The Lenkurt® Demodulator

NEWS FROM LENKURT ELECTRIC

VOL. 11, NO. 7 JULY, 1962

Take The Mystery Out Of Microwave Literature!

Microwave communication is booming; new applications and better equipment are helping a phenomenal growth that promises to become even greater. Along with the many new users of microwave, new manufacturers are appearing on the scene. The result is a Babel of technical literature and promotional material which speak in many "languages." As many as four or five different terms for the same effect may be used in various publications. This article summarizes some basic considerations of microwave radio, and relates some of the words used to describe them.

What are the basic factors which determine microwave quality and distinguish one system from another? Is it possible to come up with a "figure of merit" which can be used to evaluate microwave equipment? Although the microwave art is too complex for any single scale or figure of merit, it is possible to "boil down" and combine some of the many diverse factors used in technical literature to define equipment performance.

Five basic factors can be used to evaluate a microwave system:

Performance Quality. In essence, this is freedom from the noise and distortion which obscures the signal or tends to create transmission errors.

Load Handling Ability. The information capacity of the system—number of channels, data transmission rate, usable bandwidth, and the like. Capacity is dependent on the performance standards required, and the linearity of the system components.

System Length. Since noise and distortion are cumulative, this refers to the number of repeater sections or "hops" that can be used in tandem before performance becomes unacceptable. System length generally must be decreased with heavy loads (large number of channels).

Reliability. Only freedom from equipment failure is intended here, since protection against fading is largely a function of system or path engineering and the use of such techniques as space or frequency diversity.

Economy. This is the factor against which the other four are measured.

In general, these qualities tend to be incompatible with each other, so that one or more can be improved only at the expense of others. Thus, if load handling ability or noise performance is improved, economy will probably be reduced.

Importance of Noise

In microwave, as in other forms of electrical communication, noise is the principal enemy. Noise obscures the signal and causes transmission errors. Although noise is constantly introduced into the communications channel from the transmission medium and the equipment itself, this can be overcome by suitable design. Actually, the amount of noise present is not as important as the relative strengths of the signal and the noise; the greater the signal-to-noise ratio, the better and clearer the transmission. Accordingly, the level or amount of noise present in the receiver —regardless of its source—determines the signal threshold or minimum signal that can be received, as well as the signal level required for good transmission quality.

Noise Sources

Two basic types of noise exist within a microwave system: *idle noise* and *intermodulation noise*. Idle noise, which is always present despite the absence of modulation, consists of thermal noise generated within mixer diodes or low level amplifiers, shot noise from klystrons, or the noise often generated by semiconductor multiplier chains used in some receivers for the local oscillator.

Intermodulation noise is introduced into the system as a result of heavy signal load or increased operating level. The greater the traffic load, or the higher the operating level, the more intermodulation noise that is introduced. Usually intermodulation increases relatively slowly until a "break point" is reached, after which it increases very rapidly. However, it is desirable to operate the system at as high a level as possible (but short of the break point) in order to improve the signal-to-noise ratio.

In an FM microwave system, higher operating levels cause greater frequency deviation, which is very effective in overcoming some of the idle noise. However, only a limited amount of deviation is possible before non-linearities in the equipment increase intermodulation noise.

If the fixed amount of permissible deviation is shared by only a few channels, the signal-to-noise ratio in each channel will be quite good. However, as the number of channels is increased, inter-

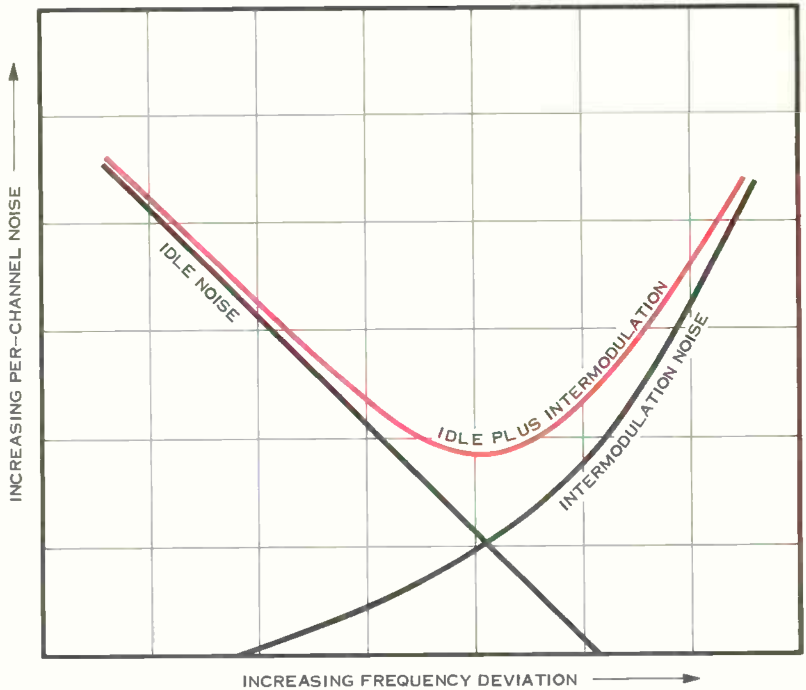

Figure 1. "Front end" idle noise is reduced in direct proportion to increase in frequency deviation due to signal level or system load. However, beyond "break point" of equipment, increasing intermodulation noise rapidly overcomes and reverses this advantage. The level at which intermodulation noise becomes dominant varies from equipment to equipment.

modulation noise limitations demand that the *per-channel* frequency deviation be reduced, with a consequent increase in idle noise. If system linearity can be improved, greater deviation can be used, thus restoring quality. Such improvements may be costly, thus placing an economic limit on the number of channels that can be handled for a given transmission quality.

How to Rate Equipment

Although the basic concept of overcoming noise to improve transmission quality is simple, many individual factors enter the problem in practical equipment. Many of these factors are sometimes used to define equipment performance, even though individually, they describe performance incompletely or even improperly. In some cases, this may originate with the design engineer, who must design "pieces and parts" of a system to standards which will result in the desired overall performance. Although these factors are meaningful to the designer, and may provide interesting comparisons, some individual fac-

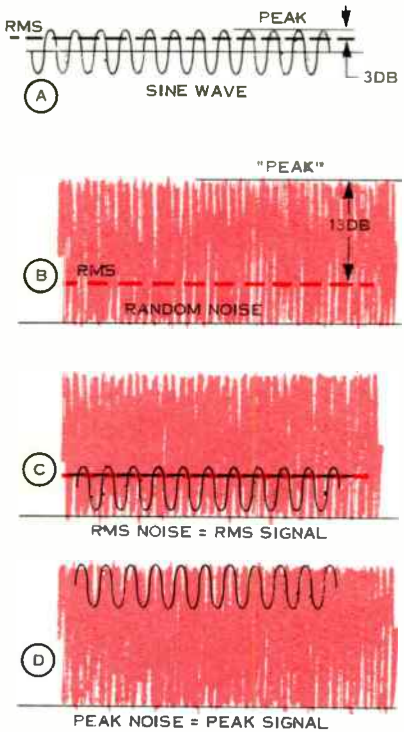

Figure 2. Effective or RMS power of sine wave is just 3 db less than peak power (A). Peaks of random noise are roughly 13 db above RMS power (B). Noise or "AM" threshold (C) is that level at which RMS signal power equals RMS noise power. FM improvement or "practical" threshold (D) occurs when signal peaks equal or exceed noise peaks, approximately 10 db above noise threshold.

tors may not provide adequate information about actual performance of the overall system. When diverse terms are used to define a single characteristic, the confusion is made even greater.

Some of the characteristics often used to describe the performance of microwave equipment are:

Receiver Noise Figure. This expresses the actual contribution of thermal noise in the "front end" of the receiver, compared to an ideal receiver. The figure is usually expressed in decibels; a receiver having a noise figure of 3 db is just twice as noisy as the equivalent ideal receiver. This is a relative expression, and by itself does not indicate receiver sensitivity. When the effective bandwidth is known, the absolute threshold of the receiver can be calculated. Thus, two receivers having identical noise figures, but different bandwidths will have different thresholds.

Noise Threshold. This is the RF input level at which signal power just equals the internally-generated front end noise power. It is determined by the bandwidth of the receiver and its noise figure according to the relationship

$$\textit{power (dbw)} = \textit{noise figure (db)} + 10 \log kTB,$$

where k is a constant (1.37×10^{-23}), T is effective antenna temperature in °Kelvin (the value 290° K is standard in current practice), and B is bandwidth in cycles per second. To convert dbw to the more conventional dbm, add +30 to the numerical value of dbw. Note: the effective bandwidth of the receiver is usually the bandwidth of the intermediate frequency amplifier (IF bandwidth), *not* receiver preselector bandwidth or the bandwidth of the transmitter waveguide filter.

AM Threshold. Synonymous with noise threshold. This term is occasionally used (even though the radio system employs FM), because there is no FM

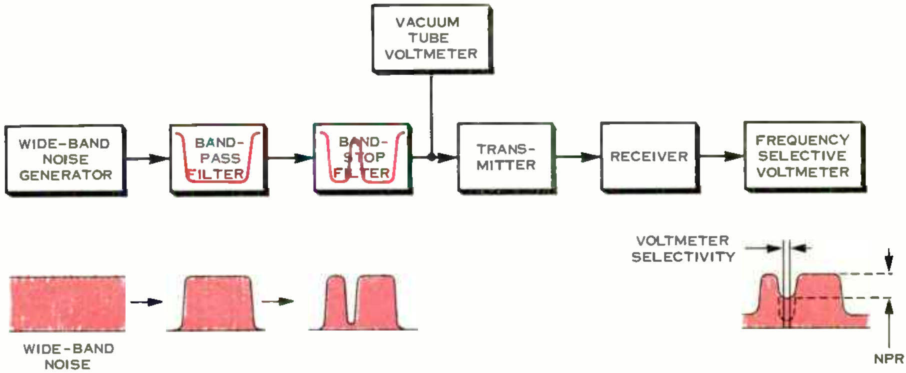

Figure 3. Typical arrangement for measuring intermodulation distortion in terms of noise power ratio. Random noise of the same effective power and bandwidth as baseband signal (but with narrow "slot" removed) is applied to transmitter. Added noise in slot is measured at output of receiver. Note that all noise contributions by both transmitter and receiver are included in a single figure; practice of quoting separate figures for transmitter and receiver is misleading.

"noise improvement" at and near threshold, and the relative *peak amplitudes* of the background noise and the signal are controlling.

Tangential Threshold. Also synonymous with noise threshold. The term stems from radar system usage and refers to a means of defining the minimum radar pulse amplitude that can be detected above the background noise.

FM Improvement Threshold. At the noise threshold level, the RMS or effective power of the signal is just equal to the RMS noise power. However, the *peak* value achieved by the noise impulses is approximately 13 db higher, as contrasted with the 3-db difference between peak and RMS values of the RF carrier. This is significant because of the unique characteristic of FM radio that signals with greater peak values dominate or "capture" the receiver, and literally suppress signals having somewhat lower peak values. Accordingly, at the *noise* threshold, noise is dominant and performance is much worse than it would be in an amplitude-modulated system at this same level.

When the signal level is increased about 10 db so that RF carrier peaks equal noise peaks, the so-called FM Improvement Threshold is reached. Above this level, the RF carrier peaks dominate, and noise is suppressed effectively. As the signal level increases, noise in the output is literally reduced — not just masked.

Typically, a baseband signal-to-noise ratio of about 30 db is obtained at the FM improvement threshold, and this improves about one db for each db increase of signal level above the improvement threshold. Normally a system is designed so that there is only a very small chance of the signal level dropping below the improvement threshold, despite propagation fading.

Practical Threshold. This is a widely used synonym for FM improvement threshold.

System Gain. Since the signal-to-noise ratio or performance quality of individual channels depends, in part, on the strength of the received microwave signal, it is important to design the overall system so that even with fading, the received signal will not drop below a certain minimum value. Since transmitter power and the receiver threshold have fixed values, only the distance between antennas, and the size of the antennas and reflectors used, are left as variables which can affect receiver input level. The attenuation of the signal as it travels through space is proportional to distance, and can be indicated in decibels of loss. Similarly, the focusing and concentrating effect of the antennas can be shown as decibels of gain. Accordingly, these two variables can be selected to just match the difference in power between the transmitter output and the signal level required by the receiver. This range of power is known as *system gain* or *equipment gain*. For example, if the transmitter has an output of one watt (+30 dbm) and the receiver has a practical threshold of −81 dbm, system gain is 111 db. Assuming that a reserve of 40 db loss is required as protection against fading, the length of the transmission path and the sizes of the antennas should be selected to introduce no more than 71 db net loss.

White Noise Loading

As indicated above, such details as receiver noise figure and thresholds do not provide adequate information about the overall performance of a microwave system. Even when the received signal is strong and satisfactory, intermodulation may become controlling, due to system load, and thus degrade performance.

One of the most definitive tests of the overall performance of a microwave system is the "white noise loading" test. (For a detailed discussion of noise loading, see DEMODULATOR, *December,* 1960.) Essentially, it requires that a band of "white" or random noise of the same frequency range and power level that simulates a multichannel signal, be applied to the transmitter. A relatively narrow portion of the noise signal (10% of the baseband or less) is blocked by a "slot" filter before the noise signal is applied to the transmitter. At the output of the receiver, the noise which has "spilled" into the slot because of intermodulation distortion is measured and compared with the noise level outside of the slot, as diagrammed in Figure 3. The ratio of noise powers is called the *Noise Power Ratio,* and provides a good indication of system performance, since all aspects of equipment performance are taken into account.

Although the Noise Power Ratio provides a good relative indication of system performance, it is more customary to rate equipment in terms of the quality of a communications channel, usually in dba. This allows the radio channels to be compared with any other kind of channel, such as those transmitted over wire, cable, or any other medium.

Per-channel noise (expressed as either signal-to-noise ratio or dba, since dba = 82 − S/N) can be derived from the NPR by relating the noise in the slot to a reference level and then applying a weighting factor. (For a detailed

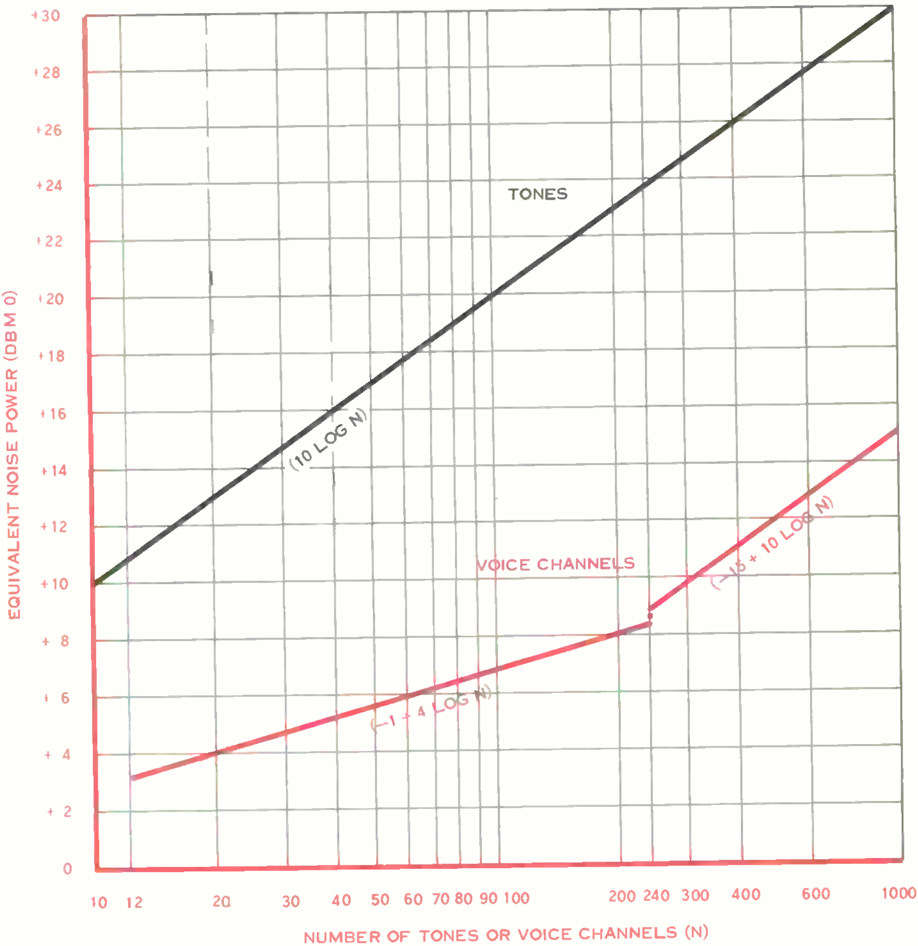

Figure 4. Random noise power recommended by C.C.I.R. for simulating the load presented by voice channels or tone signals. The two slopes representing voice channels approximate the way in which many individual channels average their power. These values also allow for the presence of some signaling and data tones.

discussion, see DEMODULATOR, *May*, 1961.) However, most commercially available noise measuring test equipment is calibrated to express noise in terms of picowatts or signal-to-noise ratio.

Note that in measuring intermodulation distortion, both the transmitter and receiver participate in the test, and the resulting noise power ratio pertains to both operating together. It is not proper to assign a noise power ratio (or NPR) figure separately to receiver and transmitter, even though the number for each then appears to be 3 db better (higher) than the NPR for the transmitter-receiver combination. For instance, if a manufacturer indicates that his transmitter has an NPR of 50 db, and the receiver also has a 50-db NPR, the actual value for the system is 47 db, twice as noisy as suggested by the "split" figures.

System Channel Capacity

Like many other fields of activity, microwave design tends to reflect the needs of the moment, or at least those qualities that appear to be desirable. With the dramatic growth of microwave, and its many new uses, operators of microwave systems are tending to look ahead and plan their systems to meet future needs. Consequently, most new microwave systems have much higher capacity than systems produced only a few years ago. For instance, in 1956, most light- and medium-capacity systems were designed to accommodate 120 channels. By 1958-59, systems with a capability of 240 channels were being promoted. Within the last year or two, the magic words have become "600 channels."

Actually, these arbitrary numbers have little meaning unless they are expressed in terms of noise performance under given conditions. Thus, a system capable of just meeting certain noise standards when transmitting 120 channels over six "hops" (five repeaters), may be quite capable of handling 400 channels over only a single hop. With 400 channels, an additional repeater might raise the noise to an unacceptable level. Conversely, the same equipment might provide very acceptable noise performance for many *additional* repeater sections if the system were loaded with fewer than 120 channels.

This trade-off does not necessarily apply equally to all systems, however. Equipment with very little idle noise, but which is poor in intermodulation distortion, might be very suitable for transmitting only a few channels (or the equivalent) for great distances. Another system, with somewhat greater idle noise but much better intermodulation characteristics, while performing relatively poorly with a light load, might be outstanding when loaded with large numbers of channels.

Accordingly, a microwave system should be evaluated under the full load for which it was designed, or that it might be called on to carry. Even better is a family of curves taken at various load levels, such as shown in Figure 6 for the Lenkurt Type 76A microwave system. Note that although the 76A is called a "600 channel" system, this particular equipment produced less than 20 dba0 in the worst channel when loaded for 960 channels. This would go up to 23 dba0 for two hops, and 26 dba0 for four.

Bandwidth. Every signal, whether it be one or more voice channels, a television signal, or a train of data pulses, occupies a certain finite bandwidth. The greater the information content of the signal, the greater the bandwidth that is required to accommodate it. Since bandwidth can place a limit on the amount of information transmitted (number of channels, for instance), the mistaken assumption has spread that bandwidth alone determines the capacity of the system. This is not so.

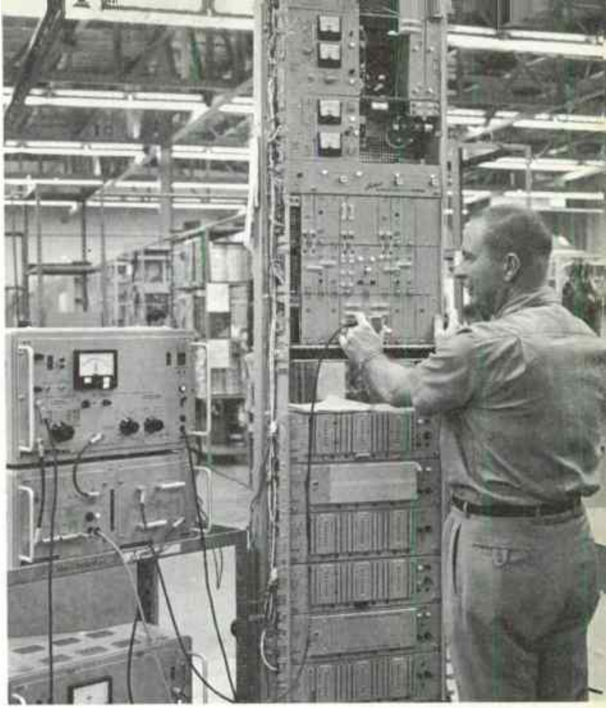

Figure 5. Production line testing of microwave equipment for noise performance. Two terminals are connected "back-to-back" through microwave attenuator. Measurements of intermodulation plus idle noise are made at both ends and middle of the baseband, using equipment arrangement shown in Figure 3.

Although bandwidth must be adequate, it is only one of several factors which determine capacity. Other important factors are the ability of the modulators and demodulators to operate over the increased bandwidth without distortion, and the linearity of baseband and modulating amplifiers.

Actually, bandwidth in excess of the load requirements is detrimental, since "front end" thermal noise increases in direct proportion to bandwidth, as indicated in the relationship shown on page 4. In the past, many types of microwave equipment have been manufactured which employed greater bandwidth than necessary for the number of channels that could be handled. This helped reduce phase distortion of the signal and also permitted the equipment to be used for diverse applications like television studio-transmitter links, thereby increasing the market.

The penalty paid for this versatility is a degradation of the equipment noise threshold. Although this does not affect performance when transmission is good and the signal is strong, it makes the system more vulnerable to fading, unless additional signal strength is obtained by larger antennas or shorter spacing between repeaters.

Transmitter Bandwidth. Strictly speaking, there is no arbitrary limit on the bandwidth of the transmitter output. By increasing frequency deviation, the bandwidth of the transmitted signal can be made as great as desired. Unfortunately, the non-linearity of the klystron or modulator will increase distortion rapidly as deviation becomes greater. The transmit waveguide filter used in all systems "cleans up" the radiated signal, and prevents high-order sidebands or other undesired modulation products from interfering with other services on adjacent frequencies. The bandwidth of this filter,

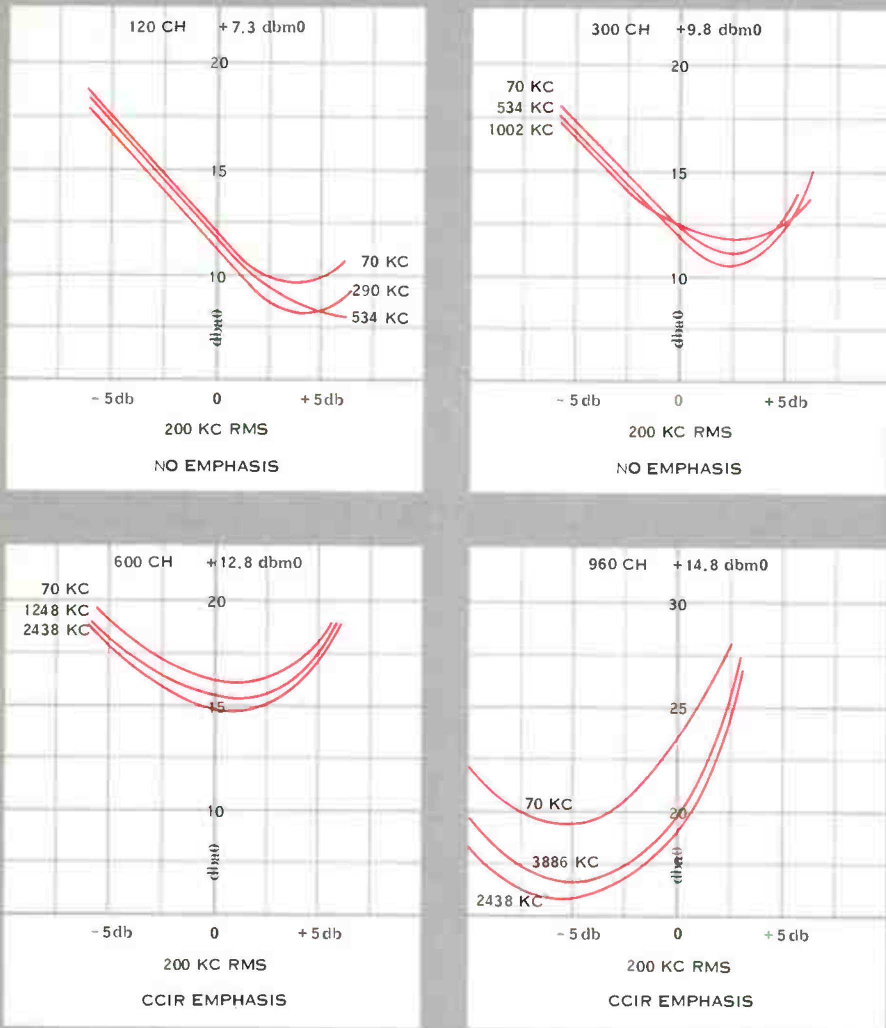

Figure 6. Family of curves showing noise performance of Lenkurt 76A microwave equipment under various load and deviation conditions. Curves for 120 and 300 channel loading were measured without emphasis, those for 600 and 960 channels with C.C.I.R. message circuit emphasis. The same broad IF passband filter was used in all cases. Note that optimum noise performance is obtained by increasing deviation for light loads, decreasing it for 960 channels. Nominal 200 kc-per-channel deviation is just right for 600-channel load, which represents the design objective of the equipment. Such performance curves vary slightly from equipment to equipment due to variations in components, equipment linearity and line-up.

however, does not determine the effective bandwidth of the system.

Receiver Preselector Bandwidth. Most microwave equipment uses a very selective bandpass filter at the receiver input, but before the mixer or first detector, to reject signals from adjacent bands. In addition, energy from noise and other interference is reduced. These filters, like those in the transmit waveguide consist of a series of tuned waveguide cavities. Generally, the more cavities used, the greater the selectivity of the filter. Since the preselector filter pass-band is always considerably greater than the effective bandwidth of the receiver, this may cause confusion when it is stated in equipment specifications. The principal value of stating preselector bandwidth is in estimating the minimum frequency spacing between adjacent systems, and the likelihood of receiving spurious signals due to local oscillator "images." It is of little use in determining receiver threshold, except that the threshold is raised by the amount of loss introduced by the preselector filter.

IF Bandwidth. The IF or intermediate frequency amplifier or its associated filters provides the ultimate selectivity for the receiver, and therefore, the entire system. It is in the IF amplifier that the signal undergoes the greatest amplification, and it is important that all spurious signals and interference be sharply rejected. Normally, IF bandwidth is measured at the "3 db points", or those points on the frequency response characteristic where the signal is attenuated 3 db. This is also known as the "half power" point. Occasionally IF bandwidth may also be given at the 0.1 db points, to indicate the full IF bandwidth that can be used with a minimum of phase or envelope delay distortion. Like other technical features, this is relatively academic, since baseband frequency response is hardly affected by the response of a properly designed IF amplifier. Although variations in IF amplifier response may introduce some phase distortion, this is normally eliminated by the phase equalizer present in most modern broad-band microwave equipment.

More Questions?

In preparing this article, based on typical inquiries received from time to time, it became obvious that all the semantic distortions and ambiguous expressions often found in microwave literature could not be discussed adequately in this limited space. Accordingly, another article on this subject is planned for the near future.

Rather than depend on our own feelings and ideas about which items to include, we invite you, the readers, to help shape the article. Your comments and questions about confusing terminology will be welcome; questions and suggestions will be acknowledged or answered individually, and those most typical will be discussed in the DEMODULATOR. •

Errata: In the June, 1962 issue on "Maintenance of Transistorized Communications Equipment," the meaning of the caption for Figure 6 was inadvertently reversed. The second sentence should read: "Neon lamp glows *unless* transistor is shorted, open, or has excessive leakage."

In Figure 7, an essential load resistor was omitted from the line connecting the collector to the (−) terminal.

Lenkurt Electric Co., Inc.
San Carlos, California

Bulk Rate
U.S. Postage
Paid
San Carlos, Calif.
Permit No. 37

MR. HUGH J. BROWN
KELLOGG SWITCHBOARD & SUPPLY CO.
775 HARD RD.
WEBSTER, NEW YORK

R-25701 21F

RETURN REQUESTED

New Systems for Fault Alarm & Remote Control Described

A new family of Alarm and Control systems, known as the Type 936, provides a series of integrated units to report alarms from many remote locations, and to allow a master station to control various functions at remote, unattended stations.

The equipment is completely transistorized. Three-state, phase-shift modulation is used to improve transmission, and a "fail-safe" design approach eliminates spurious reports due to equipment malfunction.

Detailed descriptions of the three basic systems are provided in a new publication, Form 936-P4, free on request from Lenkurt or Lenkurt Field Offices.

LENKURT ELECTRIC SAN CARLOS, CALIFORNIA, U.S.A.

GENERAL SYSTEM

District Offices
New York • Minneapolis
Atlanta • Dallas
Chicago • San Carlos
Washington, D.C.

The Lenkurt Demodulator is a monthly publication circulated free to individuals interested in multi-channel carrier, microwave radio systems, and allied electronic products. Permission to reproduce material from the *Demodulator* will be granted upon request. Please address all correspondence to the Editor.