The Lenkurt
AUGUST 1970
DEMODULATOR

MTBF
MTTR

innage
outage

reliability
availability

99.9999%

some aspects of microwave system reliability

The following is the essential text of a talk given by Mr. R. F. White, a senior staff engineer at Lenkurt Electric Co., Inc., at the International Conference on Communications held in San Francisco in June, 1970. Because of the outstanding clarity of the discussion, and because the article is of general interest to communication systems users, it is being printed here for the benefit of all *Demodulator* readers.

In recent years the objectives for total reliability in microwave communications systems have become rather staggering. One example is the Bell System's stated objective of 99.98% *overall reliability* on a 4,000 mile system, which breaks down to an allowable *per hop outage* of about 25 *seconds* per year. Users of high reliability industrial systems are also talking about average per-hop reliabilities in the order of 99.9999%, or about 30 seconds per year, for their long-haul microwave systems.

This discussion is mainly concerned with the ways in which such microwave system reliabilities are being described, specified, and calculated, and with some apparent problems in some of the methods commonly used.

The microwave industry has long been accustomed to making estimates and calculations of outages due to propagation, using empirical or semi-empirical methods.

The results are usually stated either as a per hop annual outage, or as per hop reliability in percent. And it is interesting to note that calculations using these empirical methods indicate that by the use of suitable path engineering and diversity, it is possible to achieve propagation reliabilities in the above mentioned range.

Calculation methods for estimating the probable reliability of a microwave hop with respect to *equipment* outages have also come into the picture in recent years, using the principles and practices developed by reliability engineering experts in other fields.

It has also become fairly common practice to express the calculated equipment reliability results for microwave systems in terms similar to those used to describe propagation reliability in percent as the term is commonly used by microwave engineers, or as a per hop "availability." (The latter term as used in reliability engineering is the ratio, over the period of interest, of the innage time to the total time.)

A natural extension of this practice is to add the per hop annual outages for equipment and for propagation together to get an overall outage to be used as a reliability "figure of merit" for the hop.

This discussion will attempt to show that *none* of these parameters —per hop annual outage, per hop reliability in percent, or per hop availability— provides an adequate description of the *equipment* reliability performance in the case of ultra-reliable systems. It follows, of course, that if this is so, the "overall total reliability" concept and figures of merit are equally unsatisfactory.

Microwave equipment availability or outage calculations always rest in the end on two basic concepts: the "mean time between failures" (MTBF) and the "mean time to restore" (MTTR). The relationship between the two determines the outage ratio. (MTTR will be assumed to include notification time, travel time, diagnosis time, as well as the actual time to repair or replace the failed item. Thus, in this paper, it represents the actual average length of outage associated with a failure event.)

In high-reliability systems the relationships become quite simple, as shown in Figure 1.

The "innage ratio" is the term called "availability" by reliability engineers. Multiplied by 100 to convert it to percent, it is the "reliability" as used by microwave engineers.

Figure 2 shows how these parameters might look in a more or less typical *non-redundant* microwave hop.

The 5,000 hour figure in the denominator is an assumed value for the MTBF of all the equipment of a non-redundant microwave hop; it would correspond to an average of roughly two failures per year, and since the hop is non-redundant, each would be an actual outage.

A value of 5 hours is assumed for the MTTR, and as stated above, this is taken to mean all the time from the instant of failure until the equipment is restored and back in service.

These assumed values were chosen primarily for mathematical ease and are not intended to represent any actual system. This applies to any other values used.

What happens with a *fully redundant* configuration? Here, for simplicity, it is assumed that the non-redundant equipment is simply duplicated and that a perfect automatic sensing and switching system is provided. An MTBF of 5,000 hours for each side of the redundant configuration and an MTTR of five hours for any equipment failure are also assumed. Note, however, that in the redundant system, a single or one-side equipment failure will not cause an actual system outage. Only two simultaneously existing failures, one on each side, can do this.

One further assumption is made in Figure 3, that failures on the two sides are totally random and independent.

$$\text{OUTAGE RATIO } (U) = \frac{MTTR}{MTBF}$$

$$\text{INNAGE RATIO } (A) = 1 - U$$

$$\text{ANNUAL OUTAGE} = 8760 \times U \text{ hrs.}$$

Figure 1

NON-REDUNDANT

$$U = \frac{5}{5{,}000} = .001 \text{ or } 0.1\%$$

$$A = 1 - .001 = .999 \text{ or } 99.9\%$$

$$\text{ANNUAL OUTAGE} = .001 \times 8760 = 8.76 \text{ hours}$$

Figure 2

REDUNDANT WITH ASSUMPTIONS

$$(MTBF)_{red} = \frac{(MTBF)^2}{MTTR}$$

Hence,

$$(MTBF)_{red} = \frac{(5{,}000)^2}{5} = 5{,}000{,}000 \text{ hours} = \text{about } 570 \text{ years}$$

Figure 3

These mathematics illustrate that, given these assumptions, the average time between outages (actual system failures) on this hop would be *570 years.*

Continuing with the same redundant example, Figure 4 gives the equation for calculating the outage ratio, U_{red}, for the redundant hop, and the actual calculation for this example.

This now represents a completed calculation which says, given all these assumptions, the equipment reliability characteristic for this hop can be described as 32 seconds of outage per year.

But, this figure of 32-seconds-per-year average outage is only a mathematical abstraction. Since an outage is by its very nature indivisible, there can only be, in any given year, either *no outage at all*, or an outage which, under the assumptions used, must be very much longer (5 hours per failure event in this model). Neither of these conditions –no outage or 5 hours outage– has any real relation to an annual outage of 32 seconds, and consequently the 32-second figure is a very inadequate way of describing this situation.

Figure 5 re-emphasizes the point that whenever the expected outage (MTTR) associated with a failure event is relatively large, the occurrence of such failure events must be extremely rare (MTBF very large)–if ultra-high reliability is to be achieved.

In real life microwave systems there are constraints imposed by the fact that the sytems (at least the long-haul ones where ultra-reliability is most urgently needed) involve unattended repeater stations spread over rather considerable geographic areas, and often in relatively inaccessible locations. This makes it rather unrealistic to assume that the average restoration time, even under favorable conditions, will be less than 1 or 2 hours. Travel time alone will often be greater than this, particularly for failures at isolated points occurring at night or on weekends. In fact, the mathematically convenient assumption of 5 hours may be overly optimistic.

A restoration time measured in hours must be accompanied by equivalent MTBF's measured in millions of hours (hundreds of years) in order to show calculated reliability in this range of 99.9999% per hop.

REDUNDANT – WITH ASSUMPTIONS

$$U_{red} = \frac{MTTR}{(MTBF)_{red}} = \left(\frac{(MTTR)}{(MTBF)}\right)^2 = \left(\frac{5}{5{,}000}\right)^2 = .000001 \text{ or } .0001\%$$

$$A_{red} = 1 - .000001 = .999999 \text{ or } 99.9999\%$$

$$\text{ANNUAL OUTAGE} = .000001 \times 8760 = .00876 \text{ hours}$$
$$= \text{about 32 seconds}$$

Figure 4

FOR 99.9999% RELIABILITY

MTBF MUST BE ONE MILLION TIMES THE MTTR!

e.g., If repair time is five hours, MTBF must be 5,000,000 hours (570 years).

If repair time is one hour, MTBF must be 1,000,000 hours (114 years).

Figure 5

This, coupled with the fact that it is impossible to have a fractional failure in a real system but only integral ones, is the real crux of the problem being discussed.

It has been shown how our example of a redundant hop could calculate out to an average per-hop annual outage of 32 seconds due to equipment. But it must be recognized that in a real system this is a meaningless value which cannot exist except by a wildly unlikely set of coincidences. Even if the analysis and the assumed parameters and conditions were precisely correct, the hop would have to be operated for at least 570 years in order to get even a minimum test, and in that time we get 569 years with zero outage and one year —which could be anywhere along the line— with 5-hours outage. Thus, "annual outage" is quite meaningless, and even the availability or reliability parameters would be meaningful only for the average performance over something like 10,000 years, or 10,000 hops.

The situation is quite different with respect to propagation outages and the kind of difference is shown in Figure 6. Here, a simple propagation situation has been made up which also leads to the same annual outage.

The propagation outages shown are based on a simple assumption of a diversity path with a 40-dB fade margin, Rayleigh fading on each side, and a diversity improvement factor of about 100. Under these assumptions, each side of the diversity would have a reliability of about 99.99% or about 53 minutes of outage per year, consisting of perhaps 1,000 individual hits averaging on the order of 3 seconds

	PROPAGATION	EQUIPMENT
# ONE-SIDE FAILURES PER YEAR	*1,000*	*2*
# OUTAGES PER YEAR	*20*	*1/570*
AVERAGE LENGTH OF EACH	*1.5 sec.*	*18,000 sec.*
TOTAL ANNUAL OUTAGE	*30 sec.*	*about 30 sec.*
RELIABILITY	*99.9999%*	*99.9999%*

Figure 6

each. The diversity improvement factor of 100 to 1 would lead to about 20 simultaneous hits per year, that is, 20 actual outages, each averaging about 1.5 seconds in length.

The 20 or so simultaneous hits, giving a total annual outage of about 30 seconds, constitute enough events to provide a reasonably adequate statistical population over a year, so that results expressed in this way are quite meaningful and can be related to real-life systems.

But the situation is quite different in the equipment column, in which there are about 2 one-side failures per year, and about 1/570th of an actual outage per year, so that the annual outage is 1/570th of 18,000 seconds, or about 30 seconds.

The difference in scale and sample size between the two situations is about 10,000 to 1, and it is clear that, despite the fact that in both cases there is a calculated annual outage of 30 seconds, the two types of outage are in fact totally and radically different in nature and cannot be usefully combined or treated in a similar fashion.

Twenty outages per year, each averaging less than two seconds, and one outage of several hours occurring only once every five or six *centuries* simply have nothing in common with each other.

The point is that in such ultra-reliable cases, the propagation reliability and equipment reliability of microwave hops must be treated and described separately.

Annual outage remains a good way to describe the propagation reliability. Availability, or reliability in percent, is equally good. It would be useful, however, to include information about the number of events and their average duration, the annual outage being the product of the two.

For equipment reliability, two alternative methods seem to have some merit, though neither is entirely satisfactory.

One is simply to state the equivalent system MTBF as a parameter. In the case of ultra-reliable systems this is usually the redundant MTBF. Preferably the MTBF in hours should be divided by 8760 and the result stated in years, since it is easier to relate to the real world. A statement that the MTBF of a microwave hop is 570 years is likely to arouse some skepticism on the part of engineers familiar with electronic equipment; whereas, a statement that it is 5,000,000 hours might not have the same impact.

A second possibility would be to use this equivalent redundant MTBF to calculate the probability that the hop will operate without failure for a period of a year, using the standard reliability formula as given in Figure 7.

The expression R(t) gives the reliability function in the nomenclature used by reliability engineers; that is, the probability that the device under consideration will operate without failure for a time t.

Summing up, the equipment reliability calculations, in situations of this type, are really saying that there is a very high probability that the outage due to equipment in any year will be zero, but if such an outage does occur, it will be very long (comparatively) and will probably use up the allocated outage time for hundreds, perhaps thousands of years.

This poses the very serious problem that if —as is very likely to happen— equipment reliability prognostications, showing average per-hop outages of seconds, or even a few minutes, per year, somehow get turned into specification requirements (rather than just calculations or estimates), the supplier is faced with the awesome realization

$R(t) = e^{-t/MTBF}$

Which for a t of 8760 hours and MTBF of 5,000,000 hours comes to 99.825%.

For MTBF of 1,000,000 hours, R comes to 99.124%.

Figure 7

that the only way he can meet such a specification at all, over any time period of interest —even the entire life of the equipment in some cases— is to have zero outages due to equipment.

Another serious —though perhaps less apparent— problem is that there is no evident way to make any realistic evaluation of the relative worth of simply changing the odds that there will or will not be an outage. For example, suppose one has a hop with a predicted probability of one outage every 100 years. How much would it be worth to reduce the outage probability to one every 600 years? In either case any outage in a year, or even over the life of the equipment, is highly unlikely, and in either case, if an outage does occur, its length will be the same— the X hours it takes to repair and restore the equipment.

The limitation discussed here is a basic one which does not depend at all on the validity of the assumptions or the calculations. It results simply from three things: microwave systems distributed over wide geographical areas; repeater stations (and often terminals as well) operated on an unattended basis; and outages due to equipment failure (unlike those due to propagation) requiring human intervention to restore and consequently, in general, requiring a rather large block of outage time associated with any outage event.

Regardless of the means used to describe it, there seems to be a parameter, with respect to equipment outages, which describes a situation that cannot exist in the real world, cannot be measured, and to which it is difficult to assign any economic or monetary value.

A further consideration is that the models customarily used in making equipment MTBF calculations consider only those outages or failures caused by chance, random failure of individual components for which no cause can be determined, and thus exclude most of the failures which occur in real systems— for example, failures due to human error in the design, the manufacture, the installation, the operation, and the maintenance areas; "early" or burn-in failures; wear-out failures; or unusual stress situations affecting both sides of a redundant system. Therefore, it is apparent that such *a priori* equipment reliability calculations should be treated with considerable caution.

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The *Lenkurt*®

JULY 1970

DEMODULATOR

Domestic Satellites

. . . . . . a versatile, reliable national communications network just over the horizon.

Synchronous, geostationary satellites capable of directing signals to a network of earth stations scattered throughout the United States is the image portrayed by a domestic satellite system (see Figure 1). Such a system could serve populous areas where the demand is greatest, or provide communication links to areas which are not now easily accessible with terrestrial methods.

The proposed system would provide communications for all areas within the country, and could someday be interconnected with trans-oceanic cable and international satellites to overseas points, making it possible for today's telephone user, even in remote areas, to reach 188 million telephones – 96 percent of the world's total.

Open Competition

The development of a domestic satellite system in the U. S. has been delayed pending the outcome of a government study. The results of this study have now been presented in the form of a Presidential memo suggesting the FCC give approval to any organization seeking to construct and operate a domestic satellite system, provided it meets certain guidelines.

The memo further suggests establishing a three- to five-year interim policy allowing competition to act within well defined limits to protect public interests.

Literally interpreted, the Presidential memo gives anyone with the funds and technology the opportunity to launch and operate a domestic satellite system, provided standards of compatibility are met and anti-trust laws are not violated. Specifically, the recommendations deal with financial ability, launching capability, room in space, and available frequencies.

When satellites are designed to fit a domestic network, they must compete, costwise, with existing service. Satellites can provide circuit performance and capacity equal to coaxial cable, digital systems and millimeter wave systems.

A satellite system able to compete economically with terrestrial facilities will have a limited number of drop-off points (earth stations). The earth stations should be limited for two reasons – cost and channel capacity. The channel capacity decreases with increasing station access; therefore, each earth station will have to gather traffic from a large area.

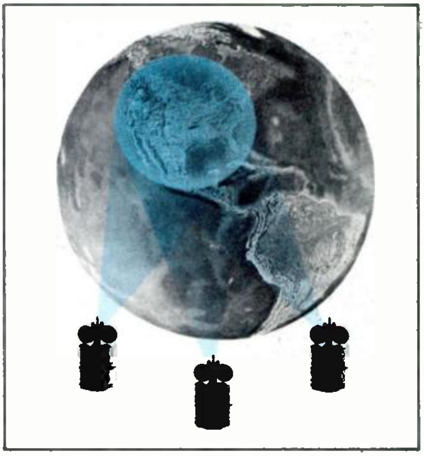


Figure 1. A domestic satellite system would use a series of synchronous, geostationary satellites for communication with all parts of a country.

The private enterprise approach to domestic satellite service may lead to a variety of special purpose systems. Three general plans are being considered, each in a different frequency range – 4 and 6 GHz, 10 to 40 GHz, and 30,000 GHz. The first system would operate in the 4- and 6-GHz range – presently used for most terrestrial radio transmission and for international satellite systems involving a few remotely located earth stations.

Radio Interference

Radio interference can be a serious problem if there is an extensive microwave network near the earth satellite station. This condition is typically found in the proximity of urban centers. In the United States, the proliferation of 4- and 6-GHz terrestrial systems makes these undesirable for satellite use. However, there are not as many 4- and 6-GHz terrestrial links in Canada, and their proposed system, using these frequencies, expects to avoid radio interference by placing the earth stations outside the metropolitan areas. Even with the interference shielding offered by hills, it will probably be necessary to place earth satellite stations 50 to 100 miles (80 to 160 kilometers) from urban centers.

Radio interference affecting a U.S. domestic satellite system operating in the 4- and 6-GHz region is shown in Figure 2. The greatest interference is between the 4-GHz radio relay transmitter and the highly sensitive earth station receiver, and between the high-gain earth station transmitter and the 6-GHz radio relay receiver.

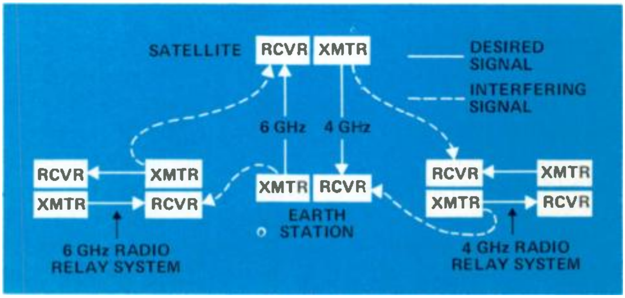
International studies are in progress to find ways to avoid radio interference, with emphasis on the possible selection of preferred or segregated frequency assignments for satellite communication systems. The bands under study are above those generally used for terrestrial microwave systems. If exclusive assignments can be made for satellite service, earth stations can be placed near large centers where most circuits will be terminated.

Bell has studied a system that operates in the millimeter-wave frequency range between 10 and 40 GHz. Radio interference is no longer a hindrance with such a system. Atmospheric attenuation, however, is a much more serious problem, since electromagnetic waves in the frequency bands above 10 GHz are severely attenuated by rain and water vapor.

Atmospheric Attenuation

A domestic satellite system operating above 10 GHz must be designed to withstand a few dB of attenuation due to atmospheric conditions – sometimes for long periods – and must have a diversity earth station for the rare occasions when excessive rainfall causes large attenuation (see Figure 3). According to studies, the most intense rain occurs in limited

Figure 2. Radio interference is a serious problem when the earth station for a 4- and 6-GHz satellite system is located near an area with 4- and 6-GHz radio relay systems.



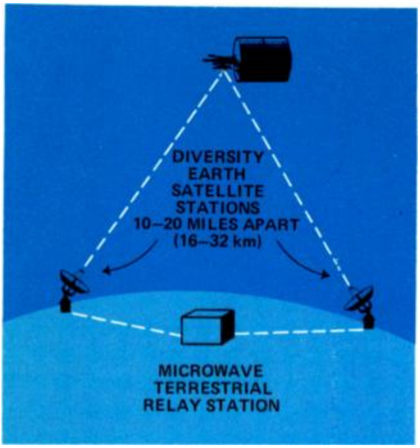


Figure 3. Diversity earth satellite stations avoid signal attenuation when heavy rainfall occurs.

cells, and rain covering large areas (several square miles) generally falls at the low rate of one inch per hour or less. Therefore, diversity earth stations separated by several miles have been proposed as a workable solution to atmospheric attenuation.

A third possible ground-to-satellite link would use a CO_2 laser. Such a system is not hampered by radio interference, and has a high tolerance against atmospheric attenuation. Although the frequency of a CO_2 laser (30,000 GHz) is higher than millimeter-waves, there is a transmission window, 40-GHz wide, centered at 30,000 GHz. This frequency, therefore, is less susceptible to attenuation than any in the visible or ultra-violet ranges. The CO_2 laser has also been suggested as a means of providing efficient inter-satellite communications – links between domestic and international systems

Time Delay and Echo

Long time delay and the associated echo became apparent with international geostationary communications satellites. The minimum distance between any two points via a geostationary satellite is 44,600 statute miles (72,000 kilometers). Consequently, a U.S. circuit via satellite will have a round trip delay of more than one-half second compared with about one-tenth second delay for terrestrial cross-country transmission in the U.S. This delay is due to the distances involved and the resulting transmission times.

The speaker's echo tolerance depends on the delay time and the loudness of the echo. There are two ways to suppress the echo within tolerable limits. One form of suppression is to attenuate the echo – making it barely noticeable compared with the speaker's voice. As time delay increases, the echo attenuation must also be increased. A voice-activated switching device can also be used in the return circuit to keep the echo from reaching the speaker.

In the early 1960's, Lenkurt Electric, Bell Laboratories, and the Dollis Hill Laboratories of the British Post Office were studying the effects of delay, echo, and echo suppression. These studies resulted in specifications for new suppressors designed for long-delay circuits. Lenkurt's 931C echo suppressor was designed to meet these specifications and is capable of compensating for delays of the magnitude encountered with satellite links.

Artificial delays were used in a simulated telephone test circuit carrying regular telephone traffic. These experiments began to show slight adverse public reactions to calls with a round trip delay of about 300 milliseconds, and a significant increase in adverse reactions with a round trip delay of about 500 milliseconds.

Three different situations arise with long delays which may be disturbing, but are tolerable. The first of these is called "simultaneous talking." If both parties start talking within one-quarter second of each other, both will continue talking until one party finally notices the other and ceases talking. When this happens, neither party will hear what the other has said.

"Hello calling" is the second condition encountered with long delays. When one party has been talking for some time, or has come to the end of what he wanted to say, he usually pauses and expects a response from the other party. This response may be delayed because the other party hesitates before answering. With the added satellite delay the talker may become impatient and start calling "Hello," indicating he is wondering if the other party is still on the line, or if the connection has been broken.

"Break-in difficulties" characterize the third delay situation. One of the parties may wish to start talking by taking advantage of a short pause in the other's speech. Therefore, he waits for a breathing pause by the other party. In a satellite call, it will take him about one-quarter second to note the pause. By the time his comments reach the original speaker, a minimum of another quarter second later, the latter may have resumed speaking. This condition is compounded if it leads to "simultaneous talking."

Although the distance to the moon is greater than it would be to a geostationary domestic satellite, most people were made aware of these long delays with the telephone conversation to the moon during the Apollo XI moon landing. All of these delay-related conditions may become more pronounced and lead to verbal communication difficulties under the pressure of time and argument.

Since subscriber dissatisfaction increases in proportion to delay time, the CCITT (International Telegraph and Telephone Consultative Committee) recommended the following limitations on mean, one-way propagation time with appropriate echo suppressors: 0 to 150 milliseconds, acceptable; 150 to 400 milliseconds, acceptable, provided increasing care is exercised on connections as the mean, one-way propagation time exceeds about 300 milliseconds; and unacceptable above 400 milliseconds.

A follow-up analysis on the simulated delay circuits showed that only a small proportion of the people had difficulty talking and hearing, and an even smaller proportion rated the connection "fair" or "poor" (see Figure 4). Therefore, it would seem that the delay-related problems are not as serious as first thought to be.

One possible way to minimize delay is to use the satellite path for transmission in only one direction, and use the shorter delay, terrestrial system for the return connection. In this way, the maximum one-way delay would be acceptable and the total delay would be significantly reduced.

Once a domestic satellite system is operating, it will be necessary to have automatic switching which would limit each call to only one satellite hop,

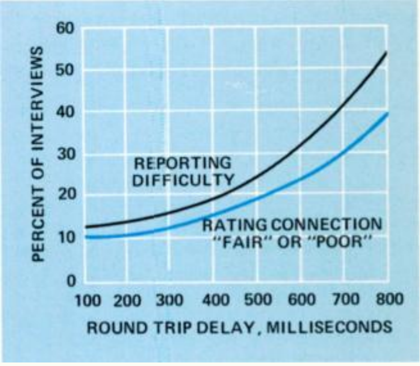


Figure 4. Only a small percentage reported having any difficulty hearing or talking during calls made on circuits with simulated delays. An even smaller portion rated the connection as "poor" or "fair".

keeping the delay within the acceptable range. One way to accomplish this is to make the domestic system available only for calls within the country. An alternative plan would develop an inter-satellite communication system requiring only one up-and-down link. The situation to be avoided is multiple up-and-down links. For example, on a call from England to Hawaii there could be as many as three up-and-down links, with a U.S. domestic system in operation (See Figure 5).

Long delays cause difficulties only when there is two-way communication. Data, television, and facsimile transmission would be unaffected by these delays and ideally suited to satellite communication systems.

Unique Outages

There are three types of outages affecting reliability on all satellite systems. The magnitude and exact occurrence of these outages depends upon the orbital placement of the satellite and the location of the earth station. The first is eclipse outage which occurs when the earth's shadow covers the satellite, causing the solar cells to become inoperative. These periods of eclipse last up to one hour, and occur each night for 43 consecutive nights in the spring and fall. However, the usual satellite design provides battery backup for most channels to insure their continuous operation. To conserve satellite weight, it would be possible to keep a channel without battery backup for television transmission — a service normally "off the air" during the eclipse periods.

Sun transit outage is caused by radiation of electromagnetic energy from the sun when it crosses directly behind the satellite. This radiation is proportional to temperature; therefore, the sun is an extremely powerful noise source which, when in direct line with a satellite, overrides the satellite signal. This condition, occurring on about five days, two times each year, causes an outage lasting approximately 10 minutes. Terrestrial protection channels can be provided to avoid losses, since these short outages can be predicted with reasonable accuracy.

If a satellite should fail, there is a distinct likelihood that it will be impossible to restore it to service, and a replacement satellite would have to be launched. A temporary means of restoring satellite circuits will have to be developed, to avoid the serious effects of this outage on a sophisticated telephone switching network.

Aircraft do not cause interference with terrestrial communication links. This is not, however, the case with satellite communication where aircraft corridors pass through satellite beams.

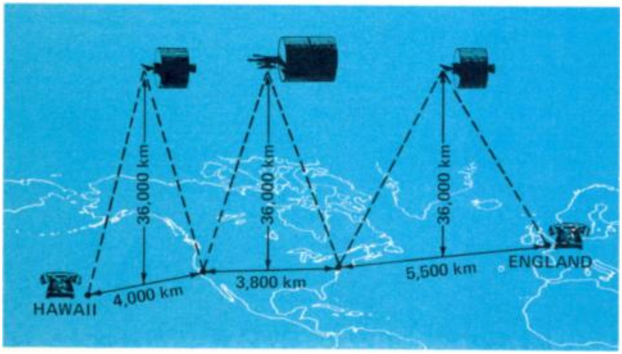


Figure 5. Limiting intercontinental communications to one up-and-down link, there are several possible routes for a call from England to Hawaii.

Figure 6. Domestic satellite earth stations will look very similar to this international satellite earth station.

This interference condition is still under investigation to determine its magnitude.

Weight vs Stabilization

Narrow antenna beams used for satellite communication require precise spacecraft stabilization. Accurate sensing for final attitude adjustments can be achieved by measuring the satellite's electromagnetic radiation. Attitude control appears to be primarily a question of the reliability of components to be used in a system designed for at least 10 years of operation. A basic aspect of attitude control is the amount of fuel (weight) required to stabilize the spacecraft.

In comparison with the amount of fuel required to keep a satellite station operating, the weight for attitude control is small – a few pounds per year per ton of satellite weight. Therefore, the stabilization weight penalty imposed on a satellite having a 10 year operational lifetime, while significant, is not prohibitive.

How Soon?

It is theorized that even if the FCC acts quickly, it would require about two years of planning and construction before a U.S. domestic satellite system could become operational. Experts predict the initial volume will be only great enough to support one satellite system, unless there is a significant increase in traffic over the next two years.

The Canadian domestic satellite system is scheduled for launching in late 1972. The specific requirements of the Canadian system are not the same as for a U.S. system; however, a great deal can be gained from their experience.

Although the cost of domestic satellite links is not expected to provide immediate economic advantages over terrestrial links, it is anticipated that its versatility and reliability combined with the present varied modes of terrestrial transmission will ultimately provide a more efficient total communications system.

Someday in the near future the United States will be covered with a network of earth stations similar to the one shown in Figure 6, and all phases of communication – voice, data, facsimile – will experience the advantages a domestic satellite system.

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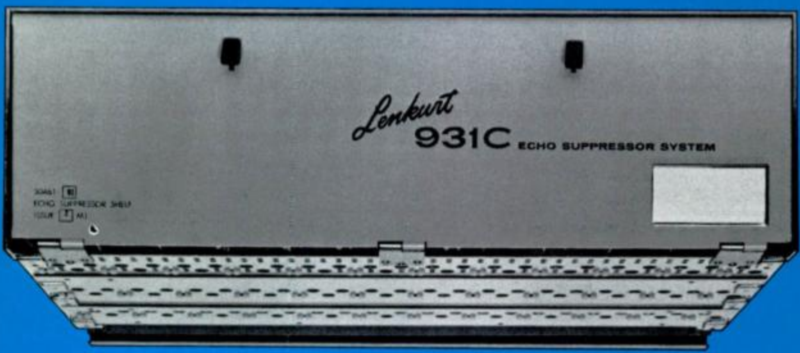

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