The Lenkurt® Demodulator

NEWS FROM LENKURT ELECTRIC

VOL. 11, NO. 9 SEPTEMBER, 1962

# COORDINATION BETWEEN CARRIER SYSTEMS

*When two or more carrier systems must share the same cable or open wire transmission path, they may interfere with each other, causing increased crosstalk and noise in both. Although this may be reduced by suitable design of the carrier equipment, increased crowding of transmission facilities may bring together systems having characteristics which increase interference. This article discusses how interference between systems occurs, the nature of the interference, and ways of reducing it.*

An ideal communication circuit would be so very clear and free from noise or interference that it would seem as though the talker were in the next room—or even face-to-face. In the case of data circuits, this freedom from interference would eliminate all errors at any transmission speed.

Unfortunately, the ideal case never prevails, and communications circuits are always subject to interference from many sources. One of the more serious problems is the mutual intereference which may occur between carrier systems sharing the same transmission facility.

When signals of any type are transmitted over wire or cable, some of the energy from the signal is coupled into adjacent pairs, where it may appear as crosstalk or noise. The degree of interference which occurs is directly related to the coupling between the pairs and certain transmission characteristics of the two interfering systems. These include relative transmission levels, frequency plans, and the type of modulation used.

Although various measures such as open-wire transpositions and the use of variable-pitch twist in cable* pairs reduce the coupling between pairs, they do not eliminate it altogether. One way of controlling the mutual interference is by using auxiliary devices such as compandors which reduce the apparent *effect* of interference without actually diminishing the transfer of signal energy from one system to the other. Since this approach is largely psychological, it is ineffective in telegraph or data transmission.

*For convenience, most subsequent references in this article will be to transmission over cable. However, it should be understood that the discussion applies just as well to open wire.

## Coordination of Levels

Interference between two systems is directly proportional to the difference in the operating levels of the two. If the signal level in the disturbing circuit is high, the crosstalk will tend to be high, on a db-for-db basis. For instance, if circuit A operates at a level 10 db higher than circuit B, crosstalk from A will appear in B 10 db higher than if the operating levels were equal. However, intereference from B will be 10 db lower.

It is important, therefore, that systems operating between the same two points maintain the same nominal transmission levels, and this level coordination should be maintained at all points along the line. If a system joins another at an intermediate point between terminals, the transmission level of the entering system should be adjusted to correspond to the levels of the other systems in the cable.

Where cables with mixed wire gauges are employed, the difference in attenuation characteristics may require a special "compromise" in operating levels in order to minimize level differences. For instance, one signal is carried on a 22-gauge pair and another on a 19-gauge pair, the signals transmitted over the 22-gauge pair will be attenuated more rapidly than those on the 19-gauge pair. In such cases, it is generally necessary to reduce the transmitting level of the system on the 19-gauge pairs by *half* the attenuation *difference* between the two.

## Frequency Coordination

The above techniques—reduction of coupling between pairs, use of compandors, and coordination of operating levels—can be used to minimize crosstalk and interference in most types of systems, including those which operate only at voice frequencies. When *carrier* systems share the same cable, however, interference can be further controlled by proper selection of frequency allocations and type of modulation. Since each carrier channel occupies its own small frequency band, it is vulnerable only to interference which falls within that band; other interference is rejected by the carrier filters which separate one channel from another.

Even the weighting characteristics of the instruments used in the communications system may have an important effect in reducing crosstalk. As shown in Figure 3, weighting characteristics and channel filters effectively "reshape" the frequency distribution of energy entering the system. The desired messages transmitted over the system are also altered, but because they are received at a much higher level than interfering energy, this shaping has less effect on clarity and intelligibility. Note that the most important frequencies for intelligibility lie between 800 and 1500 cycles per second, while most of the energy present in speech is concentrated between about 200 and 500 cps. Part D of Figure 3 represents the equivalent signal that is transferred from the "disturbing" system into the "disturbed" system.

Figure 4(A) illustrates the transmission or frequency response characteristics of the "disturbed" carrier channel. If the frequency allocations of

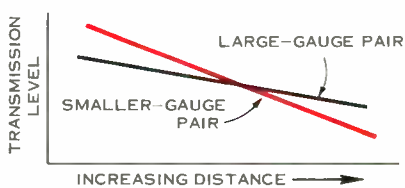


*Figure 1. Where two systems experience different attenuation rates, "compromise" reduces maximum level difference. Equal transmission levels would result in much greater difference at receiving end.*

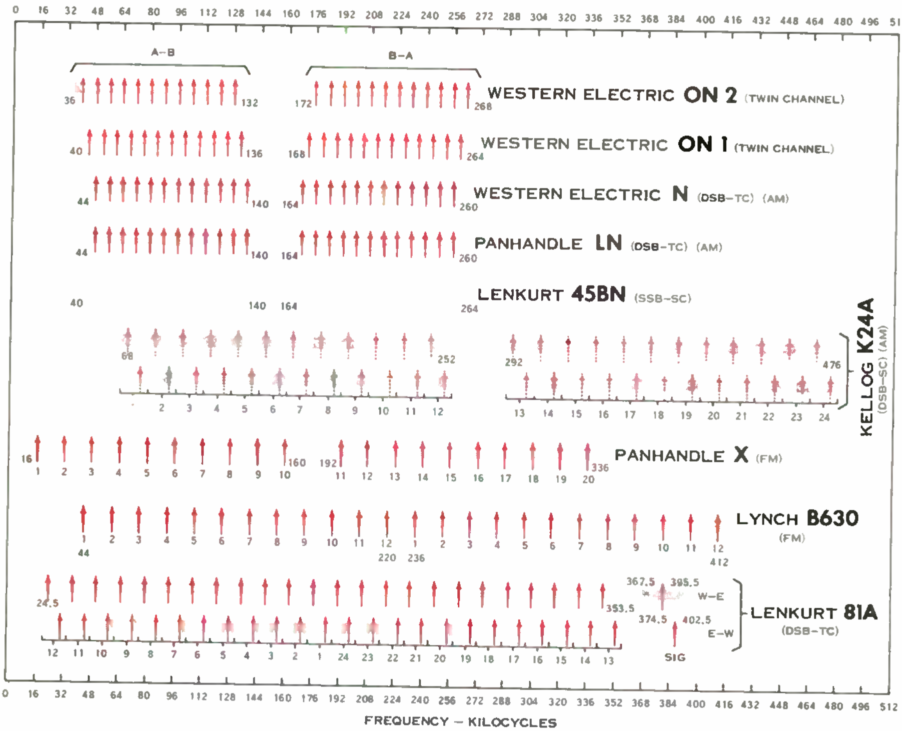


*Figure 2. Frequency allocations of several typical cable carrier systems. Note that frequency allocations differ from system to system. Interference can occur when channel frequencies coincide. Systems at upper left use carrier frequencies and operating levels designed to minimize interference, and Panhandle LN and W.E. "N" operate end-to-end.*

the two interfering carrier systems are the same, the disturbing energy will appear in the disturbed channel with the relative magnitude shown in Figure 4 (B), after having undergone attenuation by channel filters and weighting characteristics of the telephone equipment.

## Frequency Inversion

An important technique for reducing interference between systems is the use of frequency inversion between systems operating in the same basic channel frequencies. This is possible when single-sideband modulation is used, if one system transmits the upper sideband of each channel carrier, while the other system transmits only the lower sidebands. In addition to affecting intelligibility of the crosstalk, this reduces the energy coupled into the disturbed system significantly, by shifting energy peaks of the interfering signal to new locations on the transmission characteristic where there is more attenuation. Figure 4(C) shows the resulting energy spectrum when the disturbing signal diagrammed in Figure 3(D) is inverted in frequency and passed through the channel having the characteristics of Figure 4(A). Since most of the

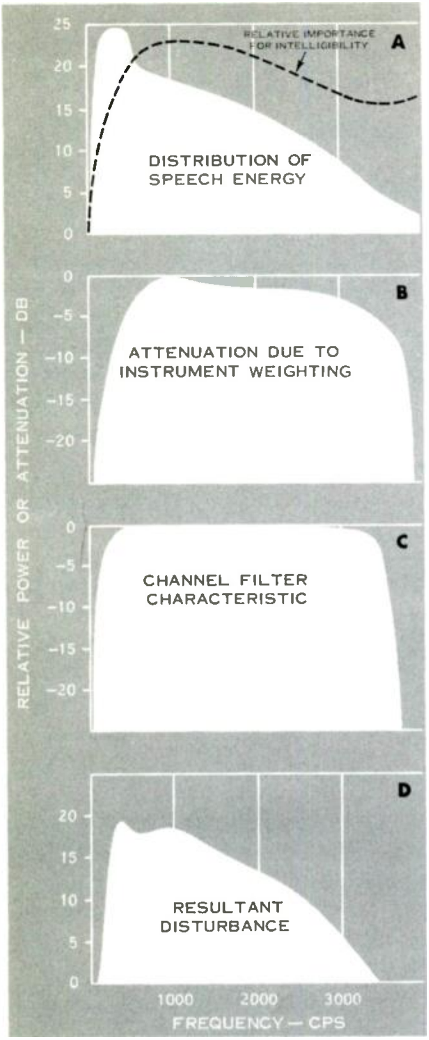


***Figure 3.** Typical power spectrum of speech and how it is affected by channel filter and instrument characteristics. Part (D) shows resulting spectrum of disturbing signal.*

disturbing energy lies in the vicinity of 1000 cps, it is sharply reduced by the relatively high attenuation introduced by the transmission characteristic of the disturbed channel. In practical systems which use this method to reduce interference (Lenkurt 33A and 45A, and Western Electric C and J open-wire carrier systems, for instance), a reduction in interfering energy of about 3 db is realized.

## Frequency Staggering

Another technique that successfully reduces interference between two systems is to shift the carrier frequencies relative to each other. Like frequency inversion, the interfering energy may be made to fall outside the pass-band of the disturbed channels. Figure 5(A) shows the energy distribution of interference when the disturbing channel carrier is shifted 1000 cps higher in frequency than the disturbed channel. When the disturbing channel frequencies are shifted 1000 cps lower than the disturbed channel, the interference appears as shown in Figure 5(B). Further shifts would result in even more improvement, but for the presence of adjacent channels. As channel carrier frequencies are shifted further, the disturbed channel begins to pick up energy from *two* channels, and interference increases with further shifting.

An additional benefit is gained by channels used for conversion. When channel frequencies are inverted or shifted in frequency 1000 cycles or more, the crosstalk becomes unintelligible. Although the same amount of interference energy may be present, it is less disturbing to talkers. Subjective tests reveal that unintelligible crosstalk can be as much as 3 db higher in level than unintelligible crosstalk to produce the same disturbing effect. Thus, frequency inversion can yield a total improvement of about 6 db, while staggering of carrier frequencies can produce even more improvement, depending on the nature of the disturbing signal and the transmission characteristics of the disturbed channels.

In the case of pulse transmission such as digital data or telegraph, "intelligibility" is not a factor, and interference is strictly a function of the amount of energy coupled into the disturbed circuit, and its frequency. If the data is transmitted over a single frequency assignment within a voice channel (as in certain types of "switched data" transmissions), the use of frequency inversion or staggering may be sufficient to cause the disturbing tones to fall outside the pass-band of the data receiver channel filter. However, where several data channels are transmitted in a single voice channel, frequency inversion and staggering may merely transfer the interference from one data channel to another. In such a case, a reduction of interference results only when the interfering tones fall outside the pass-band of the voice channel filter.

It is important to make sure that the frequency allocations of two systems which share a cable are not staggered in such a fashion that at one terminal the high level transmission of one system coincides in frequency with the much weaker incoming signal of the other system. This creates the maximum possible difference in levels, since the transmitted signal is at its strongest and the received signal is at its weakest. Assuming that both cable pairs are of the same gauge and that both systems operate at the same nominal transmitting level, near-end crosstalk will be increased by the transmission loss of the path.

## Single-sideband Versus Double-sideband

In order to simplify and reduce the cost of terminal equipment, some carrier systems employ double-sideband amplitude modulation, in which the carrier and both sidebands are transmitted. Most of the power in such a signal is in the transmitted carrier. Even at 100% modulation, the carrier has twice the power of both sidebands together. Carrier power remains constant regardless of modulation, while sideband power will vary directly with the degree of modulation.

If such a signal is staggered in frequency from another, so that the carrier frequency falls within the pass-band of another channel, it will create interference in the form of a tone, the frequency of which will be determined by its relative location in the disturbed channel. For this reason, systems that are designed to operate in the same cable with other systems which trans-

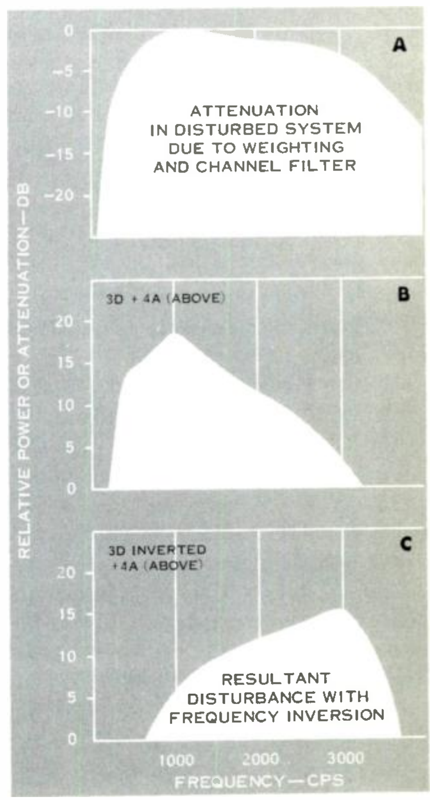


*Figure 4. Characteristics of disturbed channel and how it reduces interference. (C) shows improvement due to frequency inversion.*

mit the carrier almost invariably employ the same carrier frequencies.

In most single-sideband systems, one sideband and the carrier are eliminated, so that the transmitted signal power will depend entirely on the modulation of each channel. Only when one or more channels are modulated is power transmitted over the line. Thus, the interference caused by such a system will vary with the modulation characteristics and the operating levels used, and this will vary with the individual types of equipment.

When double-sideband systems are used in the same cable with single-sideband systems, the double-sideband (DSB) systems are inherently less susceptible to interference than the single-sideband (SSB) systems, other factors being equal. Assuming that there is no frequency staggering or inversion, only one sideband of the double-sideband transmission will be coupled into the SSB channel, so that the resulting crosstalk will be directly proportional to the difference in the levels of the two—the same as between two SSB systems.

When a DSB signal is demodulated, the voltage of the two sidebands add in phase to yield an effective increase in level of 6 db. Thus an interfering SSB signal produces interference in a DSB channel 6 db weaker than in another SSB channel.

Even when *two* SSB channels interfere with a single DSB signal, one into each sideband, the two interfering channels have no coherent phase relationship, and so add on a power basis rather than on a voltage basis. This results in a 3-db increase in interfering energy, which is still effectively 3 db lower than the DSB signal.

## Other Modulation Methods

Although single-sideband and double-sideband modulation are the most widely used means of transmitting multiple channels, other methods are sometimes used. For instance, frequency modulation may be used to reduce the need for level regulation, or to seek an improvement in noise performance. Ideally, FM is insensitive to amplitude variations and should achieve better noise performance than amplitude-modulated signals such as SSB and DSB. This improvement is actually achieved only with a relatively high modulation index or deviation ratio; that is, when the frequency deviation is

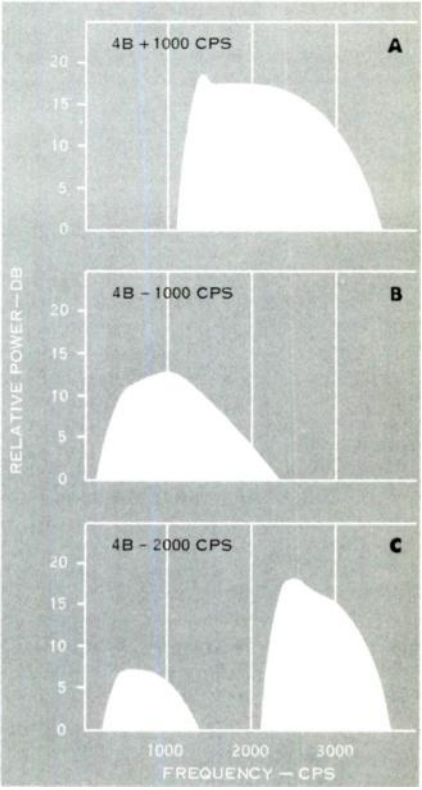


*Figure 5. Interference between two SSB channels when (A), disturbing signal is 1000 cps above disturbed channel; (B), disturbing channel is 1000 cps below disturbed channel; (C), disturbing channel is 2000 cps below disturbed channel.*

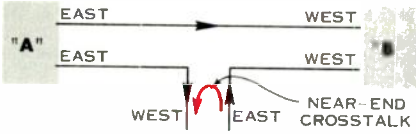


*Figure 6. "Directional" coordination is important in reducing interference. Identical allocations should be used at same location whenever possible, as at A and B. Unavoidable use of East and West terminals at C may require special treatment, such as using separate cables to junction.*

several times as great as the highest modulating frequency. Because wide deviation rapidly "uses up" the frequency spectrum available for transmitting the signal (thus sharply limiting the number of channels that can be accommodated), most FM systems restrict the modulation index to little more than unity. The result is that noise performance is essentially equal to that of a conventional DSB system. Although most noise and interference are amplitude-varying phenomena which the FM receiver should eliminate, practical deficiencies of the receiver limiters allow some interference to pass.

When no modulation is present, the carrier of the FM channel may appear as an interfering tone in other channels which take in the FM carrier frequency. This source of interference is reduced when the channel is modulated, because of the distribution of carrier power into the sidebands.

Interference from FM sidebands is very much like that from frequency-inverted SSB channels, unintelligible but proportional to the amount of energy present within the pass-band of the disturbed channel. Unlike AM sidebands, however, the energy distribution across the band will vary from instant to instant in a way that is not proportional to the energy distribution of the modulating signal, but changes as carrier energy is distributed into farther sidebands with increase in modulation level.

PCM or pulse code modulation multiplex systems introduce special problems of coordination with other systems. Practical PCM systems transmit pulses at a very high rate — about 1½ million per second. The minimum bandwidth required for transmission at this rate is nearly 1.0 mc, thus imposing a very severe transmission requirement on the cable pair. At the higher frequencies which must be transmitted in PCM, coupling between pairs becomes very much greater than at the lower frequencies which characterize SSB, DSB, or FM transmission. Although the basic nature of PCM usually permits adequate transmission under these conditions, interference with other systems in the same cable becomes intolerable, unless they are also of the PCM type. Although PCM systems are inherently able to withstand 20 to 50 db more interference than voice or carrier systems, the transmission of several systems over a single cable increases mutual interference so badly that a separate cable may be required for the return direction, in order to avoid near-end "crosstalk" or interference which causes pulse transmission errors.

Although equipment characteristics are extremely important in minimizing interference between systems, other factors, such as the way they are applied, the nature of the transmission medium, and the quality of maintenance can spell the difference between acceptable and intolerable performance. Such techniques as pair selection, and even the separation of transmission facilities, might have to be resorted to in difficult cases. ●

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## *Panhandle LN Carrier Engineering Considerations*

This new publication contains valuable information for those planning communications systems designed to interconnect with other systems using Western Electric N1 or N2 Carrier.

The publication includes a brief description of the LN system (which employs the same levels and frequency allocations as the N1 and N2), detailed descriptions of the facility requirements, and a step-by-step procedure for engineering the repeater layout (repeaters may be N, LN, or 45BN).

Copies of *Panhandle LN Engineering Considerations* are available, on request, from Lenkurt or Lenkurt District Offices.


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