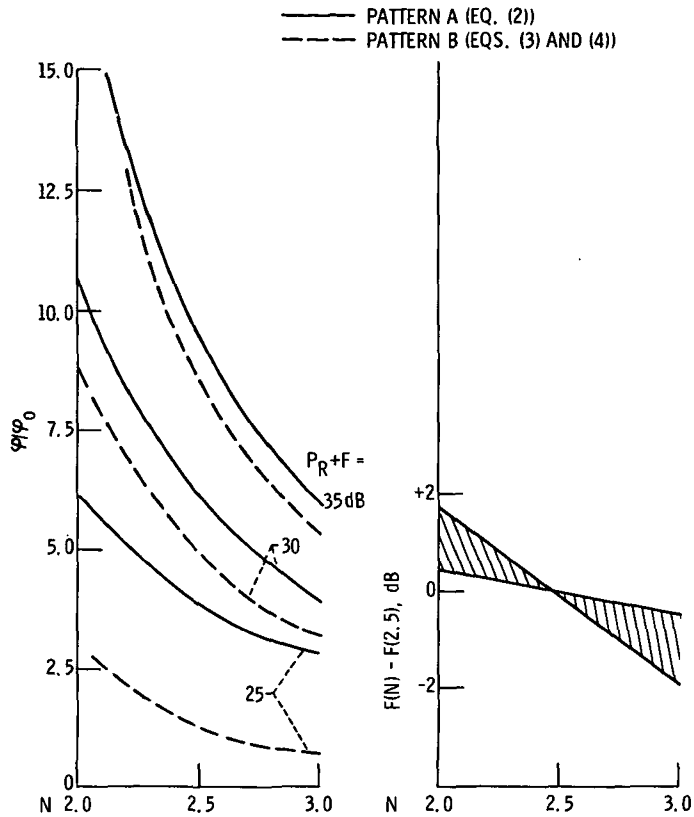


Figure 5. - Antenna Side Lobe Curves used in this paper, $N = 2.5$



(a) φ/φ_0 AS A FUNCTION OF N AND $P_R + F$ FOR TWO SIDE LOBE FORMULATIONS.

(b) ENVELOPE OF TYPICAL VARIATIONS IN $F(N) - F(2.5)$ AS A FUNCTION OF N USING RECEIVING ANTENNA PATTERN "A".

Figure 6. - Variation of φ/φ_0 with N, P_R, and F and the variation of F with N.

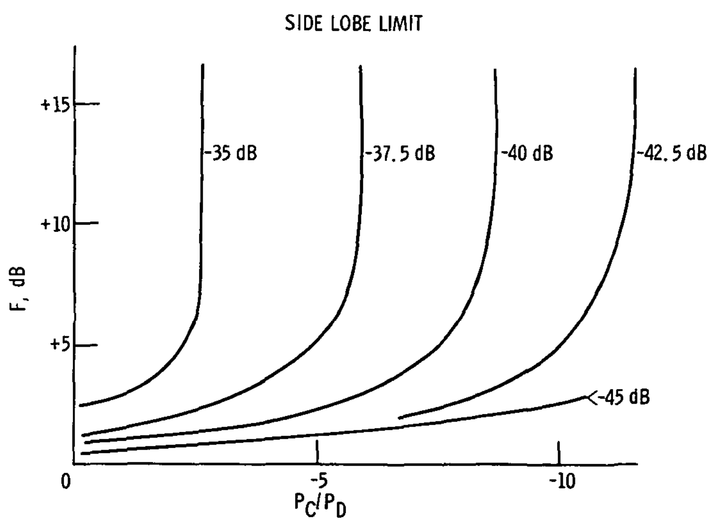


Figure 7. - Spacing factor F as a function of P_C/P_D and receiving antenna for side lobe limit. $P_R = 30$ dB, receiving antenna pattern "A", separate grouping, one typical receiver location.

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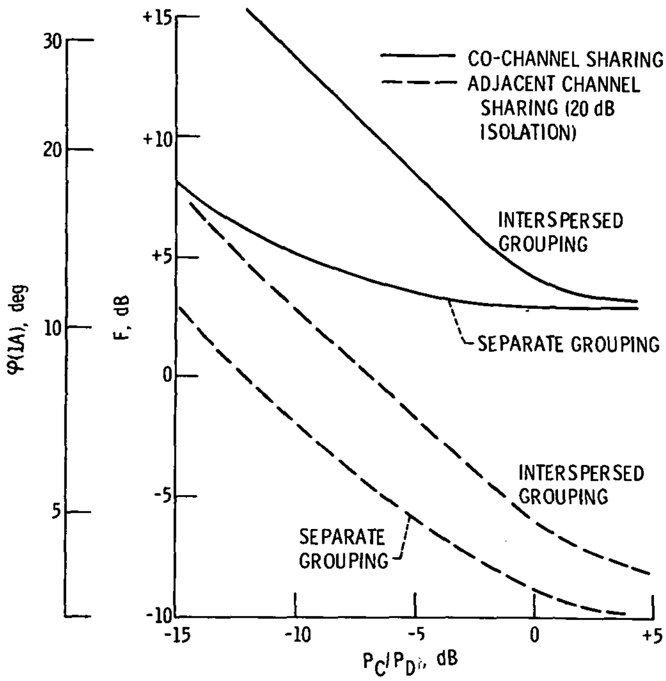

Figure 8. - Factor F and φ as a function of satellite power ratio P_C/P_D for two grouping schemes and two frequency divisions, receiving antenna pattern A, N = 2.5. For the determination of φ, receiver system 1A was used.

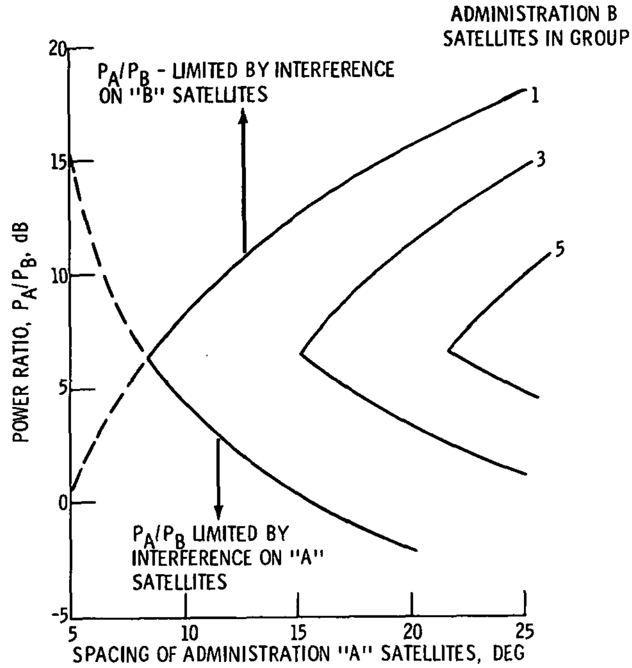

Figure 9. - Power ratio P_A/P_B as a function of the spacing between "A" satellites and the number of "B" satellites in interspersed groups, receiver systems 3A and 4B, typical receiver location.

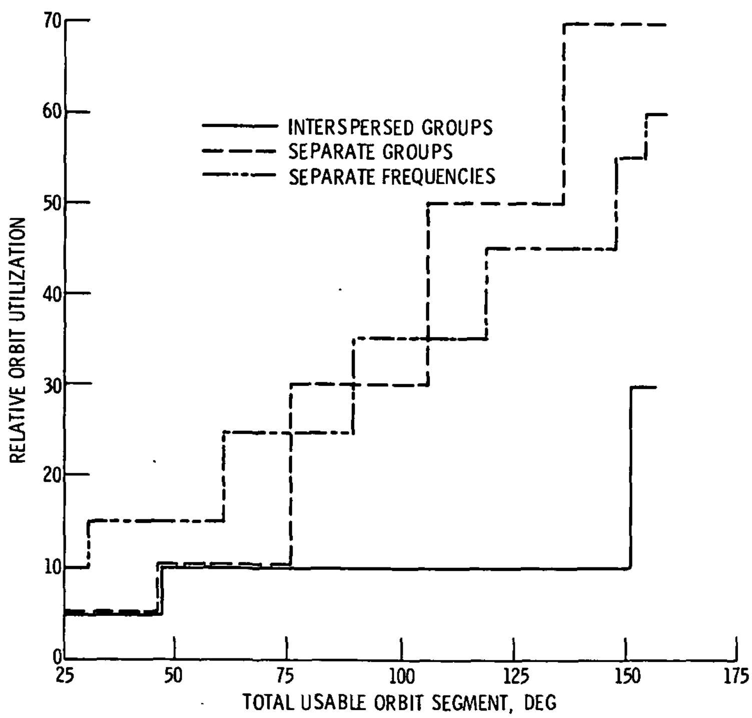

Figure 10. - Orbit/Frequency Utilization as a function of total usable orbit segment size, for three deployment schemes, multiple satellite sharing, receiver systems 3A and 4B, P_A/P_B = 15 dB.

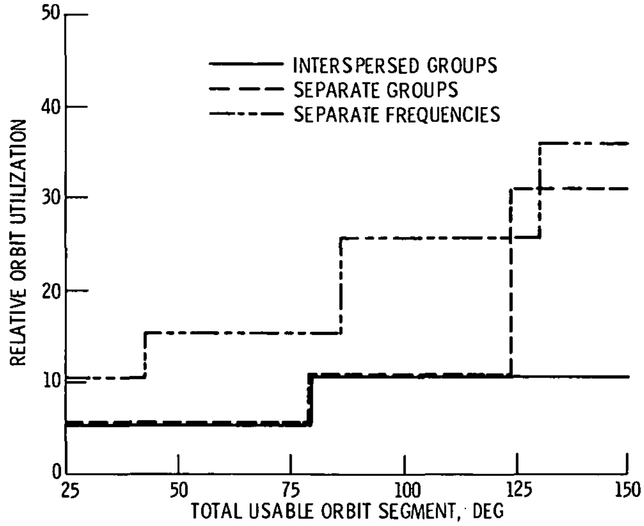

Figure 11. - Orbit/Frequency utilization as a function of total usable orbit segment size, for three deployment schemes, multiple satellite sharing, receiver systems 1A and 2B, P_A/P_B = 15 dB.

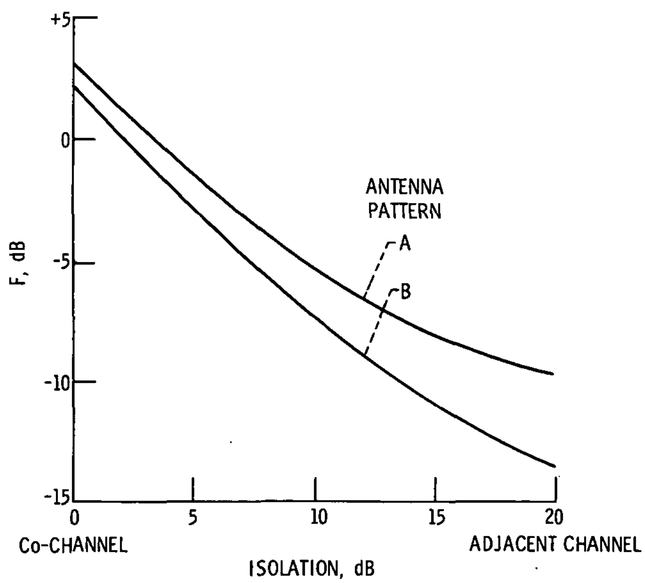

Figure 12. - Factor "F" as a function of channel isolation for the two antenna side lobe patterns shown in figure 2. Receiving antenna pattern A, N = 2.5, P_C/P_D = 0 dB, separate grouping, single satellite sharing.

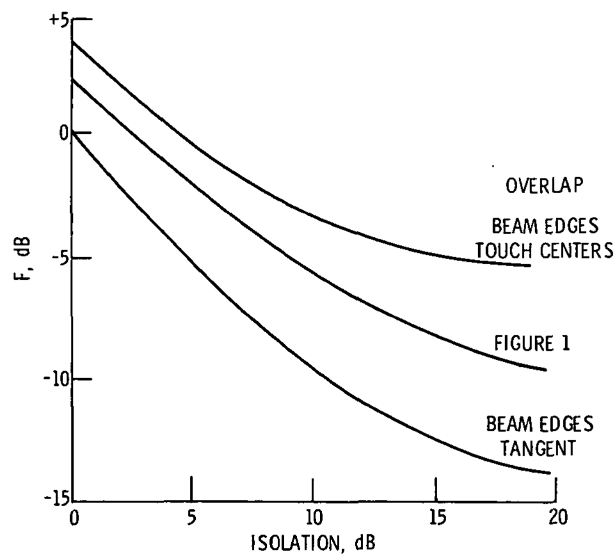

Figure 13. - Orbit Spacing Factor, F, as a function of channel isolation and degree of pattern overlap, P_C/P_D = 0 dB, receiving antenna pattern A, N = 2.5, separate grouping, single satellite sharing.

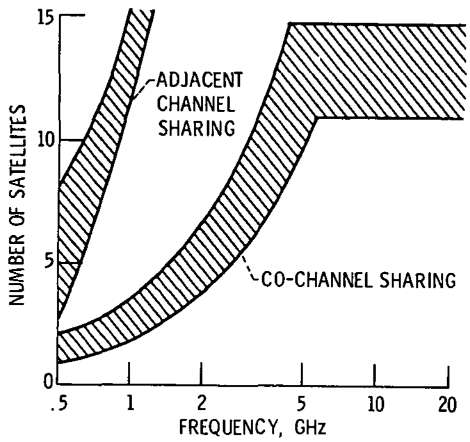

Figure 14. - Number of Satellites in a 100 degree orbit segment as a function of frequency, single satellite sharing.

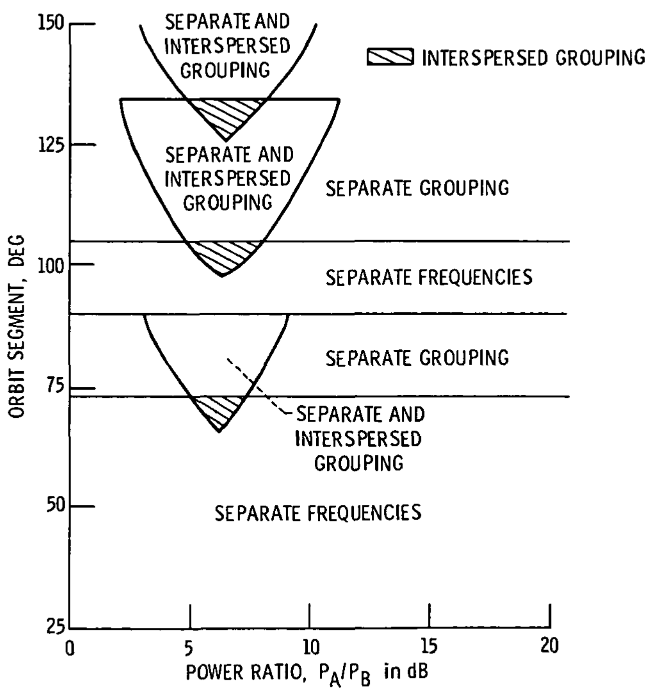

Figure 15. - Map of domains of optimum deployment scheme for multiple satellite sharing, receiver systems 3A and 4B.

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