The Lenkurt® Demodulator

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Microwave Intermodulation Distortion —and how it is measured

Modern multi-channel microwave systems achieve their best performance when operating levels are carefully controlled. If modulating levels are increased in an FM system, background noise is reduced by the wider frequency deviation, but intermodulation distortion goes up. Equipment designers seek to minimize intermodulation distortion without making the microwave equipment so expensive as to discourage its use. This article discusses some characteristics of intermodulation distortion and how it may be measured.

Every element in a communications system tends to degrade signal quality to some extent, even in the very best equipment. Amplifiers, modulators, klystrons, and other such components are inherently non-linear. That is, over a wide band of frequencies, amplitude response or rate of phase shift will not be uniform. Such techniques as negative feedback go a long way toward improving linearity, but can never achieve perfection. As performance approaches ideal, cost of the equipment rises astronomically, so that economic considerations eventually determine the performance limits of the system.

Intermodulation distortion increases as the load to be handled approaches the capacity of the device. In amplifiers, the power-handling capability of the amplifier may be the limiting factor; in modulators, klystrons, modulation detectors, and the like, bandwidth may determine how much load the device can accommodate without appreciable non-linear distortion.

Harmonics and Intermodulation

If a single frequency is passed through a non-linear device—an amplifier, for instance—the output signal will contain not only the funda-

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mental frequency *f*, but also harmonics of the frequency: *2f, 3f, 4f . . . nf*.

Similarly, if more than one frequency is passed through the non-linear amplifier, harmonics of each of the fundamental frequencies will appear in the output signal. Since these harmonics were not present in the original signal, they are the result of distortion caused by the amplifier's non-linearity. The more non-linear the amplifier, the greater the signal power that is converted to distortion products.

Another characteristic of non-linear devices is that the various frequencies passing through the device modulate each other so that additional frequencies are produced. These *intermodulation products* represent not only the sum and difference of the original input frequencies, but also the sum and difference of the various harmonics and the intermodulation products themselves.

For example, assume that the input frequencies are called A, B, C, etc. Then the harmonics which appear in the amplifier output will be 2A, 3A, 4A . . . *n*A; 2B, 3B, 4B . . . 2C, 3C, 4C, and so forth. Actually, there are an infinite number of harmonics of each fundamental frequency, but the magnitude of these harmonics diminishes very rapidly with higher order, so that only the first few harmonics of each frequency have much significance.

Second-order intermodulation products consist of such frequencies as (A + B), (A - B), (A + C), (A - C),

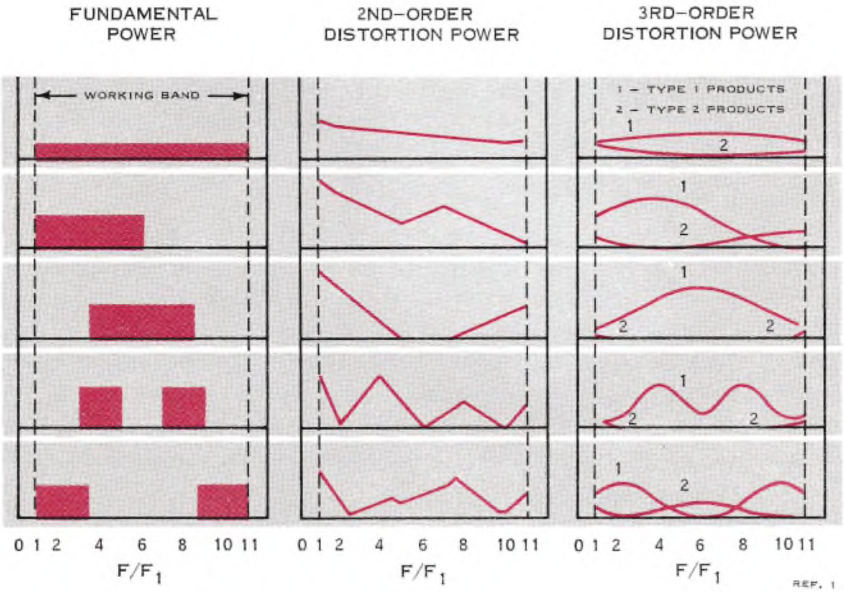

Figure 1. Each type and order of intermodulation product has a different distribution when fundamentals are distributed non-uniformly (power is the same in each example). Second-order products are greatest problem in wideband radio systems with "back-to-back" repeaters. Type 1 third-order products are most disturbing in narrow-band systems, cable and coaxial systems, and those with heterodyne repeaters.

(B + C), (B - C), and so forth. Third-order products are much more complex, and will typically consist of such frequencies as

(A + B + C), (A - B - C) . . . ,
(2A + B), (B - 2A) . . . ,
(A + B - C) . . . ,
(2A - B) . . . .

As indicated in Figure 1, second- and third-order distortion products have different distributions across the band.

The differences result from the way in which the various intermodulation products form. Second-order intermodulation can only be (A ± B), (B ± C), and the like. Third-order products, on the other hand, may be formed from complex combinations of many frequencies, both above and below the fundamentals. The third or higher-order products are divided into two groups: Group 1 products, which add on a voltage basis at each repeater, and Group 2 products which add on a power basis (except under certain special conditions). Normally, the distortion power of Group 1 products is much greater than that of the Group 2 products, and, along with second-order products, provide the greatest distorting effect.

The various types of intermodulation products will have different effects in different types of equipment. For instance, even-order products cannot appear in narrow-band systems unless the ratio of the highest frequency to the lowest is at least 2 to 1 for second-order products, $1\frac{1}{2}$ to 1 for fourth-order products, and $1\frac{1}{4}$ to 1 for eighth-order products. Odd-order products, on the other hand, appear in the band regardless of the frequency ratio. For this reason, third- and other odd-order products present the greatest problem in narrow-band systems.

Complex Signals

It is unlikely that single frequencies will be used to transmit information over a modern radio system because of the limited information capacity of such methods. Invariably, information is conveyed by a complex signal of some sort, such as produced by high-speed telegraphy, speech, or music. The number of individual frequencies in such signals is very large. When many channels are transmitted over a single system, the number of fundamental frequencies becomes extremely large.

Under such circumstances, the intermodulation products are so widespread that they resemble noise in their randomness. In a wideband radio system, intermodulation in a given channel raises noise level in other channels, rather than appearing as crosstalk.

As the signal level approaches the "break point" or overload level, intermodulation power tends to increase faster than the increase in level. In a frequency-modulated radio system, increased signal level increases the frequency deviation. This, in turn, decreases background noise in direct proportion to the increase in deviation.

The noise in a system carrying many voice channels never stays at a fixed level, but varies from instant to instant as the number of channels and the signal power of each changes. Differences in how loud or how fast the various telephone users talk may affect the total intermodulation noise at any given time (See DEMODULATOR, *August, 1959*).

Measuring Intermodulation

High-density carrier systems—those with 60 channels or more—provide a complex signal that strongly resembles "white" noise in its randomness and uniform distribution across the band. When such a signal is transmitted over a modern radio system, intermodulation products appear both within the base-band and out of band. If one or more channels are left idle, it can be observed that the noise level in these channels increases when the rest of the system is heavily loaded.

This immediately suggests a way of measuring the intermodulation characteristics of the transmission system. Because the load on the actual working system is variable and cannot be controlled, a substitute load must be found which is representative of a typical signal. Thermal or "white" noise is generally used, with the noise power being adjusted to represent the power of the actual signal. Figure 2 shows a block diagram of a typical arrangement used for measuring intermodulation distortion in radio systems.

The noise source is usually a phototube, diode, or transistor operated in such manner as to provide a wide-spectrum noise signal. The noise output is amplified and passed through a band-pass filter (usually a high-pass plus a low-pass filter) which limits the noise spectrum to the bandwidth of the radio equipment.

Following the noise generator, its associated amplifiers, and level control, a band-stop or "notch" filter is inserted to *eliminate* the noise signal from a selected band. Several such band-stop filters are usually used, in order to measure intermodulation products in different parts of the band. Usually, only one band-stop filter is used at a time, and some provision is made for quickly substituting filters.

The broad-band noise signal from which the "notch" has been eliminated by the band-stop filter, is applied to the system at the same power level as the normal wide-band signal. If the system produces intermodulation distortion, the noise in the notch will increase, and this may be measured at the receiver with a frequency-selective voltmeter. In normal practice, noise in the notch is measured with the band-stop filter in the transmitting circuit and then out. The ratio (in decibels) of the noise power, with no band-stop filter in the circuit, to the noise power

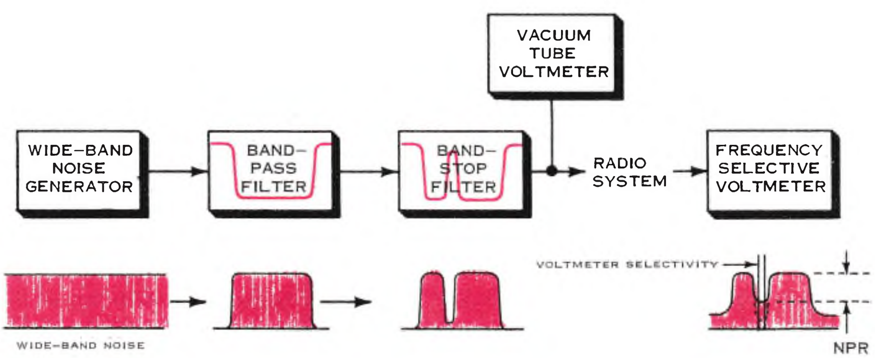

Figure 2. Block diagram of a typical arrangement for measuring intermodulation distortion in terms of Noise Power Ratio.

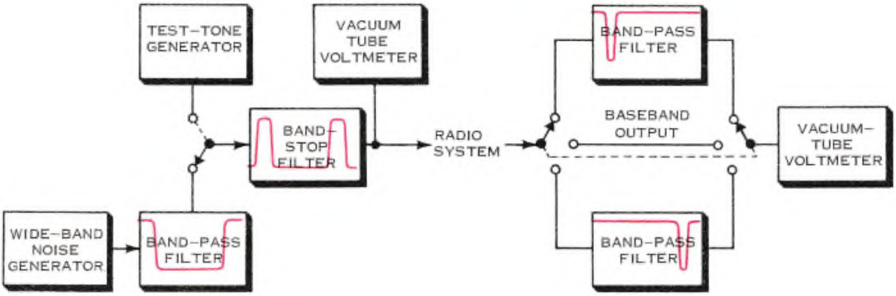

Figure 3. Block diagram of arrangement for determining signal-to-intermodulation noise ratio directly. System is calibrated with test-tone, then noise load is substituted. Total noise power from final filters provides direct signal-to-noise value.

present with the filter in the circuit is called the *Noise Power Ratio*, usually abbreviated NPR, and is frequently used to express the intermodulation distortion produced in communications equipment. NPR provides a measure of the intermodulation performance of the radio equipment over which carrier channels may be transmitted, but does not indicate how much interference will be experienced within *each* channel. Since other types of interference, such as crosstalk and background noise, are expressed in terms of their power or effect per-channel, it is desirable to express intermodulation distortion similarly, thus putting all disturbing effects on a common basis.

Intermodulation distortion may be expressed in terms of per-channel signal-to-noise ratio by adding a "correction factor" derived from the ratio of total signal power to the power appearing in one channel. Since power is distributed uniformly, this is a function of bandwidth. For example, if the total baseband is 1200 kc and the total signal load is +10 dbm, the distortion power appearing in a single 3-kc channel will be 1/400 of the +10 dbm total power. This is 26 db below +10 dbm, or -16 db relative to the channel test tone. Thus, in this example, a 16-db correction factor would have to be added to the Noise Power Ratio in order to express intermodulation distortion in terms of signal-to-noise ratio. Note that the correction factor will be different for different bandwidths and total signal power.

If it is desired to express intermodulation noise in terms of its disturbing effect, an additional 3 db must be added to the flat signal-to-noise ratio to obtain the F1A-weighted signal-to-noise ratio. This may be converted to dba by subtracting the F1A-weighted signal-to-noise ratio from -85 db. In circuits using C-message weighting, 1.5 db should be added to the flat signal-to-noise ratio to obtain C-message weighted signal-to-noise ratio. Subtracting this from -90 db yields dbrn (C-message).

An alternate way of measuring intermodulation distortion is diagrammed in Figure 3. In this method, the entire system is calibrated by transmitting a test tone through the system. The test tone frequency is selected to lie in the center of a band-pass filter at the

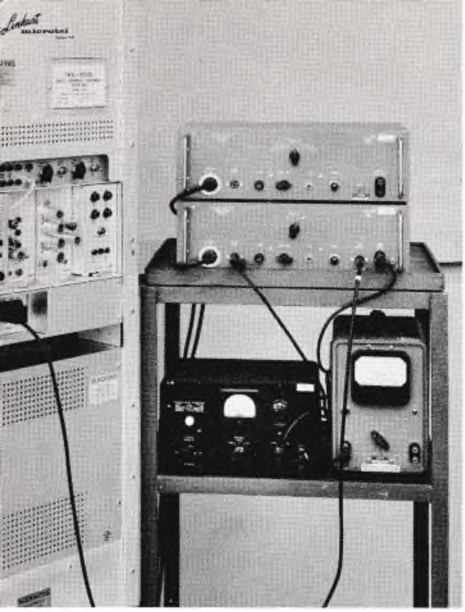

Figure 4. Lenkurt Type 5203-5204 Distortion Test Set in use. This equipment works on principle diagrammed in Figure 3.

output of the receiver. The received test tone power then becomes the reference power.

The test tone is removed and a wideband noise signal of a power which represents the baseband signal is transmitted through a band-stop filter which rejects a band of frequencies somewhat wider than the band accepted by the receiver band-pass filter. The total power measured at the output of the receiver band-pass filter is proportional to both the intermodulation distortion and the bandwidth of the receive filter. By applying a correction factor to account for the bandwidth of the filter, intermodulation distortion power may be read directly from the output of the receiver band-pass filter.

Both methods will give the same results. The latter method has the advantage of permitting special test equipment to be constructed in which filter characteristics are allowed for in calibrating the equipment, thus eliminating calculations and greatly simplifying the measurement of intermodulation characteristics. Figure 4 shows an intermodulation test set designed and manufactured by Lenkurt. This equipment requires only a noise source and ordinary laboratory RMS-indicating vacuum tube voltmeter. The instrument is calibrated to give direct signal-to-noise values (flat-weighted) for intermodulation distortion.

Intermodulation distortion measurements show the performance of the system as a whole, rather than of individual components, such as transmitter and receiver. If separate performance ratings are provided for separate components, they should be added together on a power basis to obtain a realistic evaluation of system performance. ●

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