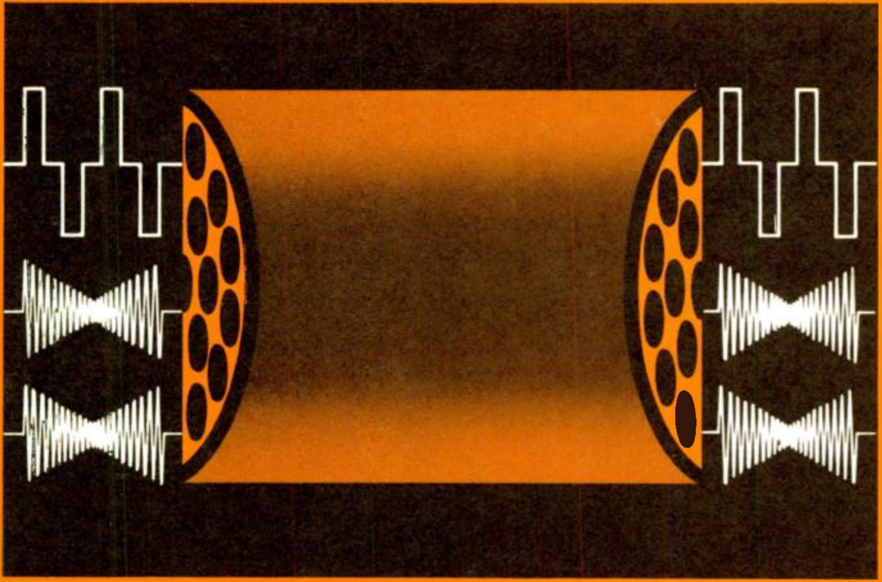
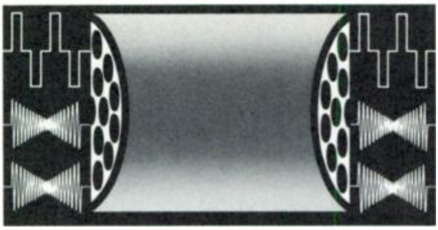
GTE LENKURT

DEMODULATOR

JULY 1971

PCM-FDM Compatibility Part 1





Under certain conditions, pulse code modulation cable carrier systems are compatible with frequency division multiplex systems on cable pairs within the same cable sheath.

It has been the practice in the communications industry to avoid placing pulse code modulation (PCM) and frequency division multiplex (FDM) systems in the same cable sheath. The reason for this taboo stems from the fact that the signal level on a PCM system is so high in comparison to that of an FDM signal that indiscriminate mixing of the two systems may result in rendering the FDM system partially or totally useless. Nearly all noise and crosstalk between the two systems is unidirectional, from the PCM system to the FDM system. The performance of a PCM system will hardly ever be affected by the presence of an FDM system on the same cable.

Because there are economic as well as convenience advantages to the user in combining PCM and FDM systems within the same cable sheath (whether for a temporary or extended period), tests have recently been conducted at the GTE Lenkurt laboratories on the problem of PCM-FDM compatibility. The preliminary results of these tests and the tentative ground rules that have been subsequently established may serve as a guideline to the user who is comptemplating a combination of PCM and FDM systems in the same cable sheath.

Why Combine PCM and FDM?

There are several instances when a user of cable carrier systems may desire to operate PCM and FDM systems over cable pairs within the same cable sheath. For example, he may want to gradually phase out an existing FDM cable carrier system and convert to PCM circuits over a cable route. Or, he may want to install PCM systems on a cable which already has FDM carrier in it to avoid the expense of installing new cable. The FDM carrier, in this case, may include subscriber carrier, N-type carrier or exchange carrier systems.

There may be many cable pairs in one cable and although the metal sheath that encompasses them provides protection from external interference, interference generated within the cable by some of these pairs may cause noise which degrades the quality of the intelligence being conveyed on other pairs.

It is important to realize that the PCM line signal of all 24-channel, T1-type, U.S.-manufactured PCM systems using D1-type channel banks look identical. Also, all D2/T1-type line signals look identical to each other (even though they are slightly different than D1/T1-type signals). Therefore, if one manufacturer can mix PCM and FDM systems on a cable, any other can also. The references to D1- and D2-type systems in this discussion imply particular types of 24-channel PCM terminals (channel banks) both of which are often used in combination with the T1-type repeatered line (regenerative repeaters and associated equipment).

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PCM-FDM Possibilities

Whether it is possible to operate a PCM system in the same cable sheath with one or several FDM systems is determined by the crosstalk coupling loss between the cable pairs involved. Given a certain crosstalk coupling loss in a cable between the FDM cable pairs and the PCM cable pairs, compatibility then depends on the frequency range of the FDM system, the baseband frequency of the FDM channels equipped, the number of PCM systems involved, the length of exposure (in terms of number of FDM repeater sections), kind of FDM system (modulation method), and the permissible amount of performance degradation allowed in the FDM system due to PCM carrier interference. When all of these factors are considered, they are evaluated against the power distribution in a T1-type PCM signal as a function of frequency (the power spectrum). What that power spectrum looks like is of vital importance when PCM-FDM compatibility is evaluated. The highest frequency slot in the FDM system will always be the one of most concern, since it will be the slot most vulnerable to interference from the PCM signal.

As a general rule, interference into the FDM carrier system can be reduced by equipping only the lower-frequency channels in the FDM system. Therefore, when phasing out an FDM system which must operate for some time on the same cable sheath with PCM, the higher FDM channels should be phased out first. The power spectrum components in a PCM line-signal drop sharply below 96.5 kHz, and interference into FDM systems below that frequency is usually negligible. The point of maximum power in a T1-type PCM power spectrum occurs at approximately 710 kHz for busy hour conditions. The maximum PCM power, in this case, indicates the maximum amount of interference that threatens the FDM system.

Cable Characteristics

The achievable crosstalk coupling loss between two cable pairs increases with the number of cable pairs in the cable sheath. This is because there is increasingly less crosstalk coupling in proportion to the physical distance between pairs.

The actual value of crosstalk coupling loss between two cable pairs depends upon which splicing groups have been selected, the splicing methods used, and the general crosstalk characteristics of the cable (such as cable gauge and dielectric insulation material).

Direction Coordination

A PCM repeatered line laid out for one-cable operation has a minimum near-end crosstalk (NEXT) coupling loss requirement between its two directions of transmission. Failure to meet this requirement may result in interference between the two directions. Such systems are often planned with the pairs for opposite directions of transmission assigned to nonadjacent splicing groups (see Figure 1). It is therefore important to keep the FDM pairs protected against interference from either direction of transmission of the PCM system. However, PCM to FDM interference between cable pairs belonging to the same direction of transmission is not nearly as serious as interference between pairs belonging to opposite directions of transmission. The reason for this is that the difference between the signal level on a PCM cable pair and that of an FDM signal on another pair, is at most points along a cable, greater for opposite directions of transmission than between pairs for the same transmission direction. The crosstalk disadvantage is thus greatest between cable pairs for opposite directions of transmission. Figures 2A through 2C show the near-end, and far-end crosstalk (NEXT and FEXT) characteristics for different directions of transmission in various systems. It is assumed that all FDM system repeaters coincide with repeater locations of the PCM system. One repeater section of the FDM system may correspond to one or several repeater sections of the T1-type PCM system.

The only NEXT paths of significance between the T1 and N3 carrier systems shown in Figure 2C are the ones indicating near-end crosstalk over repeater section 3. The contributions from the other two repeater sections arrive at the FDM repeater greatly attenuated and can be neglected. Therefore, this cause can be treated as if all the near-end crosstalk on this FDM repeater section originated on the T1-type repeater section adjacent to the FDM repeater input.

Likewise, FEXT coupling between T1-type carrier and N carrier is due almost totally to the FEXT coupling over the T1-type repeater section adjacent to the FDM repeater input.

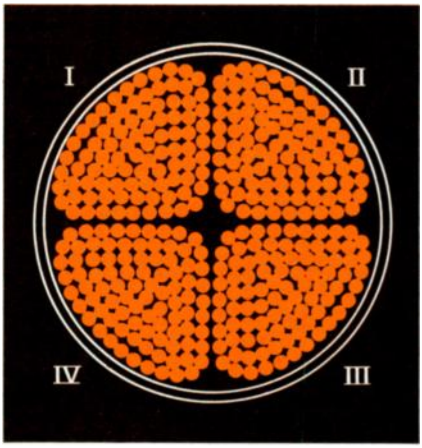

Figure 1. A cable divided into four binder groups. At a splice, if group integrity is maintained, I and III, II and IV, are still non-adjacent beyond the splice. Also, I and II, IV and III, are still adjacent beyond the splice.

If a PCM system shares a cable with an FDM system for a distance comprising more than one FDM system repeater section, the interference will add up on a 10 log k basis, where k is the number of FDM system repeater sections exposed to PCM interference.

The number of interfering PCM systems also has an influence on the determination of required crosstalk coupling loss, since the noise powers add up. If the number of PCM systems is n, and 10 log n is used to account for the number of systems, the assumption is then made (conservatively) that the PCM disturbers all interfere with the FDM system at equal coupling losses.

Each PCM system engineered for one-cable operation interferes with each FDM system both by way of near-end and far-end crosstalk. Since such a cable system has the pairs for both transmission directions inside the same cable sheath, the interference into each direction of transmission of an FDM system thus originates from both transmission directions of each PCM system (two cable operation implies that both directions of transmission are assigned to pairs contained within separate cable sheaths).

Considering that a one-cable PCM system should be engineered with pairs for opposite directions of transmission in different binder groups (often non-adjacent in the cable), in some cases one type of crosstalk (near-end or far-end) may dominate over the other. In other cases, it may be necessary to conservatively assign half of the crosstalk contribution to each type of crosstalk, when estimating minimum crosstalk coupling loss between PCM and FDM cable pairs.

The ideal condition is when the FDM systems are assigned to pairs in a splicing group or unit in the cable which lie nonadjacent to any of the two groups or units used for the two directions of transmission for the PCM carrier. If this is not possible, direction-coordination should then be considered. This implies that the two directions of transmission of the FDM system be coordinated with the PCM carrier pairs in such a way that pairs belonging to the same directions of transmission for the two types of systems are assigned to the same splicing group or unit in the cable.

Screen Separation

Several manufacturers of multi-pair cable have developed an internal screen which allows separation of cable pairs into two compartments. This screen is intended to provide electrical partitioning between pairs used for opposite directions of transmission, thus reducing near-end crosstalk in PCM systems. This offers an opportunity for direction coordination, if FDM systems are to be transmitted over such cable along with PCM systems.

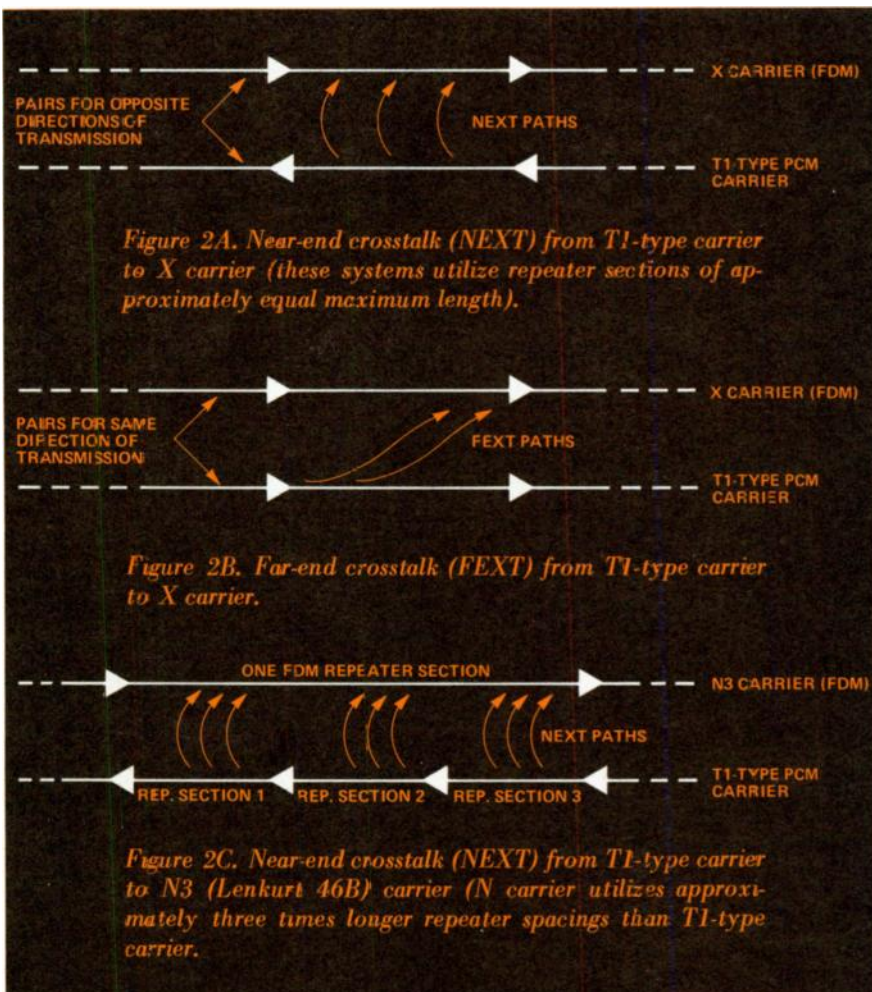

Figure 2A. Near-end crosstalk (NEXT) from T1-type carrier to X carrier (these systems utilize repeater sections of approximately equal maximum length).

Figure 2B. Far-end crosstalk (FEXT) from T1-type carrier to X carrier.

Figure 2C. Near-end crosstalk (NEXT) from T1-type carrier to N3 (Lenkurt 46B) carrier (N carrier utilizes approximately three times longer repeater spacings than T1-type carrier.

It has been suggested by one manufacturer of screened cable that the screening concept may be found useful for providing isolation between PCM and FDM systems. For example, two screens could be provided, dividing the cable core into three compartments, two for PCM and one for FDM usage.

The PCM Power Spectrum

Aside from the observation of direction-coordination between cable pairs, other important factors must be taken into consideration when investigating the possibility of combining PCM and FDM systems in the same cable sheath. What these factors are, and the nature of their potential disturbing effect, may determine whether or not compatibility between the two systems is possible.

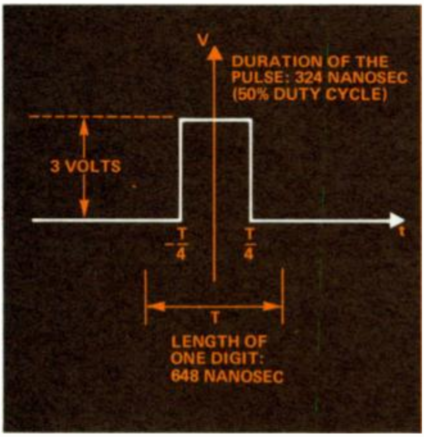

Figure 3. Unipolar pulse.

A unipolar pulse is shown in Figure 3. It represents a pulse such as it appears in the terminal equipment or in a regenerative repeater before the conversion to a bipolar format has taken place. It is an idealized pulse in that rise and fall times as well as aftershoot have been neglected. The duty cycle of the pulse train is 50 percent. This means that a unipolar string of binary ones in a terminal with a period T has a pulse width of T/2.

On a working D1/T1-type system with 24 voice channels carrying traffic, pulses occur randomly and with a pulse density closely approaching 0.50. That is, over a long enough period of time the number of binary ones and zeros (pulses and spaces) tend to be approximately equal. On a D2/T1-type system, pulses will tend to occur with a density somewhat greater than 0.50 (0.55 to 0.65 for busy-hour condition).

Before application to the transmission line, the pulse train is converted to a bipolar format by inverting every other pulse to opposite polarity (see Figure 4). The purpose of this inver-

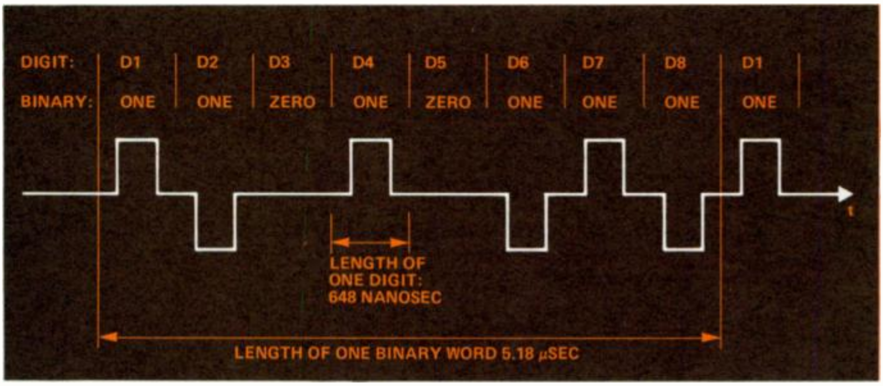

Figure 4. Bipolar pulse train.

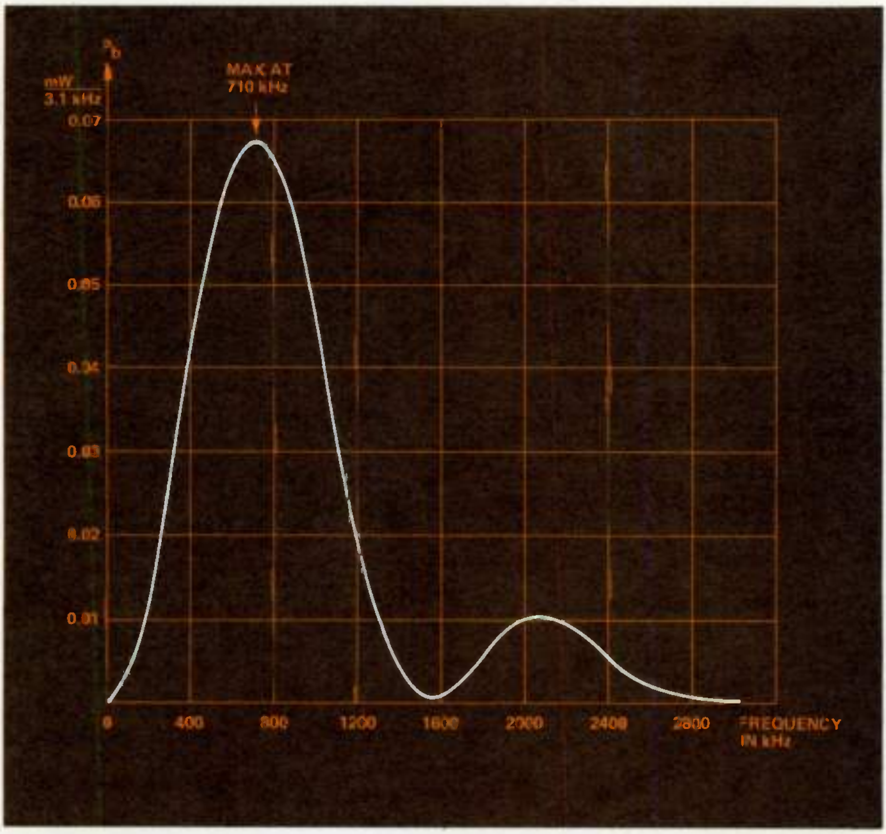

Figure 5. D1/T1-type power spectrum during busy-hour conditions.

sion is to shift the power spectrum to lower frequencies and to remove the dc component of the line signal.

The bandwidth usually available for transmission of voice information in most channels is 3.1 kHz. The random bipolar pulse train has its power distributed (in mW per 3.1 kHz slot) as a function of frequency as shown in Figure 5. This power spectrum is for a D1/T1-type PCM signal as it would appear during traffic conditions at the output of a regenerator. The curve represents the statistical average during traffic conditions and is not valid during idle or on-hook conditions. (The power spectrum during idle or on-hook conditions will be discussed in Part II.)

When PCM and FDM are combined within the same cable, the PCM power spectrum curve of Figure 5 will play an important part in evaluating crosstalk coupling between the two systems.

While this discussion of PCM-FDM compatibility has so far been of an empirical nature, Part II will investigate such factors as the PCM power spectrum and its effect on FDM systems, the effect of various types of PCM signaling on FDM, effects of idle/on-hook conditions and a method of estimating minimum crosstalk coupling loss.

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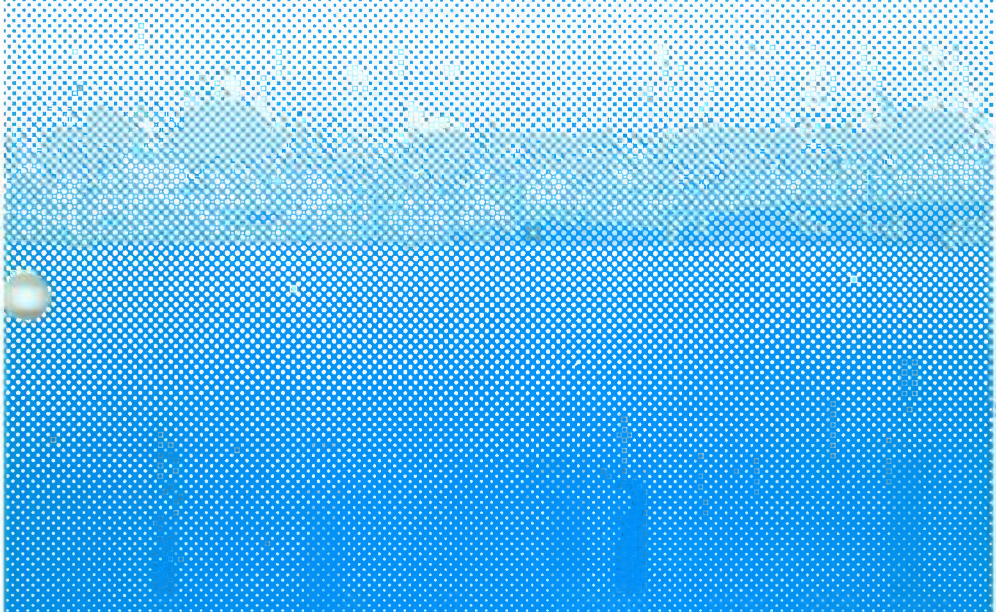

12 GHz

a new look by industrials

For industrial users, rain attenuation at 12 GHz may actually be more benign than other transmission outages. So, shouldn't the industrials use the 12-GHz band?

Most industrial users, for a variety of reasons, have usually selected the two lower frequency bands — the 2- and 6-GHz bands. A review of the FCC frequency listings shows only a few hundred licenses in the 12-GHz band, compared to many thousands in the 2- and 6-GHz bands.

The most common reason for this strong preference for the lower frequencies is the susceptibility of the 12-GHz band to rainfall attenuation. Although the effect is present to some degree at the lower frequencies, it increases rapidly with frequency. And, a rainfall intensity causing only a few dB of attenuation at a lower frequency could be sufficient to cause a path outage at 12 GHz (see Figure 1).

Even without the rain effect, users whose operational experience has been in the lower bands tend to prefer them to a band with which they are less familiar. The availability and cost of accessories such as antennas, waveguides, and test equipment have also been an important factor affecting usage.

A New Look?

Several things point toward a "yes" answer to this question. For example, as more microwave systems come into existence, there is growing frequency congestion and in some areas it is already difficult, if not impossible, to find interference-free frequencies for new systems or paths in the 2- or 6-GHz bands.

RF (radio frequency) channels are licensable with 20 MHz of bandwidth in the 12-GHz band; whereas only 10 MHz are available at 6; and 8 MHz at 2, under FCC rules. Thus, of the three bands, 12 GHz is the best suited for wideband services.

Equipment for the 12-GHz frequency band, including antennas, waveguides, and test equipment, is now widely available, with proven quality and reliability quite on a par with equipment for the lower bands. Experience in the 12-GHz band has shown that the only really important propagation differential is that of the rain attenuation effect.

FCC policy for a number of years has been aimed at promoting increased usage of the bands above 10 GHz. One requirement which has been in effect for some years is that any new systems entirely within a municipal or local area must use frequencies above 10 GHz. The Commission has also sought to encourage use of the 12-GHz band for short spur legs on long systems,

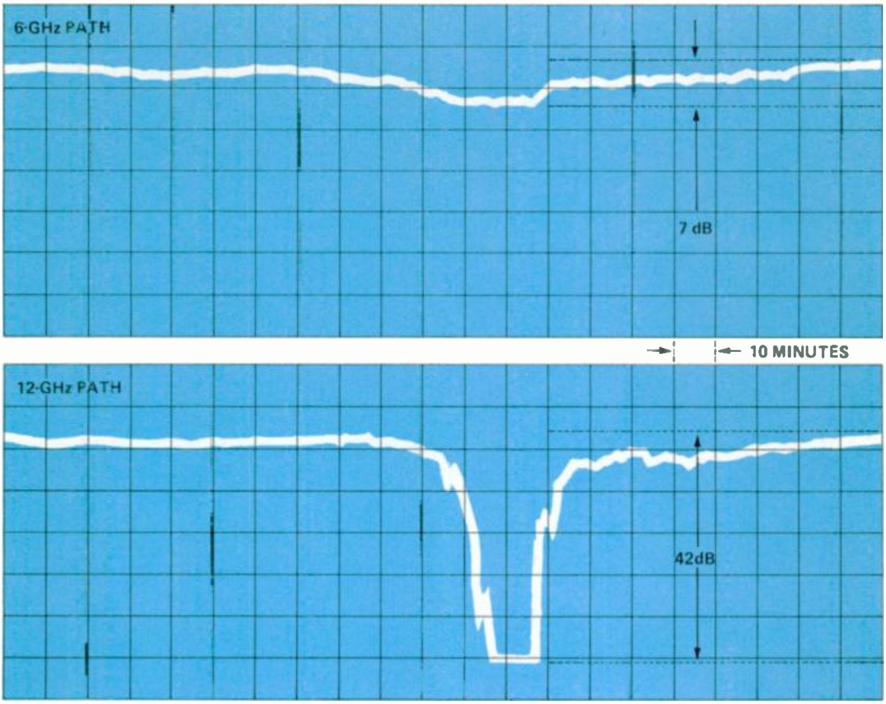

Figure 1. This recording of two simultaneously transmitted channels illustrates the susceptibility of the 12-GHz channels to rain attenuation.

thus keeping the lower frequencies available for backbone routes.

Non-Rain Transmission

Comparing 6- and 12-GHz transmission characteristics under non-rain conditions shows that there is really little difference between the two systems in overall expected performance. For example, on a given path with two given antennas, the path attenuation is greater at 12 GHz than at 6. But, the antenna gain is greater at 12 than at 6. Adding waveguide losses in order to determine end-to-end path loss (path loss plus waveguide losses minus antenna gains) shows the average 12- and 6-GHz systems to be comparable (see Figure 2).

Receiver noise-figures tend to be 1 - 2 dB greater at 12 GHz than at 6 GHz, and for comparable types of equipment there may be from 1 - 3 dB less transmitter output power at 12 GHz than at 6. Thus, with present day equipment, one might expect a given 12-GHz hop to be at a disadvantage of from 2 - 5 dB from the standpoint of equipment. This differential may well be reduced as even better components become available at the higher band.

Path clearance requirements, for a given degree of performance, are slightly lower at 12 GHz than at 6 because the Fresnel zone radius at 12 is only about three-quarters as large as at 6 (see Figure 3). However, this difference is not enough to be signifi-

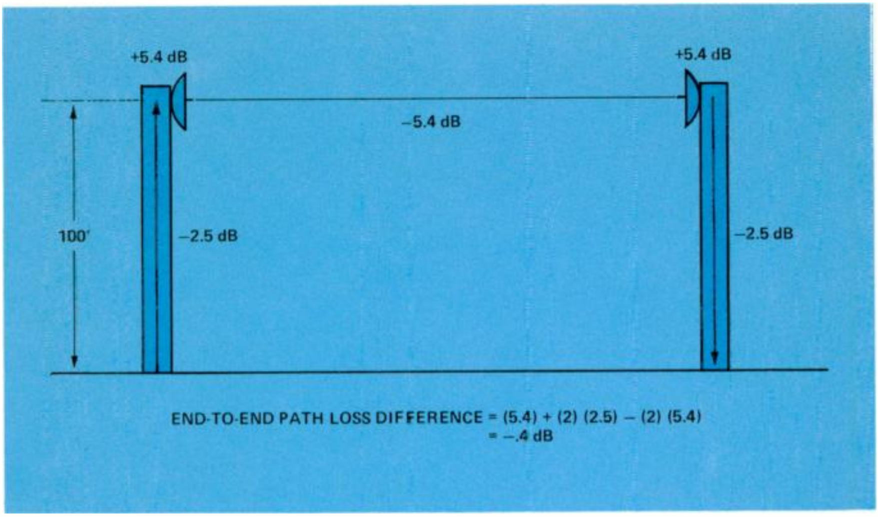

Figure 2. When compared to a 6-GHz system, a 12-GHz system has a similar end-to-end path loss.

cant. Fading of the multipath type is quite similar in nature to that experienced at 6, though it is now generally considered that the fading at the higher frequencies is somewhat greater. Where necessary, space diversity can be used to overcome multipath fading, and the same spacing is even more effective at 12 than at 6 GHz.

Summing up, the total net differential between the 6- and 12-GHz bands is relatively small, and in some cases may even favor the 12-GHz band. Thus, if it were not for the rain attenuation effect, there would be no reason why the 12-GHz band could not be used in much the same way as the lower frequency bands.

Rain Attenuation

Rain attenuation at the higher microwave frequencies has been under study and investigation for more than 25 years. Much is known about the qualitative aspects, but the problems faced by the microwave transmission engineer — that of making quantitative estimates of the probability distribution of the rainfall attenuation for a given frequency band as a function of path length and geographic area — remains an extremely difficult one.

In order to estimate this probability distribution, instantaneous rainfall data is needed. Unfortunately the available rainfall data is usually in the form of a statistical description of the amount of rain which falls at a given measurement point over various time periods — generally at least an hour in length.

The rain-induced attenuation along a given path at a given instant in time, however, is a function of the integrated effect of the rainfall existing at all points along the path and is affected not only by the total amount of water in the path at that instant but also by its distribution along the path in volume and drop size.

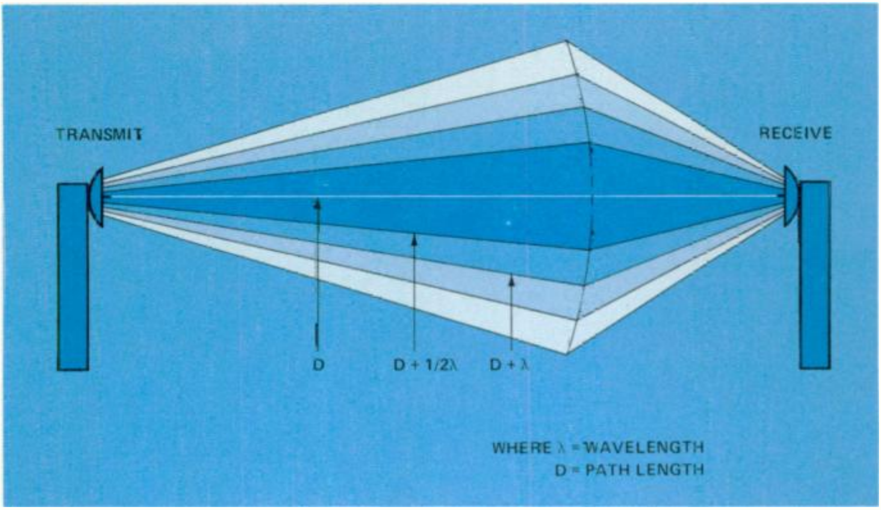

Figure 3. Fresnel zone radii are a function of the signal wavelength, and consequently, the signal frequency.

For heavy rain rates the instantaneous distribution of volume and drop size along the path is highly variable, and is difficult to predict with any sort of accuracy from the kind of rainfall data generally available.

One of the earliest and most comprehensive attempts at developing a workable prediction method was carried out by Bell Laboratories in the 1950's, and was described in a classic paper by Hathaway and Evans (1958)*. In their paper Hathaway and Evans developed a method of predicting annual outages for microwave paths operating in the 11-GHz common carrier band, as a function of path length, fade margin, and geographical area within the contiguous United States.

This study has proved to be a worthwhile prediction tool, and when used with a recognition of its limitations, is still one of the best references available for microwave engineers working within the United States. The Hathaway and Evans method can be modified slightly to adapt it to the 12-GHz industrial band rather than the 11-GHz common carrier band (see Figures 4 and 5).

Increasing fade margin and shortening path lengths are the most readily available tools for reducing the per hop outage in a given area. For fade margins other than 40 dB as shown in Figure 5, correction factors (shown in Figure 6) can be used.

The total annual rainfall in an area has almost no relation to the rain attenuation for the area. Within the U.S., the northwestern states, for example, have the greatest annual rain-

*Other investigations were carried out for the Federal Aviation Administration and are covered by Report No. FAA-RD-70-21, *Rain Attenuation Study for 15-GHz Relay Design*, and Report No. FAA-RD-70-47, *Weather Effects on Approach and Landing Systems.*

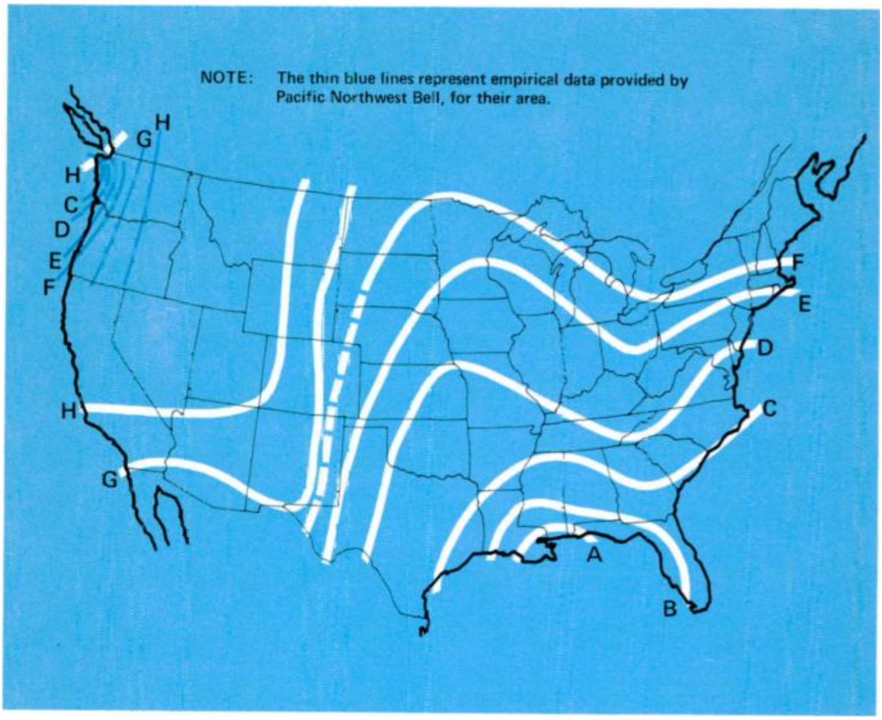

Figure 4. The contours of this map have the same average rainfall distribution and can be used with Figure 5 to predict the effect of rainfall on outage time.

fall, in excess of 100 inches per year, but it is produced by long periods of steady rain of relatively low intensity at any given time. Other areas of the country with much lower annual rates experience types of rainfall such as thunderstorms and frontal squalls which produce short duration rains of extreme intensity, and it is the incidence of rainstorms of this type which determines the rain attenuation characteristics of an area.

Even the rain statistics for a day or an hour have little relationship to the excess path attenuation. A day with only a fraction of an inch of total rainfall may have a path outage due to a short period of extremely high intensity, while another day with several inches of total rainfall may experience little or no excess path attenuation because the rain is spread over a long time period.

Reliability Objectives

A company with its own communications system is the end user as well as the operator of the system, and thus is in a more flexible position than the common carriers who are selling communications service to the public. The private user can meet exact reliability requirements for different parts of a system. For example, a spur leg to a facility of minor importance might be considered satisfactory with a pre-

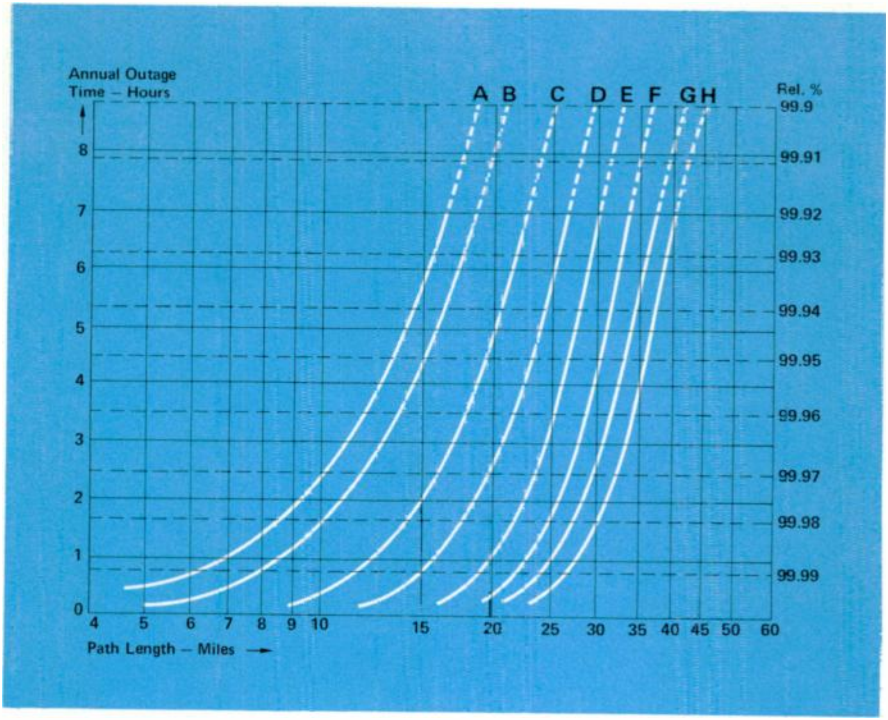

Figure 5. These curves, for use with the contour map of Figure 4, are based on 12-GHz paths with 40-dB fade margins.

dicted outage of several hours per year, in sharp contrast to the requirements for a backbone hop of a long system or into a site of major importance.

Fade Margin	Change annual outage by:
35 dB	+ 20%
45 dB	– 15%
50 dB	– 25%

Figure 6. Using these correction factors, Figure 5 can be adapted for paths with different fade margins.

In considering how to establish realistic outage or reliability objectives, several things need to be kept in mind. A single overall design objective for not more than X hours, minutes, or seconds outage over some period such as a year, is an over-simplification. The character of the particular kind of outage and its effect on the system should be taken into account and perhaps there should even be different objectives for different types of outage.

For example, propagation outages due to multipath fading are usually short. An outage of an hour per year due to multipath fading might represent 1,000 or more individual outages, averaging about 3 or 4 seconds each. On the other hand, propagation outages totalling an hour per hop due to rain attenuation, on a path with a large fade margin, might consist of four or five individual outages averaging ten to fifteen minutes each. The effects of these two types of system outage would be quite different in nature.

A distinction should be made between communications circuits for which an outage of a few seconds or a few minutes is just a nuisance or an inconvenience, and circuits for which such an outage might result in danger to life, great economic loss, or other catastropic consequences. The suitability or unsuitability of a rain-affected band such as 12 GHz could differ widely for these two situations.

Even if the maximum possible reliability objectives are established and a path or a system is engineered to the full limit of the state of the art, the possiblity of an outage can never be eliminated but can only be reduced to a very low probability. Thus it is imperative to make any ultra-important services as fail-safe as possible against a loss of the communications channel. Therefore, regardless of the degree of reliability, a system should be engineered so that if an outage does occur it can be tolerated or its effects at least kept within reasonable bounds.

It seems that in some cases, perhaps many cases, a somewhat more relaxed attitude might be taken toward rain-induced outages than toward multipath outages or even equipment outages. In several respects such rain outages seem to be somewhat benign in nature. If the fade margins are kept high and the paths are not stretched out too much, even in the less advantageous areas of the country, the number of outages per year should not be very large, and the length of individual outages on a hop should only rarely exceed some two to perhaps twenty minutes.

Furthermore, such outages would occur only with extremely heavy rainfall somewhere along the path, and the conditions when this is likely to occur are usually known in advance and fairly well publicized. This type of outage should be considered tolerable since it occurs rather infrequently, seldom happens without some advance warning, doesn't last long when it does happen, and is self-healing.

For high reliability systems, usually involving long-haul systems with a great many hops in tandem, the per hop objectives may be as stringent as 99.9999% or so, allowing only about 30 seconds outage per year. Short haul systems, up to say ten hops, might have per hop design objectives of about 99.999%, roughly 5 minutes outage per year. Spur legs or single hop systems may be designed for something on the order of 99.99% or about 53 minutes outage per year. Objectives of this kind are typical of those used in the telephone industry, for public service networks. For other situations, and for other types of service, even lower reliabilities may be acceptable, down to 99.9% or about 9 hours outage per year.

Figure 5 shows the predicted annual outages as percentages, and a little study of the numbers indicates that even in favorable areas of the country one would have to use quite short paths in order to get much beyond the 99.99% line (53 minutes per year). Attempts to extrapolate down to the 99.999% or the 99.9999% areas would be subject to great uncertainty.

Using Figure 5 as a guideline, it is apparent that there are few areas where it would be feasible to use 12

GHz as a part of the backbone route of a long-haul system using conventional path lengths, particularly one where requirements are high. On the basis of this data, it seems that the 12-GHz band would be most useful for situations in which the per hop reliability design objectives fall in the range of 99.9% up to at least 99.99%.

Diversity Plans

In the adjacent 11-GHz band, widespread use has been made of cross-band diversity systems, a form of frequency diversity in which one of the frequencies is in the 6-GHz common carrier band and the other in the 11-GHz common carrier band. This combination is a very effective one and can be used in any part of the country without any particular concern about path length. In heavy rain areas the 11-GHz half of the path can be expected to experience outages during heavy rainfall but the 6-GHz path will be only slightly affected. Furthermore, multipath fading is seldom experienced during heavy rainfall so the temporary outage of the 11-GHz path will have no effect on the system unless the 6-GHz path fails during this time because of equipment trouble, a very low probability situation in well engineered systems.

Cross-band diversity between the 6-GHz and 12-GHz industrial band is technically feasible and would be equally useful. But under FCC licensing policies in the industrial bands, cross-band diversity is only available in special cases where a definite need can be demonstrated. Also its use would not result in any reduction in the 6-GHz band usage, since industrial users are not allowed to use in-band frequency diversity.

There are a few cross-band hops in the industrial band, and Figure 1 is a recording from one such path, showing an example of a rain outage on the 12-GHz half of the path. This is quite typical of the rain induced outages in the higher bands, both in depth and length. The excess attenuation of the 12-GHz side exceeded 40 dB for a period of about 12 minutes, bottoming the recorder. The actual depth may have been considerably greater than 40 dB. During the same interval, the 6.7-GHz path experienced only a small amount of rain attenuation – about 7 dB at the maximum and of no real significance to the system.

This particular path is about 21 miles long, but the appearance of the attenuation event indicates that it was probably caused by a single rain cell occupying a relatively small portion of the path, rather than by uniform rain spread all along it. This leads to the conclusion that the event might have occurred, in about the same magnitude, even if the path had been quite short, perhaps even as short as five miles. However, the number of such events which would be expected to occur over a given period of time in a five mile path would be only one-fourth the number which would be expected to occur in a twenty mile path. In other words, it seems likely that for paths over about five miles it is not the amount of excess attenuation which determines path length, but rather the number of expected outage events and the total length of the expected outages.

Another approach to a high-reliability system uses a combination of very short path lengths plus route diversity to defeat the rain attenuation problem. These path lengths are from 2 to 5 miles, so the number of repeaters would be large compared to conventional microwave systems where the hops average something like 25 - 30

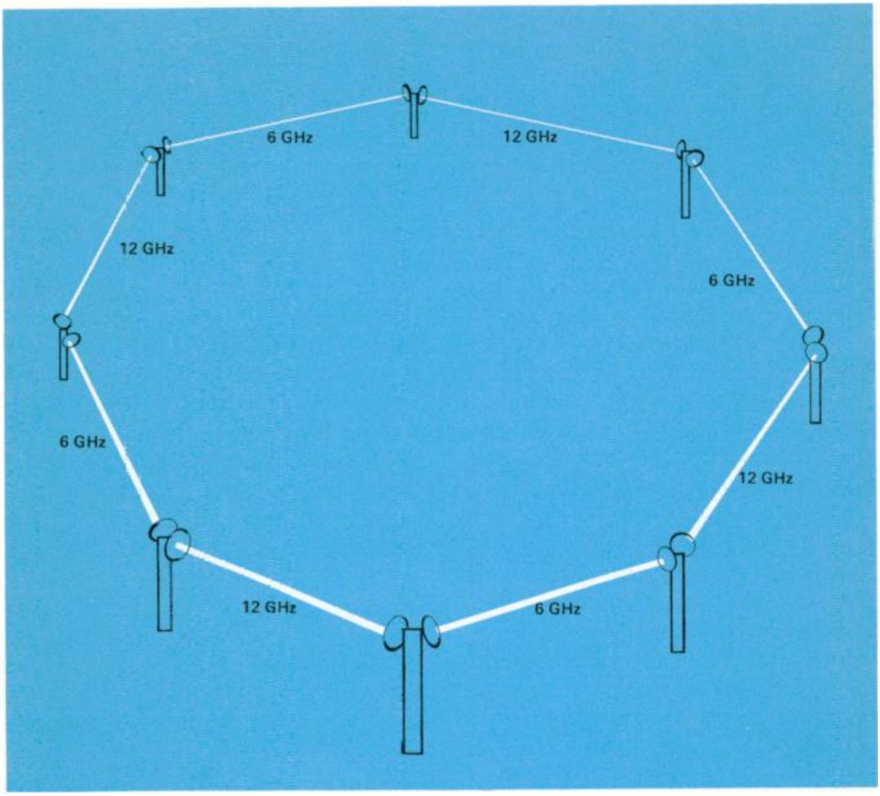

Figure 7. If one link of a closed loop network fails, a loop diversity arrangement will reverse the transmission direction to complete the transmission path between terminals.

miles in length. A system of this kind is called a "pole line radio." For such an arrangement, repeaters must be low in cost, highly reliable, virtually maintenance-free, low in power consumption, and capable of being placed in an inconspicuous housing at the top of some sort of simple pole structure. In addition the repeaters must be broadband to allow high channel density and each repeater must introduce a low amount of distortion and noise. The latter effect would be achieved by using PCM transmission for the system, with regeneration at sufficient intervals along the line to keep the error rate at the desired low level.

This whole technique, though promising, is still in the experimental stage and its potentialities and problems are still largely unknown. One basic principle is that it would require new frequency bands, not already in use by systems with conventional techniques, since the integration problems between the old and new would be large.

For the industrial user there is little likelihood that systems of this type would come into use in the 12-GHz band, though eventually, there may be something of the kind at a higher frequency.

However, there is one special situation in which a form of route diversity is already being used by some of the industrials. This is the so-called "loop system" in which a microwave system is laid out in the form of a closed loop with some sort of automatic sensing and switching system (see Figure 7). With such a system an outage or failure in any link will reverse the transmission direction around the loop.

Since the evidence indicates that intense rainfall at a given instant is unlikely to occur at two widely separated points, it seems that in such a system it would be quite feasible to use 12-GHz and 6-GHz frequencies alternately around the loop. With no two 12-GHz paths adjacent to one another, the physical separation would seem more than adequate to insure that rain outages would be essentially non-correlated and the likelihood of two paths being out simultaneously would be small.

Unfortunately, most communications systems proceed in more or less a straight line and are thus not adaptable to loop systems, so the possible application is somewhat limited. One possible application would be for systems connecting off-shore drilling platforms, which often are located in a manner suitable for looping. Another would be power companies, whose grid-type power transmission networks tend to be arranged in natural loops.

It should be kept in mind that loop systems, though extremely useful against outages which are relatively rare and rather lengthy, do not provide any protection against rapid, short fading of the multipath type. Where this type fading exists, per hop space diversity should be used to combat it, even with a loop system.

Gain from Experience

The adjacent higher frequency band, from 12.7 - 13.5 GHz, assigned to television auxiliary stations, has had rather widespread usage, a good part of it in microwave relay systems serving CATV systems. For this type of service somewhat lower reliabilities are deemed acceptable, and the systems are generally engineered with little or no regard for possible rain outage, even in the less favorable areas.

In some areas the common carriers and some of the industrial users have found themselves pushed into the higher frequency bands by congestion in the lower bands, and have generally found that although considered totally unsatisfactory before, the higher frequency bands can be quite useful.

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