The Lenkurt® Demodulator

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How to evaluate

Radio and Carrier NOISE PERFORMANCE

The tremendous growth in recent years of radio-carrier communication has been paralleled by an equally impressive, but vastly confusing, diversity of language and engineering practices. Manufacturers better known in other fields of electronics have appeared in the field of multichannel communications, and each new entrant appears to speak a different language inherited from a previous field of experience. Comparison or evaluation of systems — either existing or proposed — may be severely handicapped by the confusion of engineering practices and language used. This article reviews the noise performance of basic items of equipment, relates some of the different ways of expressing performance, and describes methods for measuring the noise performance of major items of equipment.

Of the various performance characteristics used to describe the performance of a communications systems, the amount of *noise* present in a communications channel provides one of the best immediate measures of system quality. Noise is the natural enemy of communication, working constantly to obscure the identity of a signal. Such technical characteristics as frequency and level stability, frequency response, and delay distortion are, more or less, under the control of the equipment designer and may be held to any desired value. *Noise performance,* on the other hand, is controlled not only by equipment design, but also by a combination of such other factors as increased traffic load, system layout, and operating practices.

The noise in a communications system will be found to consist of *intermodulation noise,* which increases with load, and *residual noise.* Residual noise is a useful "catch-all" term to designate all noise other than intermodulation noise. Basically, it is thermal noise from various sources such as electron tubes, transistors, modulators and the like and is present even in the absence of a signal. For this reason, residual noise is often called *idle, background,* or *intrinsic* noise. Residual noise is not affected by the amount of traffic carried by the system. By contrast, intermodulation noise becomes greater with increased traffic, and after a certain "break point" in load-handling capability is exceeded, intermodulation noise becomes excessively high.

Carrier Noise Contribution

The amount of noise which the carrier equipment contributes to the system is largely dependent upon the design of the equipment itself. Although part of the carrier noise contribution is the result of intermodulation distortion, this can be minimized by good design. Speech limiting is often used in each channel modulator to restrict the very wide range of signal levels from individual talkers. Group amplifiers and modulators are designed to handle all but the most extreme loads that would be imposed if all channels were used simultaneously.

If a frequency plan is selected which allows each modulation step to handle less than one octave, second-order intermodulation products will fall outside the passband of the carrier filters and be suppressed. Because of these design features, there is usually more residual or idle noise than intermodulation noise in properly operated carrier equipment.

Radio Noise Contribution

The noise originating in the radio portion of a communications system comes from many sources and is more difficult to control than noise from the carrier system. Frequency modulation radio is able to overcome much of the residual noise appearing in the radio system by distributing the signal over a wide radio bandwidth. However, this exchange of bandwidth for lower noise is also proportional to the signal level appearing at the receiver. Thus, fading, poor system layout, or other factors which tend to reduce the input signal to the receiver, make an important contribution to system noise.

In a frequency-modulation radio system, the FM noise reduction is directly proportional, db for db, to the input signal level, once the "FM improvement threshold" is exceeded. The threshold improvement occurs approximately 10 db above the absolute noise threshold (or so-called "tangential" threshold) of the system, and is defined as the signal level at which the system begins to suppress background noise. Between the absolute threshold (carrier-to-noise ratio of unity) and the FM improvement threshold, noise is not reduced in the system by increased input signal levels.

In conventional communications practice, the noise which occurs at the FM improvement level is still excessive. Normally, a carrier-to-noise ratio of about 30 db is required to provide minimum-quality service. The more sensitive or noise-free the receiver, the lower the signal level at which adequate communications quality is obtained.

At the transmitting end of the system, the exchange of bandwidth for noise is improved by raising the level of the modulating signal, thus increasing the frequency deviation of the radio signal. Excessive deviation, however, increases intermodulation distortion tremendously, with the result that system noise increases despite the reduction of residual noise. For this reason, the best noise performance of a radio system results from a very careful balance between residual noise caused by low signal level, and intermodulation noise resulting from excessive signal level, as shown in Figure 1. The radio equipment cannot reduce either residual or

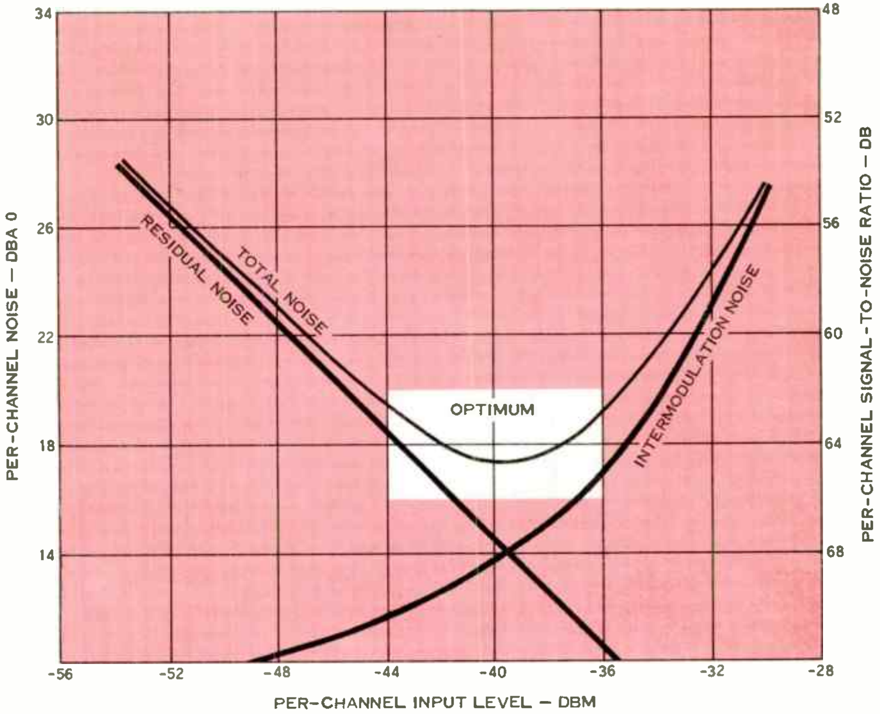

Figure 1. Increased signal levels reduce residual noise in FM radio system, but increase intermodulation. Correct operating levels provide balance between the two noise sources to achieve lowest total noise.

intermodulation noise that originates in the carrier system and accompanies the carrier signal.

Interpreting Noise Terminology

When planning a communications system, it may be more confusing than enlightening to compare the published noise performance of equipment from various manufacturers. One manufacturer may refer to "notch-to-no-notch ratio", another will specify intermodulation distortion in terms of so many db "signal-to-noise ratio" and yet another will specify noise in "per-channel dba."

The expression "notch-to-no-notch ratio" is jargon for *Noise Power Ratio*, one way of expressing the intermodulation distortion occurring in radio equipment when using one of the standard techniques for measuring intermodulation (DEMODULATOR, *December*, 1960). Noise Power Ratio (*NPR*) provides an excellent indication of intermodulation performance, when measured under standard conditions, but gives no direct indication of the *overall* performance of the system. The idle-noise performance of different types of equipment may vary widely. For example, the amount of residual noise contributed by the receiver local oscillator klystron may be substantial, and intermodulation performance figures will not take this or other types of idle noise into account.

The term "signal-to-noise ratio" (S/N) originated in single-channel communications practice and generally took into consideration only the background or residual noise in a single radio channel. With the growth of multichannel communications, it is also used to express the total intermodulation and residual noise in a single radio channel, and is frequently referred to as "per-channel flat signal-to-noise ratio." Basically, it expresses the ratio, in decibels, of signal power to total noise power in a channel. It does not take into account the actual *interfering* effect of the noise on the signal in complete circuits.

Decibels adjusted or *dba,* originated in the telephone industry as an expression of overall system noise performance. Strictly speaking, the term dba implies that the frequency response or weighting of the voice frequency equipment used is "F1A" weighting. This method of specifying noise performance is especially practical. It takes into account not only special types of noise or noise in particular items of equipment, but also the effects of all system noise.

Converting NPR to S/N

Because all of these expressions are in common use, comparisons between equipment may require that one term be translated to relative values in another. The following method of converting Noise Power Ratio to signal-to-noise ratio has been proposed for adoption by the United States *Electronic Industries Association* (E.I.A.) in its standards.

Noise Power Ratio or so-called "notch-to-no-notch" ratio is normally measured in a narrow band roughly equivalent to the bandwidth of a typical communications channel. For this reason, the first step in converting *NPR* to *S/N* requires that the Bandwidth Ratio (*BWR*) of the system be calculated in order to obtain the proper relationship between the bandwidth of the entire baseband and the bandwidth of the slot or channel:

$$BWR = 10 \log_{10} \frac{\textit{occupied bandwidth}}{\textit{channel bandwidth}}.$$

Similarly, it is necessary to calculate (in decibels) the ratio of the noise power applied to the entire baseband, to the nominal signal power appearing in a single channel. If signal power values are expressed in watts, this *Noise Load Ratio (NLR)* is

$$NLR = 10 \log_{10} \frac{\textit{Baseband Noise Test Signal}}{\textit{Channel Test-tone power}}.$$

If the Baseband Noise Test Power is expressed in dbm0 (decibels referred to 1 milliwatt at the reference or zero transmission point), the Noise Load Ratio equals dbm0, and no calculation is necessary. Figure 3 shows the noise load power equivalent to various numbers of voice channels and tone signals, as recommended by the C. C. I. R. and the Electronics Industries Association.

When Bandwidth Ratio and Noise Load Ratio have been determined, the per-channel signal-to-noise ratio may be calculated from the Noise Power Ratio:

$$S/N = NPR + BWR - NLR.$$

As an example, the per-channel S/N of a 300-channel radio system in which intermodulation is quoted in terms of a Noise Power Ratio of 50 db. It was specified that *NPR* was measured in a 3 kc "slot," and that the measurements were made with the baseband loaded with noise in the frequency range 60 to 1300 kc. Then,

$$S/N = NPR + BWR - NLR$$
$$= 50 + 10 \log \left(\frac{1300 - 60}{3} \right) - 9.8$$
$$= 50 + 26.2 - 9.8$$
$$S/N = 66.4 \text{ db.}$$

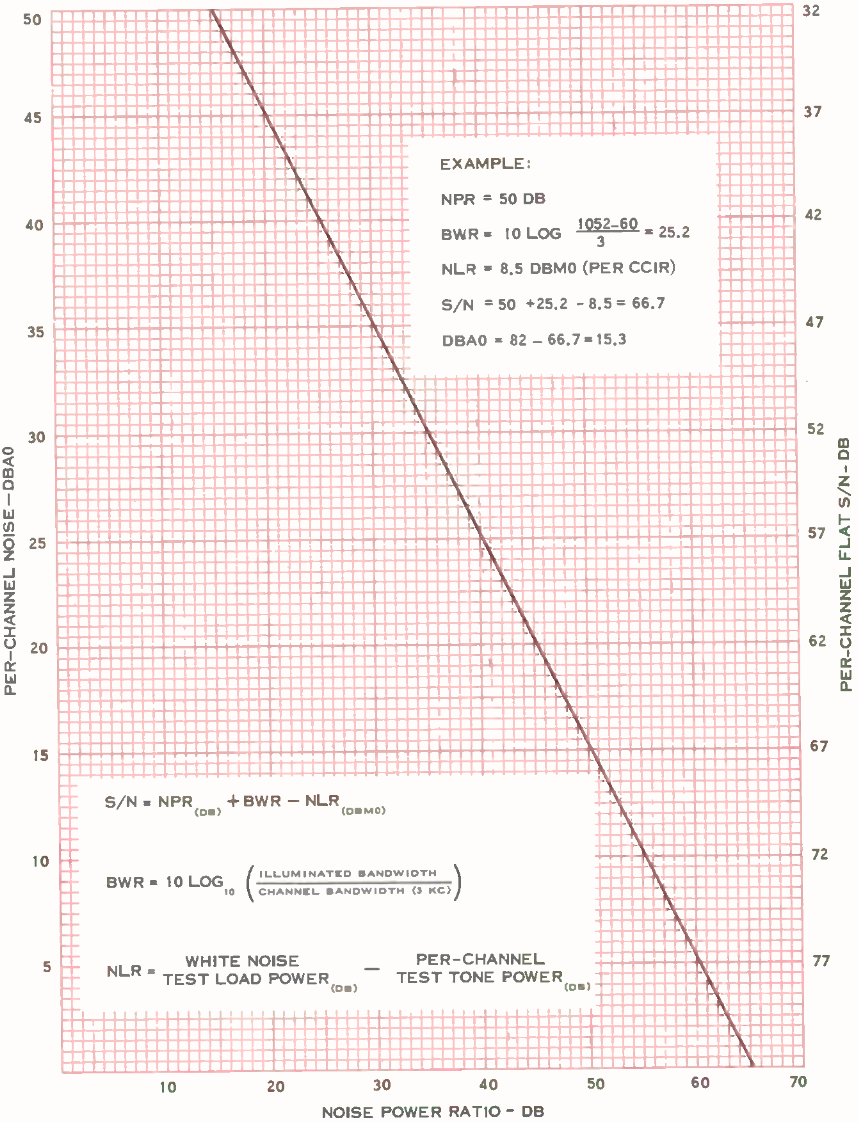

Figure 2. Relationship between Noise Power Ratio, per-channel Signal-to-Noise ratio, and dba is calculated for 240-channel system according to Electronic Industries Association formula.

The conversion of the *NPR* to *S/N* gives the signal-to-noise ratio of the channel without weighting or adjustment for the response of the human communicator and his handset. In systems where the channel response is essentially "flat" and the noise is being measured with an unweighted meter, the equivalent F1A-weighted signal-to-noise ratio may be obtained by adding 3 db to the unweighted meter reading. This addition of 3 db compensates for the noise power lost at the high and low portions of the channel passband.

Converting S/N to Dba

By definition, *dba* refers to decibels of noise power above a reference noise power, with an adjustment factor included to compensate for weighting.

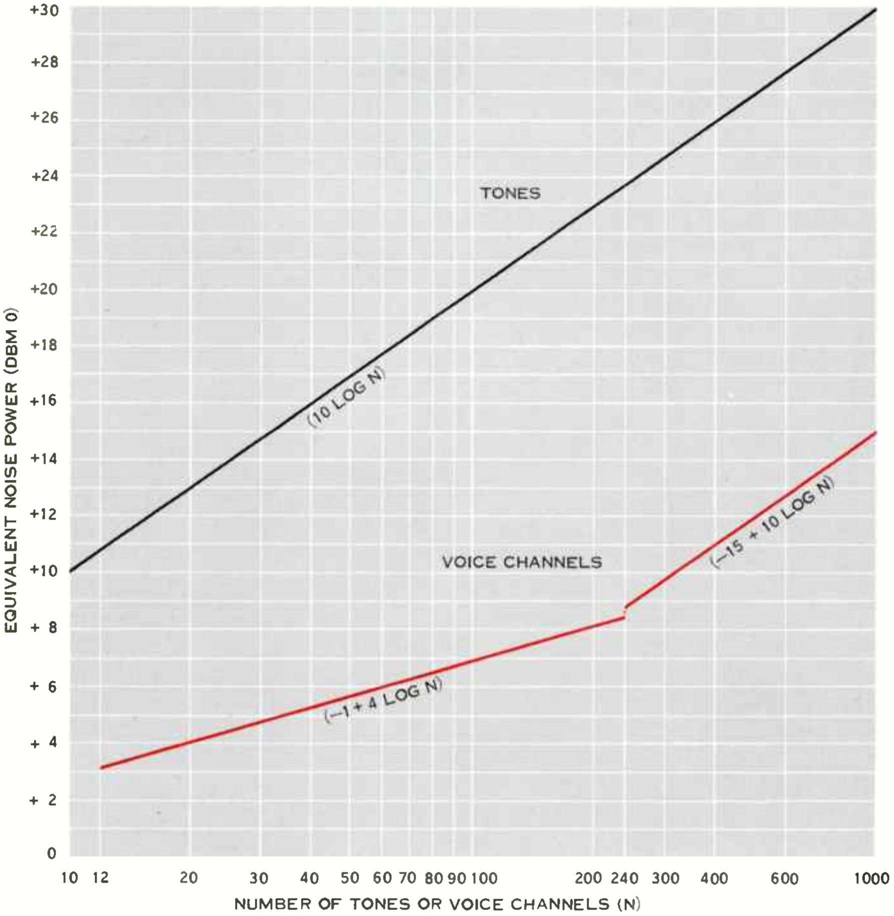

Figure 3. Equivalent white noise test signal for simulating load provided by various numbers of voice channels or tone signals. Lower values for simulating voice channels result from lower activity factor. Values shown may be used directly for Noise Load Ratio when converting NPR to S/N and dba.

Even though the equipment from which the F1A weighting was derived has been superseded by newer equipment having better performance, F1A weighting continues to be used almost universally because it provides a very close approximation to the performance of most of the world's telephone equipment.

The reference noise power to which dba is referred is -85 dbm. To obtain dba, it is only necessary to calculate how many db above this reference power the signal is. For flat voice channels, the corrected reference level is $-85 + 3$ or -82 dbm. Therefore, in this case

$$dba = 82 - (S/N).$$

Thus, a channel having a signal-to-noise ratio of 60 db exhibits 22 dba noise.

To convert the per-channel S/N of the hypothetical 300 channel system to a value in dba:

$$S/N = 66.4 \text{ db}$$

$$dba = 82 - 66.4$$

$$Noise = 15.6 \text{ dba} \quad (F1A \text{ weighted}).$$

Measurements During Installation

At the time a new communications system is installed, or whenever additions are made to an existing system, careful measurements should be made of noise performance. When properly conducted, these measurements will provide reference standards with which the long-term noise performance of the system can be evaluated, particularly if the traffic load or size of the system is to be increased. Separate measurements of carrier and radio equipment are required in order to determine their individual noise contributions.

Carrier Noise Measurements

Generally, it is impractical to obtain accurate field measurements of the intermodulation noise contributed by the carrier equipment; this would require that all channels be loaded simultaneously by suitable test signals. However, the intermodulation noise contributed by the carrier system may be estimated at periods of peak traffic if the noise performance of the radio has been determined previously. Such estimates may not be very accurate, however, since the load imposed by a large number of voice channels varies from moment to moment and may never reach a value which can be identified as "peak" load. For this reason meaningful evaluations of carrier noise usually consist of "back-to-back" measurements of idle noise.

Unlike cable or open-wire carrier systems, carrier systems for use with radio transmit and receive on the same band of frequencies. This permits the output of the transmit terminal to be connected back into the receive terminal on a "back-to-back" basis, thus permitting measurements of the carrier residual noise at one terminal.

For back-to-back measurements of idle noise, the carrier equipment is disconnected from the radio equipment and the input of the channel in which the noise is to be measured ("MOD IN") is terminated in its characteristic impedance. If the normal output or transmit level of the carrier terminal is the same as the receive level, it is then only necessary to patch the transmitter output to the receiver input. If different transmit and receive levels are used in the system, it will be necessary to adjust the transmit level to match the required receive level, either by adding or removing attenuators, or by adjusting the transmit line amplifier gain. This may require that a test tone be applied to the channel input before it is terminated, then adjusting the line amplifier gain until the correct receive level is obtained. A suitable terminated vacuum tube voltmeter connected across the demodulator output ("DEMOD OUT") will provide a direct indication of the channel idle noise power, provided that allowance is made for the difference in levels of the actual measurement point and the zero transmission point.

If the necessary jacks are available in the carrier equipment, noise measurements may be made at any modulation step in the system — channel, group, or super group. As in the case of voice channel measurements, the modulator input must be terminated in its characteristic impedance, and the transmit level adjusted, if necessary, to match the required received level.

Radio Measurements

The installation of radio equipment provides one of the best opportunities for obtaining detailed performance measurements, and provides a good check on path engineering, system performance, and equipment adjustment. In addition, installation measurements provide a reference standard of performance which is useful in maintaining the equipment and judging the effect of future growth on the system.

In an FM radio system, idle noise measurements are mainly useful for determining the sensitivity of the receiver, and then the level of the input signal to the receiver. Receiver sensitivity is determined by applying a signal to the receiver input, using a signal generator of the correct frequency, and monitoring the noise appearing at the receiver output. Input signal is increased until the output noise is reduced to the value specified by the manufacturer for minimum performance. At this point, the input signal is noted and recorded.

Even more useful than idle noise measurements are the intermodulation noise measurements of the radio. Unlike the case of a carrier, it is quite easy to measure the performance of a radio system under a simulated load. Two basic techniques are widely used, each using random noise loading to simulate the load encountered at periods of peak traffic. Both methods were described in DEMODULATOR, *December*, 1960. Figure 3 shows the noise power recommended by both the C. C. I. R. and E. I. A. for simulating various numbers of channels.

System Performance

The noise performance of a communications system is the sum of the noise contributed by the carrier equipment and the individual radio sections. In order to add these noise contributions directly, they must first be converted into watts (or rather, picowatts — 10^{-12} watt). It may be more convenient to use Figure 4 to make the addition in decibels.

The total noise introduced by a system having many repeaters may be easily calculated if the noise contribution of each section is known, and all contribute equally. Total noise = noise in one section +10 log *N*, where *N* equals the number of sections. Accordingly, in a two-section system in which each section contributes 18 dba,

$$\begin{aligned}\text{Total noise} &= 18 + 10 \log 2 \\ &= 18 + 3 \\ &= 21 \text{ dba.}\end{aligned}$$

For a system having 16 sections, the per-channel radio noise would be

$$\begin{aligned}\text{Radio noise} &= 18 + 10 \log 16 \\ &= 18 + 12 \\ &= 30 \text{ dba.}\end{aligned}$$

Total per-channel noise for the system is found by adding the carrier and radio contributions. In our 16-hop system, this would be 23 dba +30 dba, or 30.8 dba.

Radio Channel Capacity

One of the important limitations on system performance is the intermodulation noise contributed by the radio equipment. As the number of radio repeaters is increased, this noise may become overwhelming if the system is operated marginally. A common misconception is that the channel capacity of a radio system is determined primarily by its bandwidth. Actually, the load-handling capacity is equally important. A radio system with bandwidth sufficient for 240 channels, but having the load capacity for only 120 channels cannot provide satisfactory noise performance when carrying 240 channels, even if only one or two sections are used. If additional sections are added, intermodulation noise may become overwhelming at times of peak traffic, and render the system virtually useless.

Radio Pre-emphasis

Idle noise is suppressed in an FM radio system in direct proportion to the modulation index of the signal. This is the ratio of the frequency deviation of the RF carrier to the frequency of the modulating signal. Since deviation is a function of the amplitude of the modulating signal, rather than its frequency, a high-frequency modulating signal and a low-frequency modulating signal of equal amplitudes will produce the same frequency deviation. The lower modu-

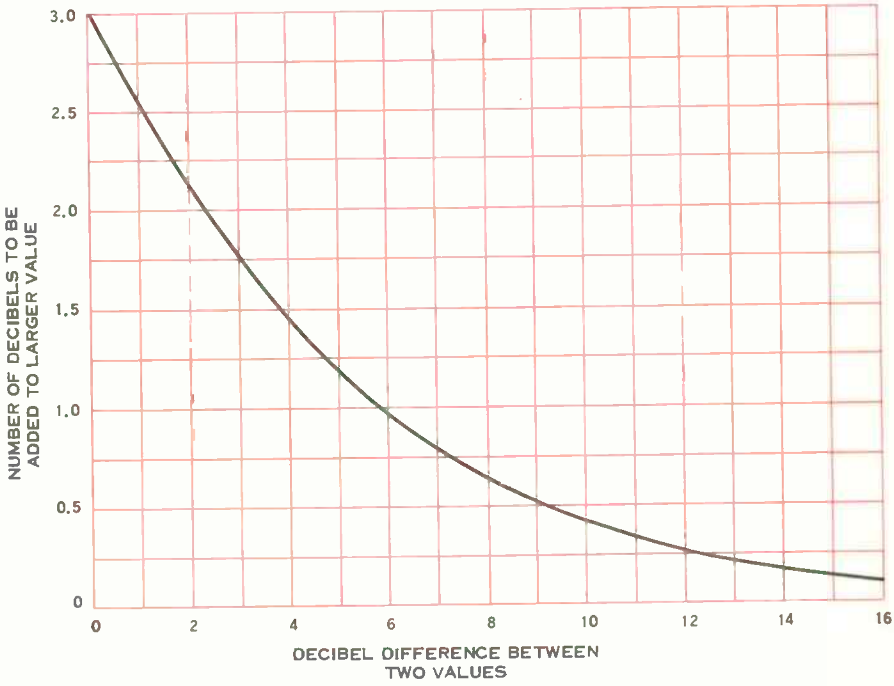

Figure 4. Graph for adding noise or signals expressed in decibels or dba. If signals differ by more than 16 db, smaller signal makes no significant contribution to total.

lating frequency, however, will have a higher modulation index than the high frequency signal and will suppress background noise more.

This is why high-frequency channels are noisier than low-frequency channels transmitted over FM radio, unless the modulation index of the higher channels is increased by increasing their amplitude. When this is done, it is called *pre-emphasis*, and serves to equalize the noise difference between high-frequency and low-frequency channels. In order that channels are restored to their correct level, a *de-emphasis* network must be employed at the receiver to compensate for the higher level of the upper channels, Figure 5 shows the effects of pre-emphasis and de-emphasis on noise across the baseband.

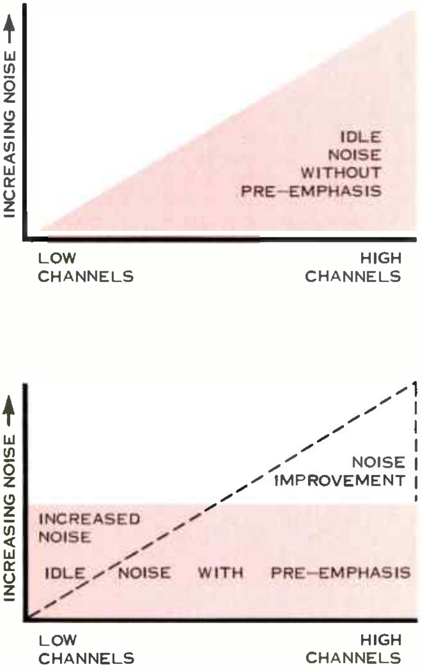

Figure 5. Idealized comparison of baseband noise distribution with and without pre-emphasis. Pre-emphasis improves high-channel noise at expense of lowest channels to achieve uniformity.

Since there is a limitation on the amount of load that can be handled by the radio system, the use of pre-emphasis requires that the level of the lower frequency channels be reduced so that the total power into the radio system remains the same. This causes noise in these lower channels to increase somewhat.

In systems intended for future expansion, the initial channels may occupy the lowest carrier frequencies, and pre-emphasis is sometimes omitted. Although this improves the noise performance of these channels during the period that the system is lightly loaded, the addition of more channels at a later time will require that some form of pre-emphasis be used if all channels are to have equal noise performance. If pre-emphasis is added later, the noise present in the original low-frequency channels will necessarily be increased. Figure 6 shows the pre-emphasis characteristic recommended by the C. C. I. R. for multi-channel communications.

For this reason it is important that a careful evaluation of system performance be made *at the time the system is installed* by loading the system to its *ultimate* capacity, and employing whatever degree of pre-emphasis will be used in the completed system. If no pre-emphasis is to be used on the system when it reaches full capacity, measurements of the noise characteristics of *all* channels, will simplify the future selection of traffic most suitable for the noisier channels.

Conclusions

Many types of communications may not seem to require the high noise performance standards that have become established in the telephone in-

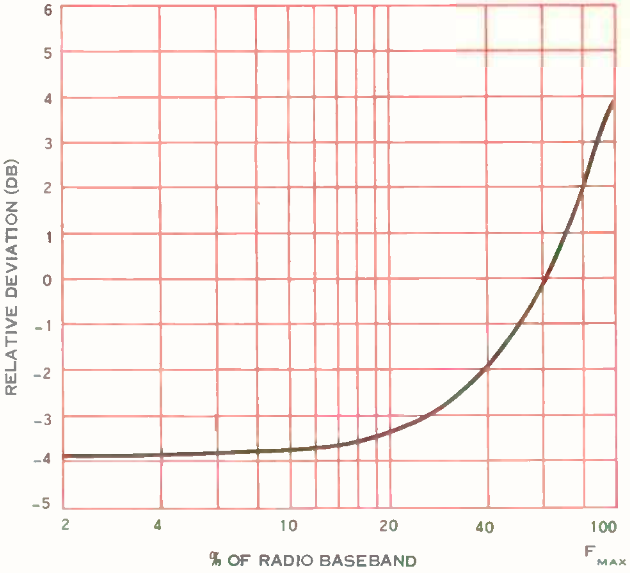

Figure 6. Pre-emphasis characteristic recommended by C. C. I. R. for multi-channel voice communications. Different characteristic is required for other types of signal.

dustry and other long distance communications services. In some applications, a minimum "talking circuit" — that is, one that just permits intelligible speech, regardless of the hash of background noise also present — is considered adequate. However, this philosophy is proving more and more to be short-sighted. This type of performance is marginal and allows no room for getting more service out of the communications plant as new needs develop.

Although a poor circuit may permit intelligible speech, other types of communication, such as data transmission, may be severely handicapped by noisy circuits. Data messages do not possess the same redundancy as speech, and which permits speech to be understood under adverse conditions. As a result, noise increases the data error rate or forces slower transmission rates. Conversely, the higher the circuit quality, the faster the transmission possible for any desired degree of freedom from error. Thus, even lightly loaded communications systems can benefit from the use of equipment and techniques designed for the highest freedom from noise. ●

BIBLIOGRAPHY

1. T. A. Combellick and M. E. Ferguson, "Noise Considerations on Toll Telephone Microwave Radio Systems," *Transactions of the A.I.E.E.*, Vol. 76, Part 1; March, 1957.
2. W. D. Baker and J. W. Joyner, "Channelization of Radio," *Proceedings of the A.I.E.E., Paper No. D.P. 59-519;* April, 1959.
3. C. A. Parry, "C.C.I.T.T. Recommendations for Multichannel Radio Relays and White Noise." *Communications and Electronics*, No. 42; May, 1959.
4. C.C.I.R., "Radio Relay Systems for Telephony Using Frequency Division Multiplex — Maintenance Measurements in Actual Traffic," *Drafting Committee Document, No. 602-E,* IX Plenary Assembly; 1959.

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