ORBIT-SPECTRUM SHARING BETWEEN THE FIXED-SATELLITE AND BROADCASTING-SATELLITE SERVICES AT 12 GHz

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October 1974

P-5311

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Abstract

This paper identifies and evaluates strategies for sharing the geostationary orbit in the band 11.7 to 12.2 GHz between domestic systems in the fixed-satellite and broadcasting-satellite services. The effectiveness of two distinct types of sharing strategies, referred to as spectrum division and orbit division, is determined for various deployments of selected baseline systems representing the two services and for various combinations of sharing tactics such as frequency interleaving, crossed-polarization operation, and crossed-beam operation. Effectiveness is measured by the "utilization factor," defined as the number of channels provided by the baseline systems when using an assigned share of the orbit-spectrum resource, relative to what they could provide if given the entire resource. Computer simulation is used to verify the intra- and interservice interference compatibility of the assumed deployments. It is concluded that total utilization factors close to 100 percent can be achieved with both spectrum-division and properly-chosen orbit-division strategies. Orbit division strategies are to be preferred however because they permit a given total channel capacity to be achieved with fewer satellites and, for certain combinations of baseline systems, they yield a total utilization factor exceeding 100 percent.

INTRODUCTION

To reflect changes in the international radio regulations adopted at the 1972 World Administrative Radio Conference for Space Telecommunications (WARC-ST), the United States recently allocated the band 11.7-12.2 GHz to both the fixed-satellite and the broadcasting satellite services. The radio regulations do not specify the sharing criteria to be followed in this band, but it is clear that the design and deployment of future systems will have to be carefully coordinated if the two services are to share the allocation equitably and efficiently. The sharing problem is complicated by the fact that system economics can make the hardware parameters that are optimum for one service quite different from those of the other; for example, broadcasting-satellite systems tend to use higher satellite eirps and smaller ground stations than do fixed-satellite systems. Another problem in the United States at least, is that a demand for 12 GHz fixed-satellite systems will probably materialize much earlier than for broadcasting-satellite systems.

The objective in this paper is to provide a technical basis for interservice coordination by identifying and comparing various strategies for sharing the orbit-spectrum resource consisting of the 500 MHz in the band and the nominal 75 deg segment of the geostationary orbit visible above 10 deg elevation throughout the contiguous 48 states. Two general types of sharing strategies, called "spectrum division" and "orbit division," are considered. In the former, each service can occupy the entire orbital segment but is restricted to an assigned part of the frequency band; in the latter, the reverse is true.

The analysis begins with the design of a set of four baseline system models to represent the range of performance requirements and system characteristics anticipated in the two services. Alternative sharing strategies are then applied to various mixes of these baseline systems using computer simulation to verify the interference compatibility of the assumed satellite configurations. For any assigned division of the orbit-spectrum resource between the two services, the strategies are compared in terms of the effectiveness with which each service utilizes its share of the resource. The measure of effectiveness is the "utilization factor," defined as the number of channels that a service can provide when using an assigned share of the resource relative to the number it could provide if granted an exclusive allocation of the entire resource. The sum of the utilization factors for the two services is the "total utilization factor," which is taken as a figure-of-merit for the sharing strategy.

BASELINE SYSTEMS

In choosing hypothetical reference or baseline systems for use in the comparative analysis of sharing strategies, care was taken to use an internally consistent set of design assumptions for the two services. The performance specifications and system margin requirements adopted for this study are summarized in Table 1 for the four message channels of principal interest. It was further assumed that the baseline fixed-satellites would provide service to the contiguous 48 states whereas each broadcasting satellite would cover a single time zone.

To define rf links capable of carrying messages with the specified quality and reliability, it was further assumed that separate FM carriers would be used for each TV channel and for FDM basebands consisting of from 12 to 1800 channels. Ground station antenna sizes were selected to reflect the plans of system applicants in the case of the fixed-satellite service and of NASA cost-optimization studies in the case of the broadcasting-satellite

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*The study reported here was carried out under Contract NAS 5-21722 with the NASA Goddard Spaceflight Center, Greenbelt, Maryland.

service. To ensure reasonably effective use of the spectrum, the baseline fixed-satellite transponders were made powerful enough to support multiple FDM/FM carriers occupying a total of about 85 percent of their effective bandwidth when working into the largest assumed earth stations. The resultant downlink parameters for two capacities of fixed-satellite service and for two types of broadcasting-satellite reception are shown in Table 2.

The baseline earth stations of the fixed satellite systems were assumed to be located in 15 major U.S. cities. A reference set of 75 links between these cities was postulated, and all satellite tranmitting antennas were assumed to be pointed at the same central U.S. point, lat. 39° N, long. 98°W. In the case of the broadcasting satellite systems, uplink transmission sites in New York, Chicago, Denver, and Los Angeles were assumed for the corresponding time zones and satellite antennas were aimed at a point which best matched their assumed elliptical patterns to the time zone boundaries. Sample reception points were then specified along these boundaries.

Table 1

BASELINE PERFORMANCE SPECIFICATIONS

Quantity	Type of Message Channel and System Telephone Fixed Satellite	TV Fixed Satellite	TV Broadcasting Satellite Community Reception	TV Broadcasting Satellite Individual Reception
Overall thermal-noise objective	5000 pWOp	55 dB	49 dB	43 dB
Uplink thermal-noise objective	1000	62	56	50
Downlink thermal-noise objective	4000	56	50	44
Probability of above-threshold operation (% of year)	99.99	99.99	99.9	99.9
Required system margin above threshold for nondiversity operation in southeast U.S. (dB)	10	10	7	7

Table 2

BASELINE SYSTEM PARAMETERS

		Fixed-Satellite Terminal		Broadcasting-Satellite	
		Large	Small	Community Reception	Individual Reception
	Unit	FL	FS	BC	BI
Satellite Transponder					
End-of-life net power to antenna	dBW	16		16	22
Antenna diameter	ft	0.86 × 1.72		2.33	1.65 × 3.3
Antenna beamwidth	deg	3.5 × 7		2.3	1.7 × 3.3
Antenna gain	dB	30		36	36
On-axis saturated eirp	dBW	46		52	58
Rf bandwidth	MHz	36		25	18
Earth-Station Receiver					
Antenna diameter	ft	32	16	12	3
Antenna beamwidth	deg	0.17	0.34	0.45	1.8
Antenna gain	dB	59	53	51	39
System temperature	°K	250	250	500	500
On-axis figure-of-merit	dWB/°K	35	29	24	12

CASES ANALYZED

Almost all of the important features of a sharing strategy can be evaluated by applying it to reference cases in which each service is represented by a single type of baseline system. Three basic combinations of baseline systems, identified as Case 1, Case 2, and Case 3, were selected for analysis.

In Case 1, the baseline systems representing the two services were deliberately chosen to have widely different parameters to illustrate the effect of large inhomogeneities in satellite eirp, earth-station figure-of-merit, and channel bandwidth. Referring to Table 2, the fixed-satellite, large-terminal baseline system (FL) is used to represent the fixed-satellite service. This system employs a 46 dBW satellite in conjunction with an earth station having a 32 ft antenna. The broadcasting-satellite service is represented by the 58 dBW satellite and 3 ft diameter receiving installation listed in Table 2 for the individual-reception baseline system (BI).

In Case 2, the fixed-satellite baseline systems of Case 1 share the orbit and spectrum with the baseline broadcasting-satellite community-reception systems (BC). The latter uses 52 dBW satellites and 12 ft ground receiving antennas. This combination is probably more closely representative of the broadcasting-satellite systems likely to be developed for U.S. applications.

Finally, in Case 3, the baseline community-reception system of Case 2 is paired with the baseline fixed-satellite system (FS) using the "small," or 16 ft, earth-station antenna. This also represents a sharing combination likely to occur in U.S. domestic applications, and it is the most nearly homogeneous mix of fixed- and broadcasting-satellite systems considered.

For each of these cases, a number of subcases were considered. These were chosen to explore the effect on sharing of varying the number of channels on the carriers of the fixed satellite systems and of using different combinations of "sharing tactics" such as cross-polarized carriers, and frequency interleaving.

ANALYTIC PROCEDURE

The following six-step analytic procedure is used for evaluating sharing strategies in each of the cases and subcases.

1. **The spacing, orbit-spectrum utilization, and total channel capacity for exclusive occupancy, assuming co-channel, co-polarized links, are calculated for each of the representative baseline systems. In the calculations for fixed-satellite systems, it is also assumed that the total interference noise on telephone channels is held to 1000pWOp. For broadcasting-satellite systems, it is assumed that crossed-path operation (see Fig 4) is not used and that the effective carrier-to-interference ratios do not exceed the protection ratio for barely perceptible interference to a "noise-free" picture; specifically 28.3dB for the 18MHz of bandwidth adopted for individual reception and 24.7dB for the 23MHz bandwidth assumed for community reception.**
2. **Using these data, the utilization factors for each service and the total utilization factor are calculated for the spectrum-division strategy as a function of the share of the spectrum, and hence of the orbit-spectrum resource, assigned to each of the services.**
3. **Based on the spacings for exclusive occupancy calculated for the baseline systems in Step 1, trial orbit-division satellite deployments such as those shown in Fig. 1 are postulated along with carrier-frequency plans appropriate to the signal bandwidths assumed for each service. The same assumptions regarding frequency plan, polarization, path geometry and interference**

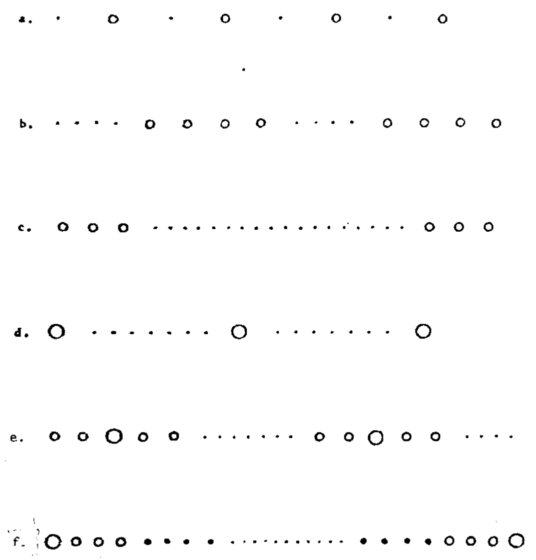


Fig. 1—Schematic examples of orbit-division deployments

objectives that were used in Steps 1 and 2 are used here. For each satellite deployment, the required intersatellite spacings are then calculated using a special approximation procedure for inhomogeneous systems.

4. The interference compatibility of each of the trial orbit-division strategies is tested for the assumed baseline ground segments by applying the computer simulation program for intersatellite spacings which bracket the approximate values calculated in Step 3. The "final" values of intersatellite spacings adopted for a given strategy are then inferred from an inspection of the computer simulation results.
5. For selected orbit-division strategies, the single-service and total utilization factors are calculated as a function of the share of the orbit, and hence of the orbit-spectrum resource, assigned to each service. The results for these orbit-division strategies are plotted for comparison with each other and with the results obtained at Step 2 for the spectrum-division strategy.
6. Finally, the enhancement of orbit-spectrum utilization that can be achieved by modifying the various sharing strategies to include additional sharing tactics is investigated. Predictions based on parametric analysis are verified where appropriate with the aid of computer simulation.

RESULTS FOR SPECIFIC CASES

To illustrate the analytic procedure just described, the results calculated for sharing by the baseline systems of Case 1 will be given in some detail and will cover both categories of sharing strategies. The results for Cases 2 and 3 will then be summarized with emphasis on the orbit-division strategies.

Case 1: Large Terminal Fixed-Satellite Systems Sharing with Individual-Reception Broadcasting-Satellite Systems

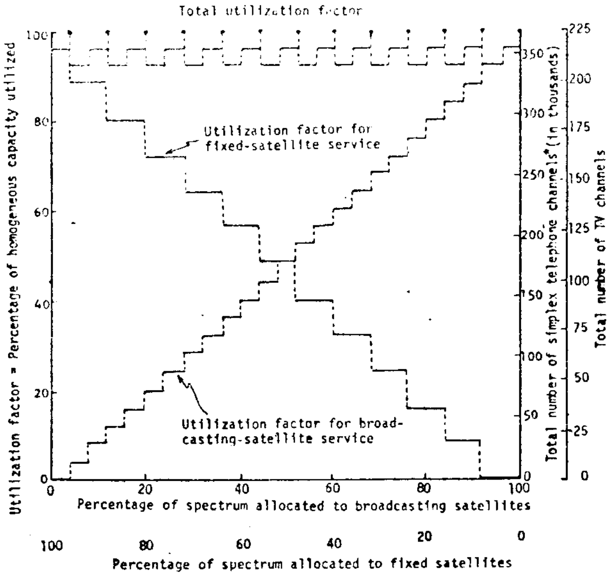
If the entire orbit-spectrum resource were allocated exclusively to fixed-satellite baseline systems with 1200 channel links, a spacing of 3 deg could be achieved. At this spacing, 26 satellites could be accommodated in a 75 deg orbital arc and, since each satellite has a capacity for 12 40MHz rf channels, each carrying 1200 channels, the capacity per satellite is 14,400 channels and the total capacity of all satellites is 26 x 14,400 = 374,400 simplex telephone channels. This capacity will be the reference for calculating orbit-spectrum utilization factors for orbit- and spectrum-division sharing strategies involving 1200 channel fixed-satellite systems of the type assumed.

If the resource were allocated to fixed-satellite systems with 900 or 600 channel links, the spacing between satellites could be reduced to 2.0 and 1.1 deg, respectively. However, these reductions are not accompanied by similarly dramatic increases in capacity or utilization and, in any case, require the use of much larger numbers of satellites. For example, the 29 percent increase in utilization gained in going from 1200 to 600 channels per carrier requires the launch of 2.6 times as many satellites.

If the entire orbit-spectrum resource were to be allocated exclusively to broadcasting-satellite systems of the type chosen for Case 1, the minimum orbital spacing would be 8.8 deg permitting 9 satellites to be accommodated in the assumed 75 deg orbital arc. Since each satellite has a capacity of 500/20 = 25 television channels, the total capacity of the orbit and spectrum for this kind of satellite broadcasting is 9 x 25 = 225 television channels. This capacity for a 100 percent assignment to the broadcasting-satellite service is used as the reference for calculating the utilization factors possible in orbit- and spectrum-division strategies with this baseline system.

If a spectrum-division strategy is used, each service has the entire orbital arc, so the fraction of the resource assigned to one service is equal to the fraction of the total 500 MHz bandwidth assigned to it. Since there is no possibility of interservice interference, each service can use the same number of satellites as it would if it enjoyed exclusive occupancy of the resource. As a result, the utilization factor for each service will closely match its assigned share of the frequency band. Since the band is divided into discrete channels, the utilization factor for a service will increase in steps as the percentage of the spectrum assigned to it increases.

This is illustrated for the broadcasting-satellite service by the curve ascending to the right in Fig. 2. As expected, the utilization factor equals the percent of spectrum assigned whenever that amount of spectrum is equal to an integral number of channels. A similar stepwise utilization applies for the fixed-satellite service regardless of the number of channels per link as shown by the curve descending to the right, except that the horizontal step size is double that for the broadcasting-satellite service.



* Numbers shown are for 1200 channel links. For 900 channel links, increase numbers by 10 percent. For 600 channel links, increase numbers by 29 percent.

Fig. 2—System capacity utilization for spectrum division between 1200 channel, fixed-satellite links and 18 MHz, individual-reception, TV broadcasting links

It is evident that, with spectrum division, the utilization factor for either service is equal to or only a few percent less than the share of the resource assigned to that service. This is true regardless of the relative size of the shares so long as it includes at least one channel. As a result, the total utilization factor with spectrum division remains close to 100 percent as shown by the upper curve in Fig. 2; it attains 100 percent whenever the television and telephone channels completely occupy the allocated spectrum.

To judge whether the utilization factors obtained through such spectrum division are in fact adequate to meet potential demand, it should be noted that the ordinate in Fig. 2 may also be given in terms of the numbers of broadcast-satellite television channels and fixed-satellite telephone channels. The values illustrated for the fixed-satellite service on the right-hand scale of the plot are for 1200 channel links. As noted in the figure, these capacities should be increased by 10 percent and 29 percent for 900 and 600 channel links, respectively.

When an orbit-division strategy is used, each service has the entire spectrum, so that the fraction of the resource assigned to a service is equal to the fraction of the orbital arc "occupied" by the satellites of that service. This fraction in turn depends on how the two kinds of satellites are deployed in orbit. For the baseline systems assumed for Case 1, the fact that the homogeneous spacings for the broadcasting satellites are significantly larger than those for the fixed satellites suggests that clustered deployments like those shown in Figs. 1c and 1d should be considered.

Table 3

ORBIT-DIVISION SATELLITE DEPLOYMENTS AND COMPATIBLE INTERSATELLITE SPACINGS FOR CASE 1 BASELINE SYSTEMS

Subcase[a]	Satellite Deployment	Compatible Intersatellite Spacings (deg)		
		φ_{FF}	φ_{BF}	φ_{BB}
1a	. o . o . o . o .	14.0	7.0	14.0
1b	.. o .. o .. o .. o ..	2.9	7.2	≥ 17.3
1c	o o .... o o	3.1	5.6	11.4
1d	o .... o .... o .... o	1.96	5.2	≥ 16.4
1e	o o .... o o	2.04	5.2	11.1
1f	....o......o......o......o....	1.18	5.2	≥ 16.4
1g	....o.......o.......o.......o......	1.18	5.2	≥ 16.4
1h	Same as 1g but with 25 dB side-lobe reduction on earth-station antennas	1.05	3.8	≥ 16.4
1i	Same as 1g but with 40 dB side-lobe reduction on earth-station antennas	0.8	2.4	13.4

[a] Fixed-satellite links carry 1200 channels in Subcases 1a-1c, 900 channels in 1d and 1e, and 600 channels in 1f-1i.

Altogether, some nine subcases, labeled 1a through 1i and employing seven different satellite deployments, were investigated. The deployments tested and the corresponding intersatellite spacings are shown in Table 3. In this table, the dots represent fixed satellites and the circles broadcasting satellites.

When the maximum capacity of the fixed-satellite links is 1200 channels as in subcases 1a, 1b, and 1c, the highest utilization factors are attained with a clustered deployment like that of subcase 1b. Here, at least two fixed satellites, separated by about 3 deg, are placed between adjacent broadcasting satellites. The dependence of the service and total utilization factors and the numbers of channels on the relative sizes of the orbital shares assigned to the services is as shown in Fig. 3. For example, if about 47 percent of the orbit is assigned to the broadcasting-satellite service, the strategy yields about 220,000 simplex telephone channels and 100 television channels. The spacing of about 3 deg between adjacent fixed satellites will permit these satellites to be operated with any smaller number of channels either on a single- or multiple-carrier-per-transponder basis, but the total capacity with such operation will be reduced in proportion.

If the maximum capacity of the fixed-satellite links is reduced to 900 channels, the cluster-deployment becomes even more effective and the spacings between fixed satellites in a cluster can be reduced to about 2 deg with an increase of about 12 percent in the total channel capacity available from such satellites. Compatible multiple-carrier-per-transponder operation will still be guaranteed with properly chosen carrier parameters, and the aggregate capacity for such operation will still be in the order of 600 to 700 channels per transponder.

A further reduction in the maximum size of fixed-satellite carriers to 600 channels permits still further spacing reductions and capacity increases, but now the sizes, power levels, and frequencies of carriers in multicarrier operation have to be very carefully controlled to achieve interference compatibility. The preferred cluster strategy yields slightly higher utilization factors and total capacities, but fixed-satellite links with capacities greater than 600 channels cannot be operated at the reduced spacings.

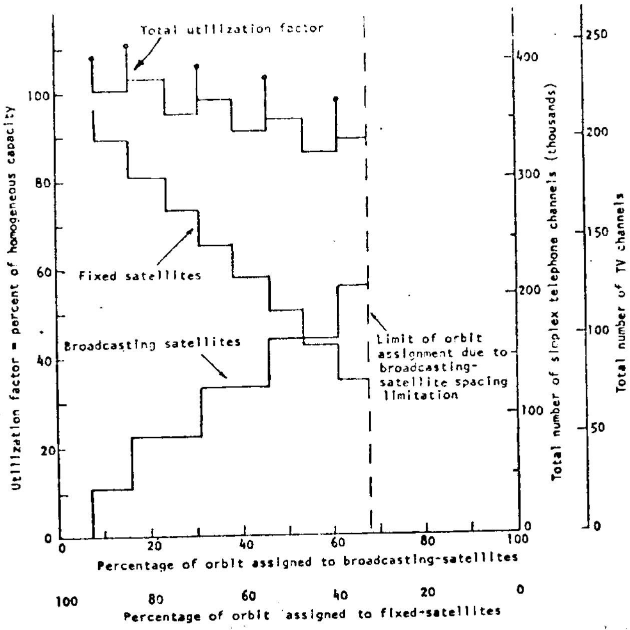


Fig. 3—Utilization factors for orbit division between 36 MHz, 1200 channel, fixed-satellite links and 18 MHz, individual-reception. TV broadcasting-satellite links (Case 1b)

Satellite deployments in which broadcasting satellites are themselves clustered at the ends of the visible orbital arc with all fixed satellites in a central cluster (subcase 1c) were found to be less effective than the deployments just described for all fixed-satellite link capacities below 1200 channels. At 1200 channels, the utilization factors were nearly equal for the two deployments.

Case 2: Large Terminal Fixed-Satellite Systems Sharing with Community-Reception Broadcasting-Satellite Systems

If the individual-reception, broadcasting-satellite systems in the preceding case are replaced by ones designed for community reception using 52 dBW satellites with 12 ft receiving antennas, then clustering the fixed satellites between adjacent broadcasting satellites is no longer the most effective way to share the orbit. For example, with 1200 channel links and clustered satellites, fixed-satellite systems would require a 60 percent share of the orbit to offer the same capacity as before (220,000 channels), and although the broadcasting-satellite capacity from the remaining 40 percent of the orbit would be doubled to 200 television channels, the total utilization factor would only be 80 percent.

The effect of reducing the number of channels on the fixed-satellite systems in this case would be to decrease the spacings and increase the capacity of those systems in about the same proportions as before, with attendant improvements in the utilization factor. However, the preferred orbit-division strategy is one in which satellites of both types are clustered. A utilization factor of nearly 100 percent can be achieved by grouping all satellites of one kind together and minimizing the number of interfaces between dissimilar satellites. Symmetrical deployments of this type include grouping either the broadcasting satellites or the fixed satellites in a central cluster with half of the satellites of the other service clustered at each end of the visible orbital segment.

Case 3: Small Terminal Fixed-Satellite Systems Sharing with Community-Reception Broadcasting-Satellite Systems

When the community-reception system just considered shares the orbit with a fixed-satellite system employing a 46 dBW satellite with 16 ft earth stations, the smaller earth-station figure-of-merit reduces the maximum link capacity to 600 channels. The spacings required between dissimilar satellites become very nearly equal to those required between similar satellites (about 2 deg).

The satellite deployment for the preferred orbit-division strategy is the same as in the preceding case, although here, an alternating deployment (one in which alternate satellites are of the same kind) also yields a utilization factor of nearly 100 percent. In all of the preferred deployments for this case, the utilization factor for each service is closely equal to its assigned share of the orbit. The capacities for exclusive occupancy are 274,000 simplex telephone channels for the fixed-satellite service and 756 television channels for the broadcasting-satellite service. Thus, the fixed-satellite service would require a 73 percent share of the orbit to yield 200,000 channels, in which case the 27 percent broadcasting-satellite share would yield 204 channels.

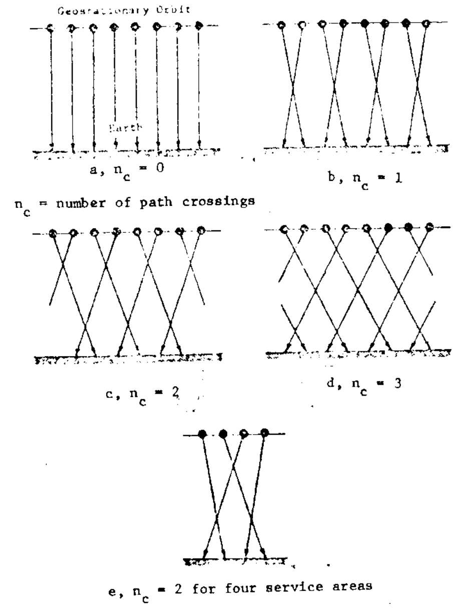
EFFECTS OF USING ADDITIONAL SHARING TACTICS

The capacities just cited for various sharing strategies were based on the assumption that certain sharing tactics were not used as explained in the description of Step 1 of the analytic procedure.

These capacities can be increased significantly by including additional sharing tactics in the basic strategy appropriate to each mix of systems. Thus, if alternate polarization is used on all adjacent satellites in the deployment, parametric analysis, verified by computer simulation, shows that spacings can be cut in half and the total capacities doubled. If carrier-frequency interleaving is used in addition to crossed polarization, the capacity of each satellite will be doubled and the total capacity, compared with the base case, quadrupled.

Since there is little likelihood of interference from terrestrial systems in the 11.7 to 12.2 GHz band in the United States, the interference objective for fixed-satellite links could be doubled to 2000 pW0p with an accompanying 24 percent decrease in spacing and increase in capacity for this service. If the protection ratio for individual reception is lowered by 6 dB to account for the masking of interference by noise at the 43 dB output signal-to-weighted noise level assumed for this type of service, the number of channels could be more than doubled.

If the positions of broadcasting satellites with nonoverlapping service areas are arranged to yield crossed-path operation, as shown in Fig. 4, the spacing of those satellites can be reduced by



a, $n_c = 0$ b, $n_c = 1$

n_c = number of path crossings

c, $n_c = 2$ d, $n_c = 3$

e, $n_c = 2$ for four service areas

Fig. 4—Schematic examples of cross-path geometry

as much as 30 percent with a corresponding increase in total channel capacity.

The use of sidelobe reduction techniques on earth-station antennas can yield further spacing reductions and capacity increases if the sidelobe suppression is greater than the single-entry protection ratio for interference from adjacent satellites after proper allowance for differences in eirp, frequency offset, and satellite antenna directivity. In a computer simulation involving fixed satellites with 32 ft earth-station antennas and broadcasting satellites with 3 ft antennas, the capacity increase was about 30 percent.

CONCLUSIONS

The fixed-satellite and broadcasting-satellite services can share the orbit-spectrum resource at 12 GHz equitably and effectively. Both orbit-division and spectrum-division strategies permit total utilization factors close to 100 percent, indicating that sharing does not significantly jeopardize orbit-spectrum utilization.

With spectrum-division there is no interservice interference so that the utilization factor for each service is very nearly proportional to the fraction of spectrum allocated to it and the total utilization factor is always near 100 percent. The spectrum may be divided between the services in any desired proportion independent of the characteristics of the satellite systems.

With orbit-division, interservice interference is controlled by careful separation of satellites in the orbit and the preferred satellite deployment depends on both the equipment and signal parameters of the sharing systems. However, the problem differs only in degree from that of finding compatible spacings for intraservice sharing and, for any given combination of systems, a deployment can be found for which the utilization factor of the corresponding orbit-division strategy approaches 100 percent. For certain combinations of systems, the total utilization can significantly exceeed 100 percent, although in these cases, there is a limitation on the relative size of the orbit shares that can be assigned.

Compared with an orbit-division strategy using the same types of systems, spectrum-division imposes a serious economic penalty: each service has to use more satellites to provide the same total capacity. Since an orbit-division strategy can provide equally high and in some cases higher utilization factors, it is concluded that orbit division is to be preferred to spectrum division.

The satellite deployment that characterizes the preferred orbit-division strategy for a given set of systems depends on the degree of inhomogeneity among those systems. When satellite eirps, earth-station antenna diameters, or signal modulation indices are quite different, a "clustered" deployment in which two or more satellites of the less powerful system are clustered between adjacent satellites of the more powerful system yields the highest total utilization. When the system parameters are more homogeneous, the deployment becomes less critical, and in most cases, somewhat higher utilization factors are obtained by gathering satellites of the same kind together in clusters and minimizing the number of interfaces between clusters.

With an appropriate division of the orbit and the 12 GHz spectrum between the two services, but without coordination of frequencies and polarization, the fixed-satellite service can provide at least 200,000 telephone channels and the broadcasting-satellite service can provide about 100 television channels for individual reception, or 200 television channels for community reception. These capacities are roughly equal to the aggregate capacity of the 20 domestic fixed satellite systems originally planned for the 4 GHz band. With careful frequency and polarization coordination the total number of channels can be quadrupled and still further increases are possible through the use of other sharing tactics.

Although the methods and results developed in this study provide the technical basis for developing an effective orbit-spectrum plan for domestic 12 GHz fixed- and broadcasting-satellite systems, it is considered premature to draw up such a plan at this time. More exact knowledge is needed and should be developed in a number of areas including the nature, diversity, and magnitude of potential future demands in the two services, the values of interference protection ratios to be adopted for television transmission, the permissible interference levels in telephone channels, the antenna patterns and sidelobe polarization discrimination that can be realized in practice, system margins for rainfall, and the effect on orbit-spectrum utilization of using digital modulation techniques in both services.

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