Meeting - Friday, May 2, 1969

Dr. A. D. Wheelon, Vice President, Engineering
Hughes Aircraft
Culver City, California

February 7, 1970

Dear Mr. Lutz:

Thank you for your letter of February 3rd regarding our domestic satellite policy. I certainly recognize that there are many problems to be resolved if this policy is to be effectively implemented. Our judgment was not that they would be easy, but that they could, in fact, be worked out and that on the whole we were better off with this particular set of problems than another. I have forwarded a copy of your letter and enclosure to the Acting Director of Telecommunications Management who is concerned with our preparation for the forthcoming WARC.

Although I certainly would not endeavor to "set you straight," I would enjoy the opportunity to meet with you some time when you are in Washington; alternatively, I plan to visit Hughes on February 13 and might have the opportunity to see you then.

Thank you again for your thoughtful letter.

Sincerely,

Clay T. Whitehead
Staff Assistant

Mr. Samuel G. Lutz
Chief Scientist
Hughes Research Laboratories
3011 Malibu Canyon Road
Malibu, California 90265

cc: Mr. Whitehead
Central Files

CTWhitehead:jm

HUGHES Research Laboratories
A DIVISION OF HUGHES AIRCRAFT COMPANY
3011 MALIBU CANYON ROAD
MALIBU, CALIFORNIA 90265

3 February 1970

Mr. Clay T. Whitehead
Staff Assistant
The White House
Washington

Dear Mr. Whitehead:

I greatly appreciated your letter of 23 January, despite my delay in replying. Because of a personal tragedy I have been away from office.

Thanks for the copy of the White House Memorandum, and congratulations. I noted with pleasure the first paragraph under "Recommendation," which seems quite in line with thoughts which I tried to express in my letter of 5 September. I certainly am not suggesting that my letter was responsible for this or other parts of the memorandum but it is gratifying to learn that others have arrived at views similar to mine, though better expressed.

I have only one area of concern or possible disagreement with the memorandum (or with the U. S. position for the WARC, etc.) and this relates to the discussion of orbit utilization, contained under "Technical Framework." I refer specifically to the statement that "even 10 or 12 U. S. satellites would represent a small fraction of the number which could be accommodated for western hemisphere use." Of course, I appreciate and agree with the intent, of counteracting undue concern about inefficient orbit utilization. To play the devil's advocate, however, one might ask how small is a "small fraction," and how large an arc might the western hemisphere use. COMSAT people in CCIR talk about satellite separations in the order of 5^{o}, based on the use of "standard" (90 foot) earth stations. On this basis, an 120^{o} arc for the Americas could accommodate about 24 satellites. Other nations would not consider 12 U. S. satellites to be "a small fraction!" To make matters worse, we talk about using 30 foot earth antennas in domestic systems, but orbit separation tends to increase in proportion to the antenna beamwidth, or in inverse proportion to the aperture. Thus, we might be talking about 10 or 12 satellites separated by about 15^{o} and I feel sure that this would worry our "good neighbors." A common "answer" to this concern is that we can use more highly directive antennas on the satellite to compensate for the use of smaller earth antennas. This is true, but only under restrictive conditions and to a degree which I have not yet seen established adequately.

Another threat to good orbit utilization is the trend toward "softening" the modulation (by lowering the FM deviation or using multi-phase PCM) in order to crowd more channels into the frequency band. In doing this, the separation between satellites must be increased out of proportion to the increase in channels per satellite, causing a decrease in channels per degree of orbit. Intelsat and others would like to continue crowding more channels into each satellite, because of the "second satellite problems" such as I discussed in London, in a paper which I sent you. Technically (by controlling modulation hardness, allowing the 10,000 pW noise budget to contain a larger fraction of adjacent satellite interference, etc.) it would be possible to make the 10 or 12 U. S. satellites be "a small fraction" (i.e. 10% or less) of those which could be used by the western hemisphere and to obtain correspondingly more channels from this part of the orbit. The trouble is that it seems easier and cheaper to waste this orbital capacity!

When I first wrote to you, last September I had been optimistic (or perhaps naive) in my expectation of constructive action by Study Group IV of CCIR at its impending meeting, but the results were (in my opinion) quite alarming. I can explain best by enclosing a draft copy (not for release!) of comments which I expect to make during a panel discussion at the AIAA Satcom meeting in Los Angeles, the 6th of April.

Finally, please do not construe these comments as a criticism of the memorandum. Rather, I am trying to look beyond it, toward helping you and other governmental "policy or position formers" to recognize the need for a stronger position on effective orbit utilization, in CCIR and especially at the forthcoming WARC. If you desire additional information or discussion, or if you wish to "set me straight," I will be delighted to see you whenever I next visit Washington. Unless I take off for Australia or elsewhere, this may be February 17-18.

Sincerely,

S. G. Lutz

Samuel G. Lutz
Chief Scientist

SGL:dw

Attachment (1)

Draft Paper for AIAA panel on "SPECTRUM FOR SPACE"

ORBIT UTILIZATION - FROM BOTH SIDES

by

S. G. Lutz
Hughes Research Laboratories
Malibu, California

Twentyfive years ago Arthur Clarke[1] called attention to the possibility of the geostationary satellite and that just three such satellites could be used to cover the inhabited portions of the earth. Today we finally have such a system, and perhaps we are starting to recognize that mere global coverage does not provide global telephone service - but this will be discussed later.

Since soon after Sputnik, it has been recognized[2] that many geostationary satellites should be able to reuse and thus share the same frequencies, if their earth stations use highly directive antennas. How many? About a hundred, based on conservative interference assumptions and the use of today's "standard" large antennas at 4 and 6 GHz, and many more if the need should become great enough and if cooperation between the satellite operators is adequate. Thus, we frequently consider this multiplicity of satellites, or of orbital stations, as providing a second dimension, orthogonal to the frequency dimension, in respect to satellite use.

It has also long been recognized that further reuse of the satellite communication frequencies should become possible whenever satellites can have ~~pencil/beam-antennas~~ very narrow antenna beams, capable of covering small areas of the earth. Although this technique could permit the use of more single-beam satellites with reduced orbital spacings, the use of multi-beam satellites seems probable.[3,4] Hopefully, this will provide an additional multiplication of satellite communication capability, hence another orthogonal dimension to the orbit/frequency "spectrum." Figure 1 is a representation of this 3-dimensional concept of the spectrum. A cylindrical coordinate system has been chosen, because the orbit is a closed dimension, with only 360 degrees, whereas the frequency axis is open-ended, to laser frequencies and beyond. Of course, only certain frequency bands are available, and even these are not equally useful.

Finally, the radial axis corresponds to frequency re-uses by independent (i.e., sufficiently separated) earthward beams. An adequate discussion of the potential usefulness of this earthward-beam axis would become involved ~~and speculative~~, or possibly controversial, so only a few pertinent comments will be offered here:

1. Frequency re-use by multiple earthward "spot" beams is a future possibility only. The state of the art in current development includes the provision of one narrow earthward beam from the 30 foot reflector to be carried by ATS-F and G, and the provision of two earthward beams, at <u>different frequencies</u>, from the two smaller reflectors on INTELSAT-IV.

2. In order to achieve adequate isolation, beam separations in the order of 10 beamwidths may be required - thus suggesting multi-spot applications to the exclusion of area coverage.

3. The narrowing of earthward beams encourages transmission at correspondingly higher EIRP to earth stations having correspondingly lowered G/T. This would amount to trying to substitute greater satellite antenna directivity for the economy of smaller earth antennas, but this would tend to nullify any re-use advantage. In this sense, it could be argued that this axis and the orbit axis are not independent. For the future, more study surely is needed. For the present we do not have

these problems because we do not yet have co-frequency multiple earthward beams.

Other techniques for improving orbit utilization have been studied, such as channel interleaving, use of orthogonal polarization, etc., but their potential benefits appear limited. It seems more important to examine briefly the role of modulation, or of its bandwidth expansion or "hardness" to interference, in relation to orbit utilization.

Such studies, of exploratory nature, seem to have started around 1966, but the first publication of thorough studies resulted from the Woods Hole summer study of 1967.[5] At its 1968 interim meeting, CCIR Study Group IV drafted Study Programme 2I/IV (also interim S.P.L.2.al) and an International Working Party IV/1 on "Technical factors influencing the efficiency of use of the geostationary satellite orbit by communication satellites sharing the same frequency bands." In the U. S., the studies and preparation of documents was handled by a special working party, designated IV-S and staffed largely by COMSAT. This group produced nearly 30 documents for the Ottawa meeting of the IWP in June. The 7 other participating nations submitted a total of only 13 such documents. In a 3 day meeting, the IWP produced a report, designated CCIR IV/334, which was revised by the subsequent interim meeting (September 1969) as CCIR IV/432. More will be said later about these.

One document of special significance, IV/294, resulted from COMSAT studies and later formed the basis for a paper[6] at the London Conference on Digital Satellite Communication. Unfortunately IV/294 was classed as an information document, so it will not appear in CCIR's printed "green books."

Although these studies of efficient orbit utilization have uncovered a few possible surprises, in general they have confirmed conclusions which seem intuitively obvious. For simplicity, the following discussion will assume a homogeneous orbit system of identical equi-spaced satellites, with single earthward beams all directed at the same point. Orbit utilization will be measured in voice channels per MHz and per orbital degree and will be influenced (in order of importance) by

1. Earth antenna "size" (D/λ), hence its gain and 3 dB beamwidth.

2. Modulation, bandwidth expansion ratio (modulation"hardness" to interference, FM index).

3. Ratio of interference to thermal noise.

4. Earth antenna sidelobe decay rate.

5. Other factors, such as use of cross polarization, channel interleaving, etc.

We will concentrate attention on the effects of the modulation hardness, or its bandwidth expansion, and on the interference ratio. These two parameters influence orbit utilization in ways which can be, shall we say, unpopular with satellite system planners and operators. It is quite understandable that these people are more interested in voice channels per satellite, and per dollar, than in channels per degree of orbit! The effects of the earth antennas and their sidelobes are of major importance too, but these seem more visible and easier to understand.

Figure 2* shows how satellite channel capacity increases with the sum of the satellite EIRP and the earth station figure of merit, G/T, assuming FDM-FM, single carrier per repeater, negligible guard-bands and a 10 dB peak-to-r.m.s. ratio. Within the steep sloped power limited region (where all Intelsats operate, thus far) a small increase in the satellite EIRP (or earth station G/T) produces a relatively large increase

* From CCIR Report 211-2 (1970) Fig. 3 or Fig. 5.

in channel capacity. Beyond, in the progressively flattening bandwidth-limited region this rate of capacity improvement dwindles. Nonetheless, this bandwidth-limited region is one of intense interest, because of the advent of multi-repeater satellites with higher gain (narrower beam) antennas, such as Intelsat IV.

Figure 3* gives a quite different picture of bandwidth-limited operation using the bandwidth expansion ratio as the abscissa. Here, one sees the tremendously greater signal to noise (and/or interference) ratios required as the bandwidth expansion is reduced, in order to pack in more channels. Increasing the bandwidth expansion lowers this S/N requirement by the familiar "FM improvement" making it "harder" with respect to interference. The second curve relates orbit utilization to the bandwidth expansion ratio, on an interference-limited basis. The dashed lines which cut this curve show the required minimum geocentric angles between satellites when only standard (90 foot) earth antennas are used. Clearly, crowding in more channels by softening the modulation is like inflation, or alcohol: a little may seem desirable and justifiable, but an excess could be tragic.

Moreover, this figure suggests unrealistically high utilization of the orbit because it assumes satellite signals so strong that their interference would dominate, making thermal noise negligible. Actually, the CCIR is recommending[7] that, of the circuit's 10,000 pWp0 total of noise, not more than 1,000 pWp0 be interference from other satellites and their earth stations. Thus, this limits the interference to thermal noise ratio to 1/10 or less.

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* From Fuenzalida's Figures 1 and 3 (loc. cit) or CCIR Report IV/294 (1969) Figs. 1 and 5.

Figure 4* shows the effect of this ratio, ρ, for values greater than 1/10, assuming constant modulation hardness. The recommended $\rho \leq 1/10$ leads to satellite separations more than 2.6 times greater than for the interference-limited ($\rho=\infty$) assumption used in Fig. 3. Note particularly that permitting the interference to equal the thermal noise (i.e., ρ=1.0) would bring the satellite spacing to within 16% of its minimum, at the cost of only 3 dB in additional satellite EIRP, an increase which otherwise will be used to crowd in a few more channels, at a waste of more channels per unit of orbit arc. Higher interference ratios clearly are insufficiently rewarding, and many may feel the same about ρ=1.0. However, it seems ~~grossly~~ inconsistent for the CCIR to study and (presumably) to encourage efficient utilization of the orbit, while at the same time recommending such a wastefully-low interference ratio.

Now, let us approach orbit utilization from the opposite view, that of application and planning. Here we will see quite a different situation, one which often is in conflict with these principles of efficient orbit utilization, or even with the corresponding concept of intelligent waste of the orbit. We will ~~first~~ consider uses of the 4 and 6 GHz band, because it is the "now" band from an economic viewpoint.

Thus far, Intelsat is the sole commercial user of this band, in which it finally has implemented the 25 year old concept of a three satellite global system. Now we are recognizing some of its problems or limitations. For telephony, it is not global in terms of one-hop circuits. European stations can't see the Pacific satellite and we can't see the

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* Replotted from Fuenzalida's Figure 4.

Indian Ocean one. Latin America sees only an Atlantic satellite and its calls to Japan must go two-hop, or via trans-Pacific cable. Another problem is that of growth, to more than three satellites. ~~Another~~ A second Intelsat III is needed because the Atlantic traffic is overloading the first one, but which nations should use it and which should ~~not~~ continue using the first? Only the U. S. has earth stations ~~for~~ for the use of both satellites, ~~and for~~ giving us direct access to all Atlantic stations. Otherwise the Atlantic will be so divided that only three European nations will have access to Latin America while two other European stations will have access to Africa, the Near East and to Canada.

If further traffic growth were to require four or more Atlantic satellites, someday, and if they were to be used similarly by single-station nations, multiple access or interconnectivity would be greatly reduced. By analogy, one can think of a city which (years ago) was first served by a single telephone exchange, but which soon needed several. If these exchanges ~~were~~ had not been ~~not~~ interconnected, would people have used a separate telephone for each exchange?! One hopes that Intelsat will profit from this aspect of telephone history and progress to a better global system philosophy, that of a system with growing numbers of satellites at <u>all</u> parts of the orbit.

Today, however, Intelsat shows a proprietary interest in only three parts of the orbit; for its Pacific and Indian Ocean satellites and, eventually perhaps, for several Atlantic satellites. But, because several multiple such satellites seem to require multiple earth stations, Intelsat seems to favor a minimum number of progressively larger satellites, even though their use would result in fewer channels per unit of orbital arc.

As to the rest of the orbit, between these Intelsat arcs, the general view seems to have been that it would be used for various "domestic" or "regional" systems. In a few such systems, telephone service might be justified, but there often are economic and other deterrents. Systems for the distribution of television have aroused considerable interest, especially when proposed for "educational" TV. Also, "data transmission" has imagination-appeal, especially for computerized education. The practical situation, however, is that no such systems are beyond their planning stage, with most still in the "nationalistic dream" stage. Consequently, there is not yet a vested interest, or invested interest in protecting and developing the non-intelsat arcs.

At this point it might seem appropriate to discuss some of the many proposals for systems using "smaller" (lower D/λ) antennas, and especially those intended for use at lower frequencies. These range from aeronautical and data collection systems at VHF, having negligible earth antenna directivity and correspondingly low orbit-occupancy, to ones using 45 foot or 60 foot antennas at 4 and 6 GHz or above. However, such a discussion would digress and tend to distract us from the roles of modulation hardness and interference to noise ratio and from how these roles may be viewed from both sides.

Instead, let us now examine how these two views come together; that of orbit and spectrum conservation versus that of design freedom and expediency. We might better ask what happens when efforts are made to compromise these views, as seems to have been the objective of CCIR's International Working Party. Its 39 page report[8] disposed of the interference to noise ratio in Par. 5, from which we quote:

"..... Several documents provided graphs showing the way in which total orbit capacity would rise, though at a progressively slower rate as the proportion of the total noise allowed for interference increased. Six of the eight members of the Working Party considered that a total amount of interference noise of 1000 pWpO in a telephone channel should be allowed, possibly on a provisional or temporary basis. Two members expressed the view that initially a small proportion (perhaps less than 1000 pWpO) of the total noise should be allowed for interference, but that at a later stage it might be necessary to increase this allowance (perhaps up to half of the total noise) when problems of congestion in the orbit arise.

"However, there was a general view that the performance of any system should always be under the virtual control of the system designer and most members felt this argued in favor of a limit no greater than 1000 pWpO."

The need for reasonably hard modulation, and the consequences of over-crowding the repeaters with channels by reducing the deviation and bandwidth expansion excessively were disposed of as being one of the "other factors affecting the number and location of geostationary satellites." This Par. 7.1 reversed the emphasis in the following words.

"From some economic and operational points of view, a proliferation of satellites within any total system is undesirable and the best economic results can be obtained when the satellite is made as sensitive and as powerful as present technology permits. From a purely technical point of view, the most efficient orbit utilization is achieved by using a high density of relatively low-capacity satellites. Since the technical and economic efficiencies indicate opposing trends, a compromise may be required to provide both economic viability and reasonable technical efficiency of orbit utilization."

At the September 1969 Geneva meeting of Study Group IV, this and other documents were revised, for approval by the CCIR Plenary session and publication in the next issue of the "green books." In the revised version[9] Par 5. retained the admission that:

"Studies of the effect of inter-satellite interference noise allocation indicates that the orbit capacity would rise, though at a progressively slower rate as the proportion of the total noise allowed for interference is increased."

Then, lest someone later propose that satellite operators might sometime be asked to donate a dB or two of their soaring satellite EIRP's to permit fuller use of the orbit by other nearby satellites, it continues as follows:

> "However, an increase in interference noise generally reduces the capacity of the individual of the individual satellites. It is therefore obvious that large interference noise allocations are an economic burden to satellite system operators. It is also important to ensure that the performance of any system should always be under the virtual control of the system designer.
>
> "This implies that the interference noise allowance should not be set at too high a level when satellites of systems operated by different administrations may occupy neighboring parts of the orbit."

Continuing to Par. 7.1 one finds it has been completely rewritten, eliminating the slightest mention of modulation hardness in the vigor of the defense against interference. It now reads:

> "From some economic and operational points of view, a proliferation of satellites within any system is undesirable. For very efficient orbit utilization, the satellite systems would have to operate in an interference limited mode but this would present many difficulties including that of unfavorable economics. Since the technical and economic efficiencies indicate opposite trends, a compromise may be required to provide both economic viability and reasonable technical efficiency of orbit utilization."

A final observation is that the CCIR is supposed to be a technical consultative committee, which on convenient occasions cites its "terms of reference" to suppress economic analyses. In this case, however, it appears that most of the technical analyses will be suppressed from publication in the CCIR green books by having classified its source documents, such as IV/294, as being merely "information documents."

Perhaps the 1000 pWpO of interference is all that the CCIR would even agree to recommend. Perhaps we also may hope that satellite system designers and operators will show some restraint in not resorting to excessively low FM deviations, or to using 32 phase PCM, to gain a few more channels per satellite. Possibly the forthcoming ITU World Administrative Radio Conference may (somehow) find effective means to curb wasteful use of the orbit. One might have more hope of this, however, if the technical studies and results were publicized in a clear and impartial manner.

References

1) Arthur Clarke, "Extraterrestrial Relays...." Wireless World, Vol. 51 pp. 305-308, October 1945.

2) S. G. Lutz, "An Eventual Satellite Communication System," IRE Transactions, PGSET, 1960 National Symposium on Space Electronics and Telemetry, Paper 2-4.

3) "An Integrated Space/Earth Communications System to Serve the U. S.", AT&T Proposal, submitted to the FCC in response to Docket 16495, 1966.

4) W. G. Schmidt, "An On-Board Switched Multiple-Access System for Millimeter Wave Satellites." Intelsat/IEE International Conference on Digital Satellite Communication, London, November 25-27, 1969, pp. 399-407.

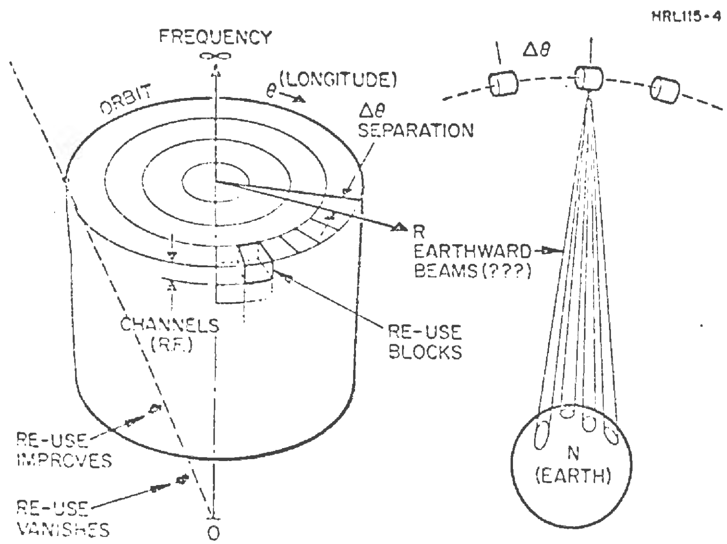
5) "Useful Applications of Earth-Oriented Satellites," National Academy of Sciences, 1969, Volume 9. See Appendix D, Sections D.2, by W. E. Bradley, and D.3, by H. W. Evans.

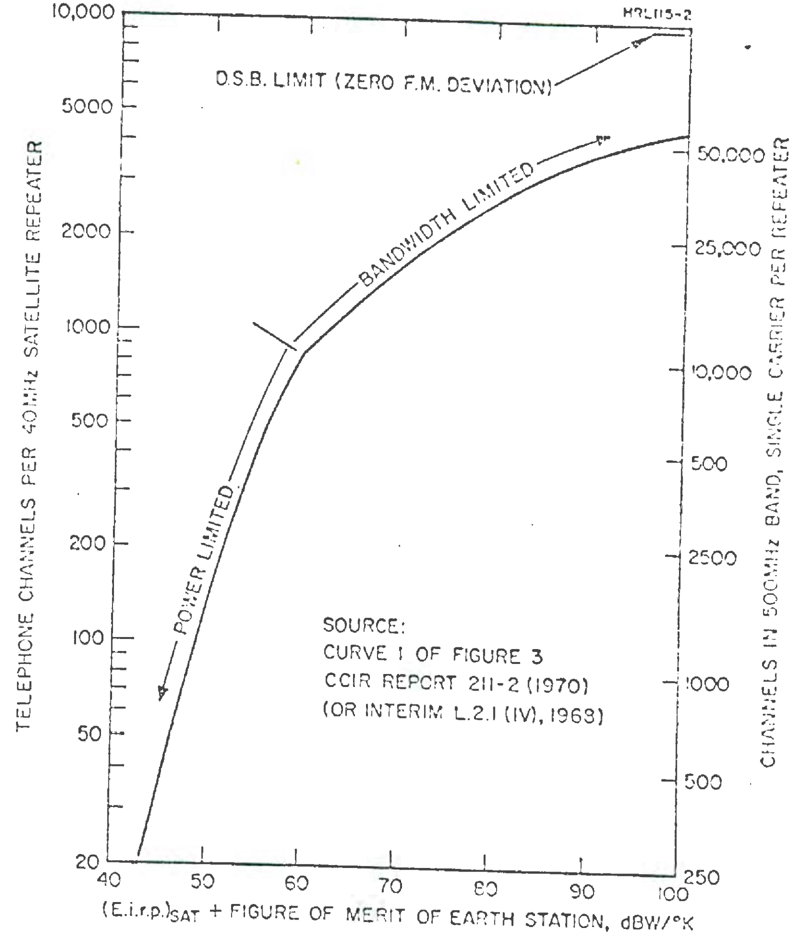
6) J. C. Fuenzalida, "A Comparative Study of the Utilization of the Geostationary Orbit," IEE International Conference on Digital Satellite Communication, London, November 25-27, 1969.

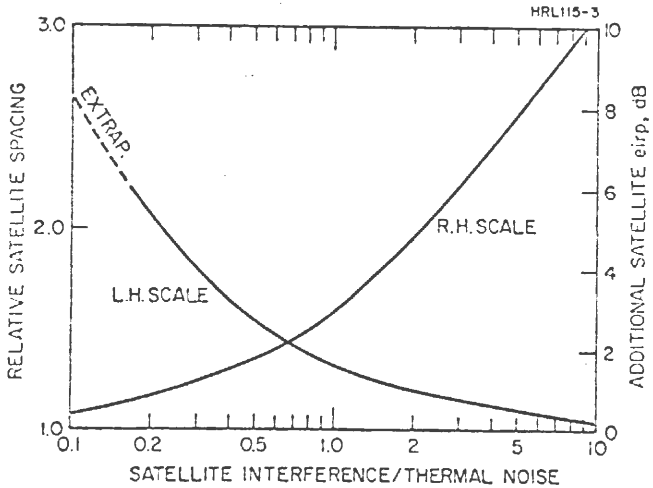
7) New Recommendation. See CCIR Doc. IV/427 (September30, 1969, or "pink" Doc. IV/1008 (October 8, 1969).

8) CCIR Doc. IV/334, 4 July 1969.

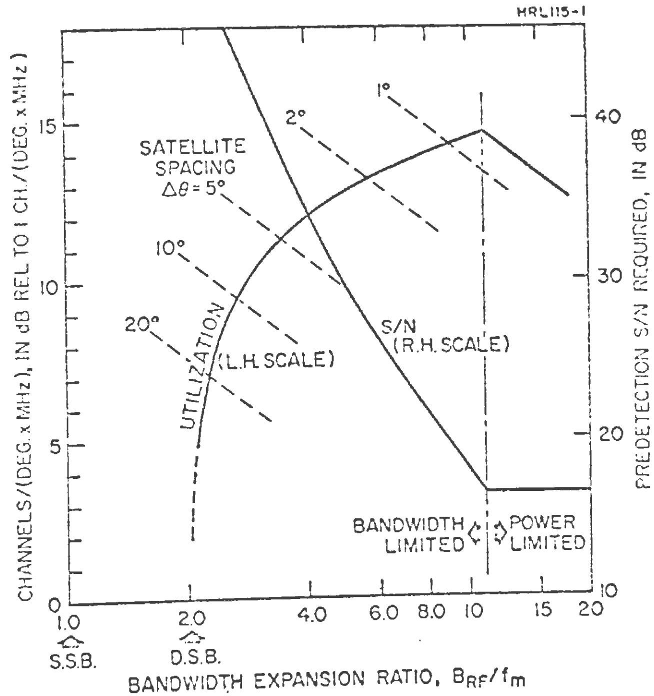
9) CCIR Doc. IV/432, 30 September 1969.


HRL115-4
FREQUENCY
∞
ORBIT
θ (LONGITUDE)
Δθ
SEPARATION
R
EARTHWARD
BEAMS (???)
CHANNELS
(R.F.)
RE-USE
BLOCKS
RE-USE
IMPROVES
RE-USE
VANISHES
O
Δθ
N
(EARTH)


HRL115-2
D.S.B. LIMIT (ZERO F.M. DEVIATION)
BANDWIDTH LIMITED
POWER LIMITED
TELEPHONE CHANNELS PER 40MHz SATELLITE REPEATER
CHANNELS IN 500MHz BAND, SINGLE CARRIER PER REPEATER
10,000
5000
2000
1000
500
200
100
50
20
50,000
25,000
10,000
500
2500
1000
500
250
40
50
60
70
80
90
100
(E.i.r.p.)SAT + FIGURE OF MERIT OF EARTH STATION, dBW/°K
SOURCE:
CURVE 1 OF FIGURE 3
CCIR REPORT 211-2 (1970)
(OR INTERIM L.2.1 (IV), 1963)


HRL115-3
RELATIVE SATELLITE SPACING
ADDITIONAL SATELLITE eirp, dB
EXTRAP.
L.H. SCALE
R.H. SCALE
3.0
2.0
1.0
10
8
6
4
2
0
0.1
0.2
0.5
1.0
2
5
10
SATELLITE INTERFERENCE/THERMAL NOISE

4


HRL115-1
CHANNELS/(DEG. x MHz), IN dB REL TO 1 CH./(DEG. x MHz)
PREDETECTION S/N REQUIRED, IN dB
SATELLITE SPACING $\Delta\theta = 5°$
1°
2°
10°
20°
UTILIZATION (L.H. SCALE)
S/N (R.H. SCALE)
BANDWIDTH LIMITED
POWER LIMITED
15
10
5
0
40
30
20
10
1.0
2.0
4.0
6.0
8.0
10
15
20
S.S.B.
D.S.B.
BANDWIDTH EXPANSION RATIO, B_{RF}/f_m

3