The Lenkurt® Demodulator

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HYBRIDS

Hybrids, used so widely in modern telephone systems, are really a "necessary evil." They provide the means for accomplishing a vital compromise between the superior performance of four-wire circuits and the lower cost of two-wire circuits, but each hybrid introduces some transmission impairments. Since hybrids make the transitions from four-wire to two-wire circuits, a single long-distance call may go through several such junctions — and transmission performance suffers by the sum of their imperfections. This article discusses the operation and limitations of hybrids, how their performance is measured, and the effect of Direct Distance Dialing on hybrid performance requirements.

Although they find many other uses now, hybrids were developed primarily to allow repeaters to be placed in two-wire lines. Since most amplifiers can operate in only one direction, two amplifiers are commonly used at a single repeater point — one for each direction of transmission. Therefore, when a repeater (other than a negative-impedance device) is placed in a two-wire line, a hybrid must be used on each side of the repeater point to provide a short section of four-wire circuitry. Today most long circuits operate over four-wire carrier facilities for their entire length. Such lines do not need hybrids at intermediate amplification points, but they do need hybrids for connection to two-wire drops and switching equipment.

Any device which provides impedance matching between certain circuits and isolation between other circuits may be referred to as a "hybrid junction," or more commonly as a "hybrid." It may be a three-winding transformer, a resistance bridge, or a waveguide device for microwave frequencies. But in common telephone usage, the term refers to a junction between a balanced four-wire circuit and a balanced two-wire circuit.

For illustrative purposes, a hybrid can be considered as simply a network having four arms, or ports, as shown in Figure 1. The function of the hybrid is to permit signals to pass freely between *adjacent* arms of the network, but to block signal passage between opposite arms. Various types of hybrids attain this in different ways, but the principle is the same. An incoming signal is "split" so that part of the power is applied to each of the adjacent arms. Portions of the signal power are then recombined in such a way that they "cancel" each other; thus, no net power is delivered to the opposite arm.

In a typical telephone arrangement, the transmit and receive branches of the four-wire circuit connect to opposite sides of the hybrid. One of the other connections goes to the two-wire line, and the remaining one goes to a balancing network required in the "cancelling," or "balancing" process.

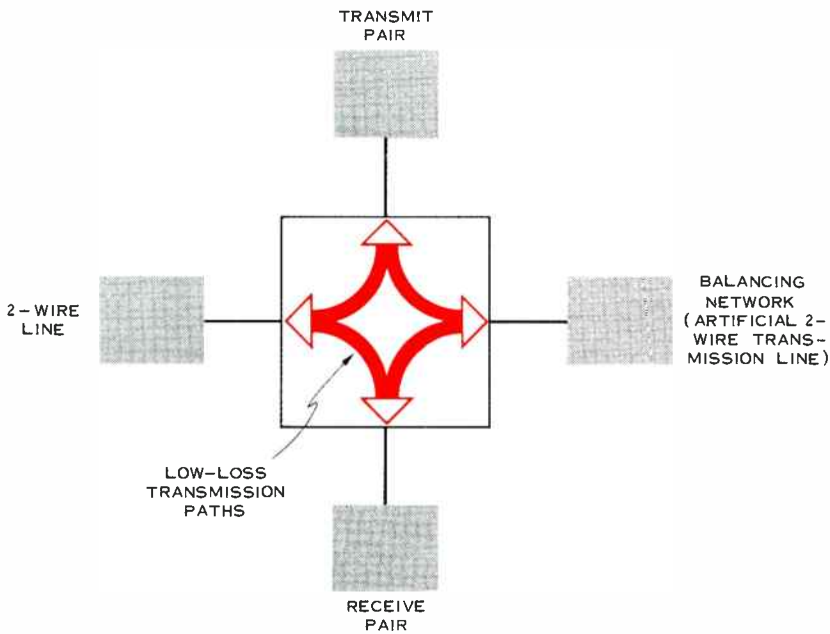

Figure 1. A hybrid may be any network which offers a low-impedance path between adjacent connections, but a high degree of isolation between opposite connections. In telephone practice, it provides the junction between four-wire and two-wire circuits.

Ideally, a hybrid would have infinite loss between opposite sides, thus providing complete isolation between the two branches of the four-wire circuit. At the same time, there would be no loss between adjacent arms — a signal could go unhindered from the two-wire line to the four-wire transmit branch, or from the four-wire receive branch to the two-wire line.

Since such performance is never attained in practice, actual hybrids are judged by how closely they *approach* the ideal. The isolation between the transmit and receive branches of the four-wire line is often called *transhybrid loss*. Since high transhybrid loss is directly related to the balance achieved between opposite legs, transhybrid loss is also known as *transhybrid balance*. The undesired loss between the two-wire line and the four-wire line is usually called *insertion loss*.

If the transhybrid balance is too low, enough of the power from the receive branch of the four-wire line "leaks" across the hybrid to go out on the transmit branch. This power appears at the other end of the four-wire line as an echo. Figure 2 shows how this might occur at a repeater point in a two-wire line. If the transhybrid balance at the east hybrid is too low, a portion of the eastbound signal returns to the west. If the same thing happens at the west hybrid, the echo goes back again to the east. If the loss around this echo loop is greater than the gain of the amplifiers, the echo will die out. But if the gain is almost as great as the loss, the echo may go around the loop several times before vanishing. This produces a "ringing" effect which may give a talker the impression that he is speaking into a rainbarrel, with its hollow, cavernous sound.

If the gain in the loop exceeds the loss, the echo does not die, but builds up and becomes self-perpetuating. In effect, the loop becomes an oscillator in the same way that an amplifier can be made to oscillate by using positive feedback. This condition is known as "singing." It creates a howl in the subscriber's earpiece, usually making the connection unusable.

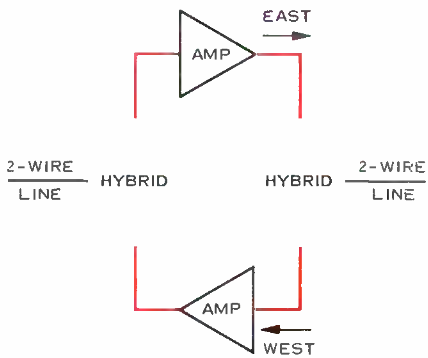

Figure 2. One of the earliest hybrid functions was to provide a short section of four-wire circuitry at a repeater point, permitting one-way amplifiers to be used in a two-wire line. Red line indicates possible "sing path" when some power "leaks" across hybrid.

A hybrid may also produce echoes by reflecting power back down the two-wire line. Such reflections occur at any impedance irregularity; that is, if the input impedance of the hybrid fails to match the characteristic impedance of the two-wire line, some power will be reflected rather than transferred through the connection. How much power is reflected depends primarily on how closely the hybrid's balancing network matches the impedance of the two-wire line. The quality of this match can be expressed as *return loss,* the ratio (in db) between the transmitted power and the reflected power. (The reflected power may be the sum of reflections from *several* mismatches plus the power which "leaks" across the hybrid despite the transhybrid loss.)

Performance Measurements

From the telephone subscriber's viewpoint, singing and echo are among the more annoying telephone transmission defects. Furthermore, a singing circuit can overload amplifiers or other devices common to more than one circuit, thus degrading the performance of several channels. Singing can also cause crosstalk in adjacent channels.

Since hybrids are intimately involved in the problems of echo and singing, their transmission performance is evaluated in terms of these factors. *Echo return loss* (ERL) refers to an average of return loss measurements made every 500 cps between 500 and 2500 cps. Echo is most noticeable to the subscriber in this frequency range because his telephone receiver is more sensitive to these "middle" voice frequencies. Studies of people's tolerance to echo indicate that louder echoes can be tolerated if they closely follow the original signal. However, an echo of a given magnitude becomes more noticeable as the delay between a signal and its echo increases. Thus, the echo problem is compounded on long lines where propagation time is greater. There are likely to be more impedance irregularities to cause echoes, and because of the distance involved the additional time delay makes these echoes more noticeable. Present minimum ERL objectives for Direct Distance Dialing vary with the type of connection, reaching 27 db for intertoll applications.

Figure 4 shows a typical test set-up for measuring ERL. In this arrangement an oscillator and a voltmeter are connected to opposite sides of a test hybrid (Hybrid A) at the four-wire

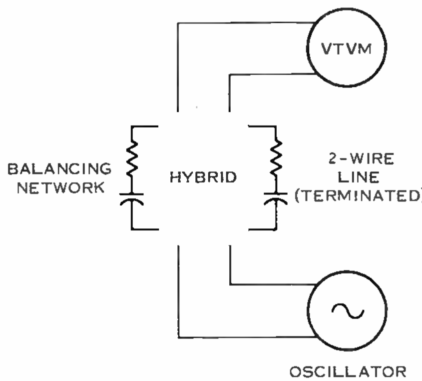

Figure 3. Typical test arrangement for measuring how much isolation the hybrid provides between the branches of a four-wire line. Ideally, no oscillator power would reach VTVM.

connections. The distant end of the two-wire line is terminated by the hybrid under test (Hybrid B). The four-wire connections to Hybrid B are terminated in 600 ohms, while each balancing network consists of 600 ohms in series with 2.1 microfarads. (This is a typical impedance used to simulate the impedance of a two-wire

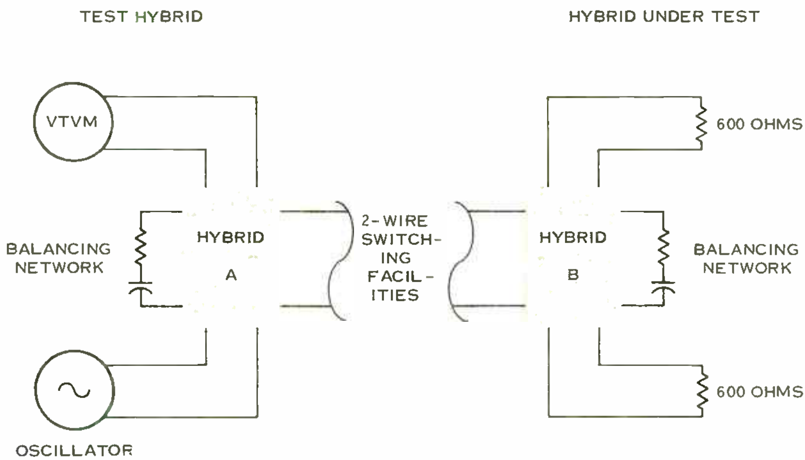

Figure 4. Typical test arrangement for measuring echo return loss. ERL measurement here depends primarily on the quality of the termination which Hybrid B provides for the two-wire line.

line in an office which uses a 600-ohm standard impedance.) Under ideal conditions, none of the oscillator output would reach the voltmeter. However, in any practical situation, some of the power *does* reach the meter. The amount of power depends primarily on whether the impedance of the Hybrid A balancing network is the same as the impedance of the two-wire line when terminated by Hybrid B. Any impedance mismatch between Hybrid A and the terminated line causes power to be reflected directly back into the hybrid.

The tendency of a circuit to sing is measured in terms of the *singing margin*, the net loss around the "sing path." In other words, the singing margin is the gain which must be added to a particular circuit to make it sing. The *critical frequency* is the frequency of lowest singing margin — the frequency at which singing first occurs when gain is added. The critical frequency usually occurs between 250 and 500 cps or between 2500 and 3400 cps — within the passband but outside the echo range. The critical frequency is usually near the "edges" of the voice band because the return loss is lower there.

Transformer Hybrids

The transformer hybrid is one of the oldest and most widely used types. Its operation can be visualized from the diagram of Figure 5. A signal coming into the hybrid at the four-wire receive terminals produces a current flow through the primary winding of transformer 1. The current through the two halves of this winding induces equal

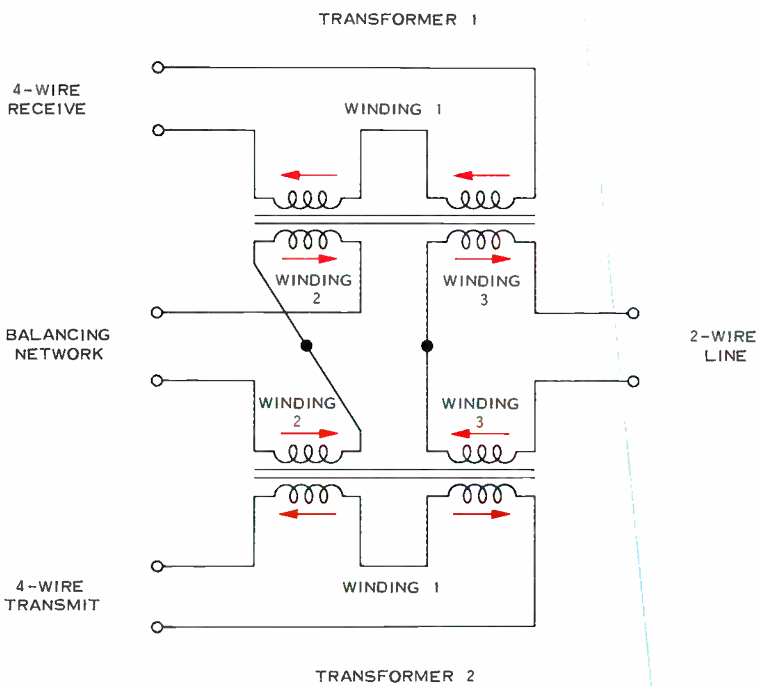

Figure 5. Two transformers may be connected to form a high-quality hybrid. Red arrows show how current flow in four-wire receive branch induces secondary current flow in the two-wire line and the balancing network. No current flows in four-wire transmit branch because opposite potentials are induced in the two halves of the winding, cancelling each other.

currents in secondary windings 2 and 3, which are connected to the balancing network and the two-wire line, respectively. Thus, half the applied power goes to the two-wire line and the other half is dissipated in the balancing network. Since half the power is wasted, the minimum theoretical loss in going through the hybrid is 3 db.

Windings 2 and 3 are connected in series to two corresponding secondary windings of transformer 2. Thus, the current to the balancing network flows also through winding 2 of transformer 2, and the two-wire line current flows through winding 3. Both these currents cause induced potentials in the halves of the transformer 2 primary — but these induced voltages are equal and opposite, effectively cancelling each other. Thus, no current flows in the transmit branch.

This, of course, is the ideal case, which provides complete isolation between the two sides of the four-wire circuit. In a practical case, several factors make the ideal unattainable. Both transformers must be carefully constructed for the voltages involved in the final "cancelling operation" to actually be equal and opposite. A slight difference in the windings, for example, would result in a net difference between the voltages, producing a current through the transmitter.

But such a current could result even if the transformer windings were perfectly matched — because the impedance of the balancing network must also match that of the two-wire line. If these two impedances are not the same, different currents will flow and different voltages will be induced in winding 1 of transformer 2, thus preventing full cancellation. The result is the same as though the transformer windings were not matched. Through careful construction of the transformers and matching of the balancing network to the two-wire line, however, satisfactory isolation can be obtained between the sides of the four-wire circuit.

For transmission in the other direction, the signal enters the hybrid from the two-wire line and is split equally between the transmit and receive branches. This current flow in the primary windings of both transformers induces voltages in the number 2 secondary windings of both transformers.

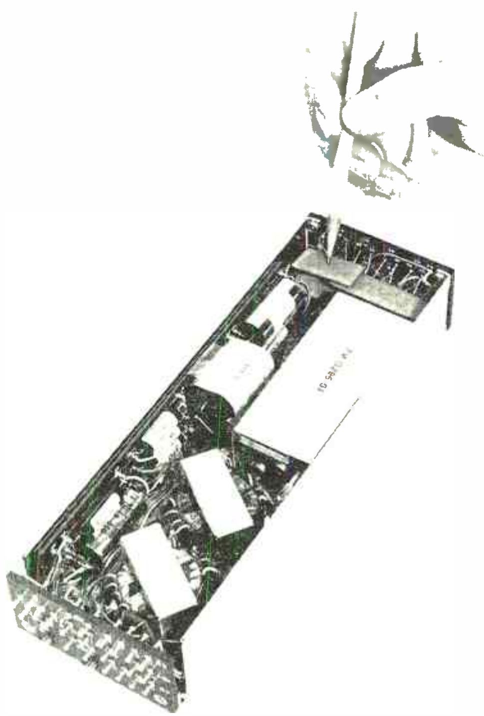

Figure 6. Two transformers in foreground, connected as shown in Figure 5, are the heart of this four-wire terminating unit. Pencil points to balanced attenuator pad (microcircuit package) which permits loss in both transmit and receive directions to be adjusted by front-panel strapping.

But these induced voltages are equal and opposite, so no power goes to the balancing network. Again, the minimum loss is 3 db because half the power is wasted in the receive branch. In practice, the loss in either direction of transmission is likely to be about 3.5 db because of transformer core losses and winding resistance.

Resistance Hybrids

A hybrid can also be made of a resistance network in the form of a Wheatstone bridge. Figure 7 (A) shows a resistance hybrid as usually drawn, while in Figure 7 (B) the same hybrid is redrawn to illustrate the bridge configuration more clearly.

Consider a signal applied to the receive terminals and assume that both R_1 and R_2 are equal to the resistances of the two-wire line and the balancing network — (typically these would all be 600 ohms). Signal power is then split, with half going to R_1 and the balancing network and the other half going to the two-wire line and R_2. Points A and B are at the same potential so no power flows to the transmit branch. Furthermore, since the power dissipated in the resistors and the balancing network is wasted, the two-wire line receives only 1/4 of the power. In other words, the resistance hybrid has a minimum loss of 6 db when all arms of the "bridge" are equal.

For transmission in the other direction, consider a signal applied at the terminals of the two-wire line. This signal is divided equally among the transmit and receive terminals and their associated resistors, R_1 and R_2. No power goes to the balancing network because points B and C are at the same potential. Since that portion of the signal applied to the resistors and to the transmit branch is wasted, the receive branch gets only 1/4 of the power and again the minimum possible loss is 6 db.

The foregoing discussion has assumed that all arms of the bridge have equal impedance, but this is not a necessary condition for hybrid balance. The requirement for balance is only that the product of resistances R_1 and R_2 must equal the square of the nomi-

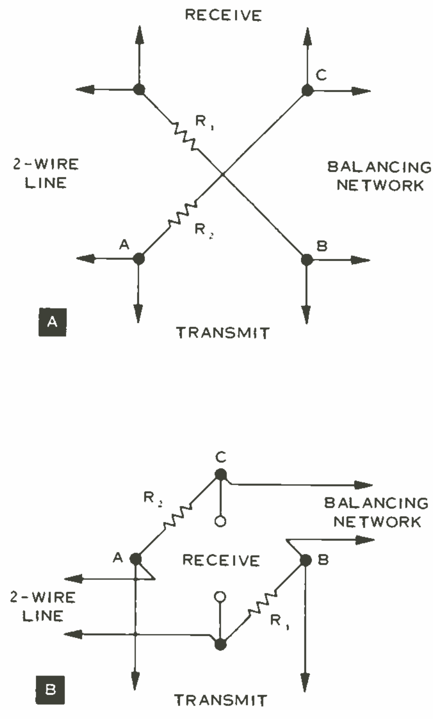

Figure 7. Resistance hybrid as usually drawn (A), and redrawn to illustrate bridge configuration (B). Although less expensive than transformer type, resistance hybrids introduce more transmission loss.

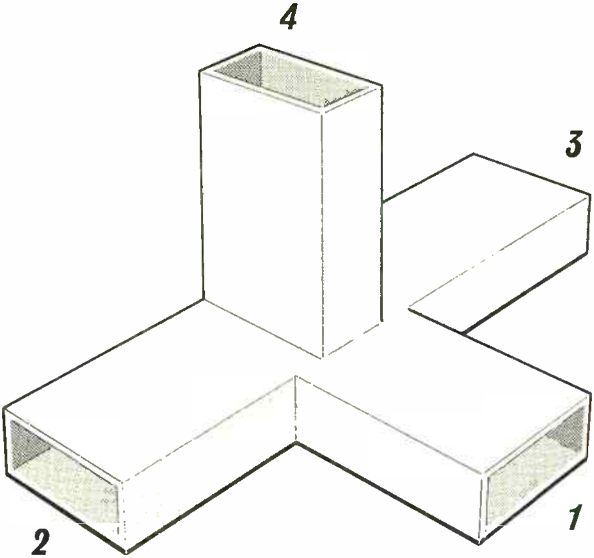

Figure 8. "Hybrid tee," used for microwave frequencies, provides isolation between opposite arms, but maintains low-loss path between adjacent arms. A signal in arm 4 produces equal and opposite signals in arms 2 and 3, nothing in arm 1. With input to arm 1, equal in-phase signals exist in arms 2 and 3, with no coupling to arm 4.

nal hybrid impedance. Stated mathematically,

$$R_1 R_2 = Z_o^2.$$

This means that if R_1 is made small and R_2 is made large, loss in one direction of transmission can be made smaller than 6 db. But this small loss must be paid for by a correspondingly larger loss in the other direction. Lower loss in one direction can also be obtained in a transformer hybrid, but the price is the same — higher loss in the other direction.

Comparison of Hybrid Types

The decision whether to use a transformer or a resistance hybrid may depend on several factors, but in some cases there may be literally no choice. For example, if the circuit is to be used at frequencies much higher than 1 Mc, a transformer hybrid is not likely to be seriously considered. Such factors as iron loss in the transformer core and interwinding capacitance severely limit the high-frequency performance of transformer hybrids, while resistance hybrids are nearly independent of frequency — at least until the microwave region is approached. (For microwave applications, a waveguide device such as the "hybrid tee" shown in Figure 8 would be used).

On the other hand, if the proposed application is, say, a voice-frequency repeater connection, the choice will probably be a transformer hybrid, simply because its loss is so much lower than that of the resistance hybrid. With a hybrid on each side of a repeater in a two-wire line, the two resistance hybrids would increase the transmission loss by 6 db — the equivalent of perhaps 100 additional miles of open-wire line.

If physical size and weight enter the problem, the resistance hybrid has an

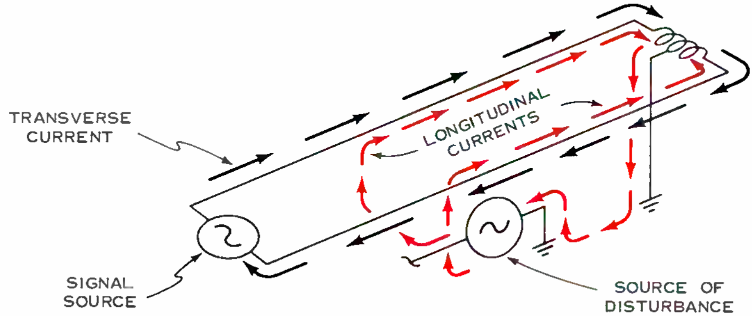

Figure 9. In a perfectly balanced line, longitudinal currents (red) cancel out in transverse circuit, but seek a ground return. Any imbalance converts some longitudinal current to transverse, producing interference.

advantage over the transformer type. Iron-cored transformers are heavy and considerably bulkier than resistors.

Cost is nearly always a factor in the choice of a hybrid. A resistance hybrid is less expensive than one which uses transformers, but the resistance type also has inherently more loss. Hence, in many cases, the cost of the hybrid itself must be balanced against the cost of additional gain.

Longitudinal Balance

Another factor which should be considered in choosing a hybrid is "longitudinal balance." In a conventional telephone system, speech or carrier signals are carried on a "balanced" transmission line consisting of two conductors at the same electrical potential above ground. Normal signal current flows in opposite directions in the two conductors, but interference often produces *longitudinal* currents which flow in the *same direction* in both conductors (as shown in Figure 9). These longitudinal currents tend to cancel each other, but they seek a path to ground. If any imbalance exists, these currents do not cancel, and interference with the desired signal results. If the ground path is through the primary winding of a hybrid transformer, imbalance can be introduced by any difference between the halves of the winding (for example, a different number of turns in the two halves). Not only does this unbalance the line on the primary side, but the interfering currents induced in the secondary windings do not cancel either. Thus, "longitudinal balance" applied to a transformer hybrid is a measure of how well the transformer resists interference.

Longitudinal balance is often measured in db. When, for example, a figure of 60 db is specified, it means that the net interference, (which is not cancelled by the transformer balance) is 60 db below the level of the desired signal. The longitudinal balance can also be measured in ohms (called Z_u, for unbalanced impedance). Here it is a direct measure of the impedance imbalance between the halves of the winding. A Z_u figure of 0.5 ohm is usually considered good for a 600-ohm impedance.

If a resistance hybrid is used, any unbalance of the two-wire line is presented to both sides of the four-wire circuit. In many cases isolation transformers would be required to correct this situation. Therefore, a transformer hybrid is often the easier solution.

Impact of Nationwide Dialing

The increased incidence of long-distance calls, particularly with the advent of Direct Distance Dialing, has changed the performance requirements for much of the telephone plant. With the subscriber dialing his own connection thousands of miles away, no operator is present to check the quality of the circuit and perhaps use another if the first one is bad. This means that all possible connections must be good. Thus, almost without exception, performance requirements have become more stringent. Certainly this is true of the requirements for hybrids.

The system of random interconnection used in the United States and Canada permits as many as seven toll links (eight on calls between the two countries) to be connected in tandem — in addition to two terminating links (tool-connecting trunks). The significance of this, in terms of hybrid requirements, is that there are many more opportunities for impedance irregularities to produce echoes, and a multitude of "sing paths." Therefore, it becomes particularly important to maintain the minimum values of echo return loss and singing margin for the random-interconnection system to consistently meet the objectives of nationwide dialing.

The increasing use of four-wire transmission facilities means that hybrids are no longer used in some of their "traditional" applications. Hybrids used with repeaters in two-wire lines are seldom used now because few new long circuits are two-wire, and those that are often use negative-impedance repeaters. Most switching facilities, however, are still two-wire — simply because of the expense of four-wire switching. So hybrids must be used to connect the four-wire circuits to the switching equipment.

A far-off ideal would be to use four-wire circuitry exclusively from drop to drop. This would eliminate many of the transmission problems now encountered. But such a system is not in the foreseeable future. In the meantime, hybrids form a vital and integral part of the modern telephone plant, and their performance requirements are becoming more stringent. •

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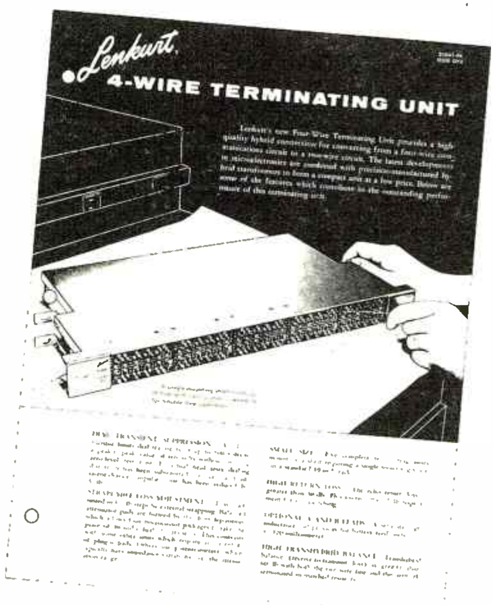

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