The Lenkurt® Demodulator

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SPEECH LOADING *of carrier systems*

One of the principal engineering problems in the design of a carrier system is the interfering effect of noise or crosstalk. The most likely source of such interference is modulation products due to distortion which could occur during momentary overload of the system at times of heavy traffic. Although such distortion can be reduced by suitable design, it costs too much to provide better performance than is required during all but the busiest hour. Since speech frequencies and power are distributed according to certain statistical patterns, probability theory may be used in estimating the loading effect of various numbers of carrier channels. This article discusses some of the characteristics of telephone traffic and how they affect the loading of carrier systems.

Most long distance telephone circuits these days are likely to be transmitted over carrier systems. In such systems, many channels may be handled together by common amplifiers, modulators, or demodulators. For reasons of practicability, none of these transmission elements are perfectly linear. As a result, distortion occurs when traffic is so great as to overload the amplifiers or exceed the design rating of the modulators and similar circuit elements.

In the case of a single channel, modulation products resulting from non-linearities are directly related to the power and frequency of the signal applied to the channel, and appear as a form of distortion of the signal.

In multi-channel carrier systems, however, the case is entirely different. Most modulation products appearing in any given channel are unrelated to the signal applied to that channel. At higher carrier frequencies, modulation products may be distributed over many other channel allocations. Thus, instead of causing distortion of the impressed signal, carrier system overload results in background noise and crosstalk that increases as the system load becomes greater. In some cases, crosstalk may even be intelligible. In larger systems, however, most distortion appears only as random noise which reduces signal-to-noise ratio.

Distortion

Distortion increases significantly when large signal voltage peaks drive some element in the system beyond its region of linear operation. In the case of amplifiers employing negative feedback, there is only a slight increase in distortion and intermodulation products as signal level increases, until the amplifier "break" point is reached. This point is achieved when grid current begins to flow or plate current cut-off occurs. Accordingly, distortion increases very rapidly with signal voltage after the "break" point is reached.

Intermodulation products occurring below the amplifier break point consist mostly of second and third harmonics of the signal. When the signal voltage exceeds the "break" point of the amplifier, many higher order modulation products appear, spreading interfering energy over a very wide frequency range, sufficient to cause interference in most or all of the channels in a large system.

Now, it is very desirable to maintain the signal level as high as possible without causing overload. A high signal-to-noise ratio enhances the quality of communication and reduces interference. It is very easy to achieve a maximum signal level that falls short of causing distortion if only one channel is involved and the transmitted signal is at a fixed level, as in telegraph transmission. In multi-channel carrier, however, even where the transmission level of each channel is known and does not vary, the power level of the composite signal does vary. Since many different frequencies are transmitted, the phase relation between these various frequencies varies randomly. Sometimes several frequencies will reach a peak together, causing a momentary rise in total voltage. At other moments, the various frequencies may combine to lower the total signal voltage well below average. A simplified example is shown in Figure 1. In this example, two frequencies of equal amplitude are applied to an amplifier. Since only two tones are involved, the output variation is periodic, rather than random. In this case, output power will vary from nearly zero to a value equal to the sum of the power outputs of each taken alone.

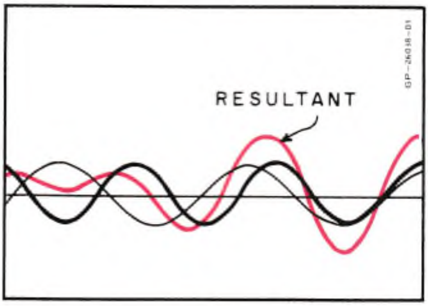

Fig. 1. Phase addition and subtraction of two signals of equal level but different frequency cause power to vary periodically.

As numerous tones are applied to a common amplifier, as in a carrier system, the phase combinations that may occur greatly increase. The periodic changes in output illustrated in Figure 1 are reduced as the various signals "average out." However, there is always the chance that many or all of the signals could achieve a peak value simultaneously. It can be shown mathematically that this becomes less and less likely as the number of channels increases.

In the case of telephone channels which carry speech or similar complex waveforms, the structure of the composite input signal is far more complicated than when simple tones comprise the input signal. Not only does each signal consist of a variety of frequencies, but also of a great range of amplitudes. Various frequencies comprising the speech may be characteristically of lower amplitude than others. This great variation works to the advantage of the carrier system designer by increasing the randomness of the signal changes, but makes the possible extremes of signal voltage more difficult to calculate.

In actual telephone carrier systems, many other factors may also influence the "load" on the system. Some of the more important include speech habits of the telephone user, hourly variations in system use, the psychological effect on the speaker of circuit quality, and the technical characteristics of the subscriber's equipment and local telephone plant. Holbrook, Dixon, Subrizi, and others at Bell Telephone Laboratories have led in determining the nature of these factors and their effect on system loading.

Variable Volume

Those who talk over telephones show a remarkable sensitivity to the "presence" or quality of the circuit. Apparently there is a built-in compensation mechanism that causes a person to talk louder if the circuit is even slightly degraded. Bell Telephone Laboratories discovered that the average subscriber raises his talking volume about $1\frac{1}{2}$ db for every 1,000 mile increase in the length of his call. Such a response might be psychological, or due to increased noise, distortion, or other characteristic that would tend to mask the speech. This sensitivity to circuit quality may account for a decrease in talking volumes in the past several decades. In 1939 the measured average speech volume (power) into long distance switchboards was about -10 dbm, and about -12 dbm for local calls. In 1953, observed levels averaged -15 dbm for long distance calls and -19 dbm for local calls. As fidelity of transmission improves, these levels may be expected to continue dropping.

Circuit Activity

In general, conversations are about equally divided between the two talking parties. Obviously, each carrier channel is idle half the time while one party listens to the other. In addition, pauses, spaces between words and syllables, and time required to establish a connection and summon the called party to the phone, further reduce average channel activity. All of these factors add together so that an average channel actively transmits speech only about 25 to 40% of the time. Since this phenomenon is also a random contribution to system loading (or unloading), it can only be predicted on a statistical basis, since there is always the possibility that every talker in the system *could* talk simultaneously, raising the activity factor momentarily to 100%. Figure 2 shows how activity varies for different numbers of channels, if the activity factor is 25%.

Sure Thing

In a gambling casino, the management may not know whether any given player will win or lose a play, but it can calculate with great precision the *percentage* of plays that the house will win, and the share of money introduced into the game that it will retain. In a similar fashion, telephone system engineers use probability to calculate the range of volumes to be expected, the number of channels active at any instant, and the likelihood of an unfortunate combination of signals that would result in system overload. Thus, the telephone engineer doesn't know how you as an individual will speak into your phone, but he can predict with reasonable certainty the resultant of a number of individual calls, as it will appear to the carrier system.

By using statistical methods of computing load, a system designer can provide a transmission path that will give excellent service without danger of overload except during the very busiest periods. Telephone company practice has been to design the entire system for a "break" point of 1% of the busiest period. Thus, for the busiest hour, overload *may* occur during 36 seconds (1% of 3,600 seconds). Since this total time is distributed throughout the entire period as a number of brief moments of possible audible disturbance, the net effect on an individual conversation is negligible. To increase system capability to assure *no* overload at all would increase system cost way out of proportion to the benefits derived.

Before statistical calculations can be performed, it is necessary to have some data on which to base the calculations. A series of tests were conducted by the

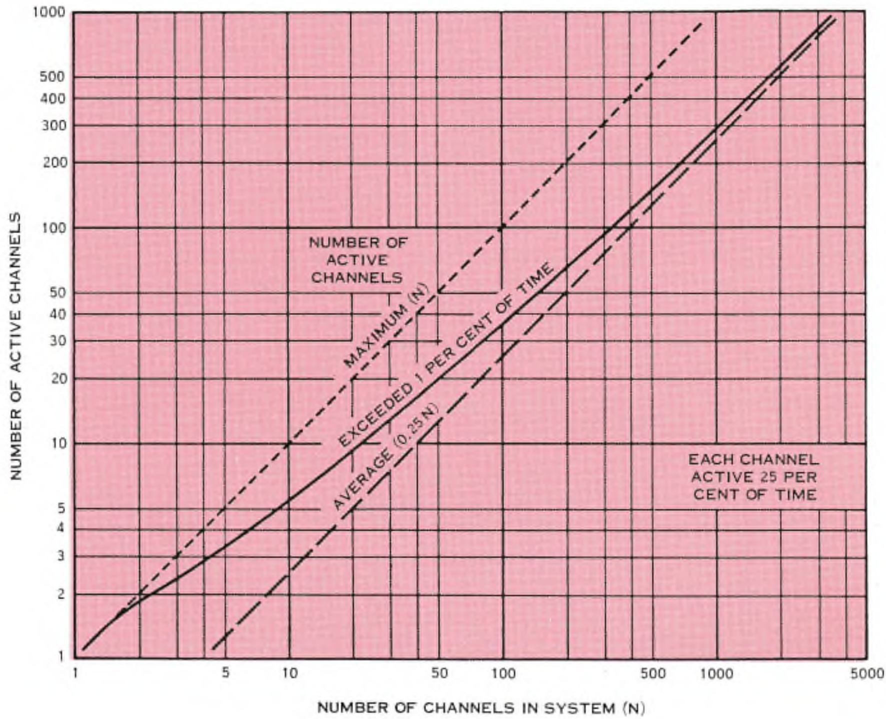

Fig. 2. Number of active channels exceeded 1% of the time in various systems when average activity is 25%.

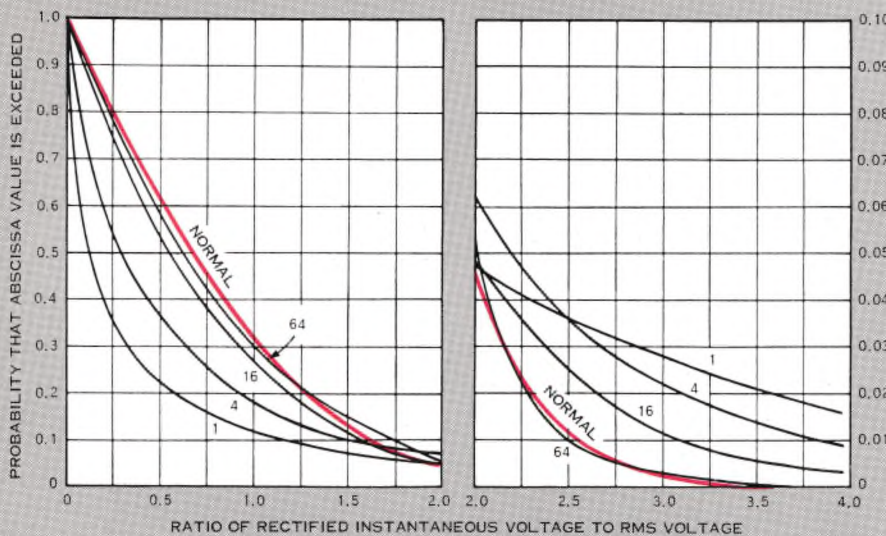

Fig. 3. Cumulative distribution of instantaneous voltage for various numbers of talkers.

Bell Telephone Laboratories to determine actual voltage distributions for various numbers of talkers. Under carefully controlled conditions, speech voltages were measured for 1, 4, 16, and 64 channels. Average speech volume was carefully controlled in these tests, which are summarized in Figure 3. In order to show values from the different tests to a common scale, voltage distributions were plotted as the ratio of instantaneous voltage to rms voltage. This ratio is a direct measure of voltage distributions with respect to the nominal rms voltage of a signal, and shows the likelihood of any particular peak voltage being achieved if the rms voltage is known.

Note that although the ratio for a single talker has a low average value (there is only a 15% probability that signal voltage will exceed 0.75 the rms voltage), the single talker signal has the highest probability of reaching very high ratios. As the number of talkers increases, the voltage distribution more closely approaches the normal statistical distribution, shown by the red line. These larger numbers of talkers maintain a higher average ratio, but show a lower probability of reaching very high ratios. This is due to the "averaging out" of signal peaks, as described earlier.

Since amplifiers, modulators, and the like are responsive to instantaneous peak signal values, rather than average or rms values, systems must be adjusted to accommodate the possibility of large peak voltages. In normal telephone practice, the total average input voltage (or power level) to the carrier system is set so that the overload or break point is not reached more than 1% of

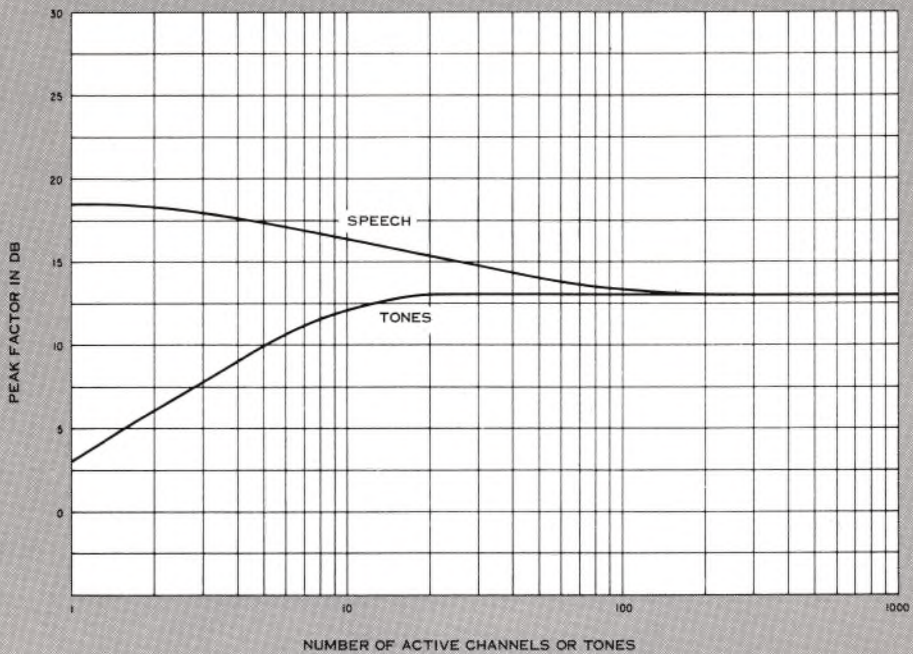

Fig. 4. Multi-channel peak factor. Values of signal peaks (above rms) exceeded only 1% of the busiest hour.

the busiest hour. Since the voltage distribution varies with the number of talkers using a system, the amount the average signal level must be reduced, known as the *peak factor,* will vary with the size of the system. Figure 4 shows peak factors for tones and speech in terms of the number of active channels.

As an example of how the peak factor is used in determining input levels to a multichannel amplifier, let us take the case of a 24-channel system. From Figure 2 we see that for average activity of 25%, the system will not exceed about 10 active channels more than 1% of the time. From Figure 4, the peak factor for 10 active channels is approximately 16.5 db. Now, if the maximum tolerable power into the common amplifier or radio transmitter is 17 dbm (a typical value), the power exceeded 1% of the time must be reduced to a value of 16.5 db below -17 dbm, or to -33.5 dbm. For simplicity, assume that the power exceeded 1% of the time is -30 dbm. Then the composite signal must be reduced to -33.5 dbm by 3.5 db of attenuation before being applied to the common amplifier or transmitter.

Figures 2, 3, and 4 are based on material by B. D. Holbrook and J. T. Dixon of Bell Telephone Laboratories, and originally published in The Bell System Technical Journal.

COMMUNICATIONS MEASUREMENTS

A few of the measurements and scales most commonly used in carrier communications are tabulated below in a form that permits direct comparison. Some quantities, such as random noise, speech, complex sound waves, and volume, are not directly related to specific amounts of power, but are customarily measured by test instruments of known characteristics, and calibrated against a special reference. Suggested by a paper in Electrical Engineering by W. A. Fowler.

POWER				QUANTITIES RELATED TO POWER BY THE CALIBRATION OF THE MEASURING EQUIPMENT				QUANTITIES REQUIRING TRANSLATION FROM ONE MEDIUM TO ANOTHER FOR MEASUREMENT					
ELECTRICAL			MECHANICAL	VOLUME	NOISE			SOUND			RADIO FIELD STRENGTH		
COMMON UNITS	WATTS IN POWERS OF TEN	IN DBM (DB REFERRED TO ONE MILLIWATT) DBM	ERGS PER SEC.	STANDARD VOL. IND. CALIBRATED IN VU (STEADY 1000 CPS POWER IN 600 OHM CIRCUIT)	READING OF NOISE MEASURING SET IN DBA (DB ABOVE REF.) 1000 CPS TONE: 114 TEL. SET WEIGHTING	1000 CPS TONE: F1A TEL. SET WEIGHTING	RANDOM NOISE	1000 CPS FREE PROGRESSIVE WAVE IN AIR: EQUIV. ACOUSTIC POWER FLOW IN WATTS PER CM^2	ACOUSTIC PRESSURE IN DYNES PER SQ. CM µ BARS	READING OF MEAS. SET IN DB ABOVE REFERENCE	EQUIV. POWER FLOW IN SPACE: WATTS PER SQUARE METER	VOLTAGE IN SPACE: MILLIVOLTS PER METER	EQUIV. DB ABOVE REFERENCE OF 1 µV/M
100 K W	10^{5}	+80	10^{12}	+80			NO FIXED RELATIONSHIP TO SPECIFIC POWER. READING VARIES WITH METER CHARACTERISTICS, NATURE OF INTERFERING NOISE. USUALLY SPECIFIED FOR EITHER 114 OR F1A WEIGHTING.						
10 K W	10^{4}	+70	10^{11}	WITH ATTENUATION +70									
1 K W	10^{3}	+60	10^{10}	+60									
100 WATTS	10^{2}	+50	10^{9}	+50									
10 WATTS	10^{1}	+40	10^{8}	+40									
1 WATT	10^{0}	+30	10^{7}	+30									
100 M W	10^{-1}	+20	10^{6}	+20							10^{-1}	6140	136
10 M W	10^{-2}	+10	10^{5}	+10							10^{-2}	1940	126
1 M W	10^{-3}	0	10^{4}	0	90	85		10^{-3}	630	130	10^{-3}	614	116
100 µW	10^{-4}	-10	10^{3}	-10	80	75		10^{-4}	200	120	10^{-4}	194	106
10 µW	10^{-5}	-20	10^{2}	-20	70	65		10^{-5}	63	110	10^{-5}	61.4	96
1 µW	10^{-6}	-30	10	-30	60	55		10^{-6}	20	100	10^{-6}	19.4	86
.1 µW	10^{-7}	-40	1	WITH AMPLIFICATION -40	50	45		10^{-7}	6.3	90	10^{-7}	6.14	76
.01 µW	10^{-8}	-50	10^{-1}	-50	40	35		10^{-8}	2.0	80	10^{-8}	1.94	66
.001 µW	10^{-9}	-60	10^{-2}	-60	30	25		10^{-9}	.63	70	10^{-9}	.614	56
100 µµW	10^{-10}	-70	10^{-3}	-70	20	15		10^{-10}	.20	60	10^{-10}	.194	46
10 µµW	10^{-11}	-80	10^{-4}	-80	10	5		10^{-11}	.063	50	10^{-11}	.061	36
1 µµW	10^{-12}	-90	10^{-5}	-90	0	-5		10^{-12}	.020	40	10^{-12}	.019	26
.1 µµW	10^{-13}	-100	10^{-6}					10^{-13}	.006	30	10^{-13}	.006	16
.01 µµW	10^{-14}	-110	10^{-7}					10^{-14}	.002	20	10^{-14}	.002	6
.001 µµW	10^{-15}	-120	10^{-8}					10^{-15}	.0006	10	10^{-15}	.0006	-4
.0001 µµW	10^{-16}	-130	10^{-9}					10^{-16}	.0002	0	10^{-16}	.0002	-14

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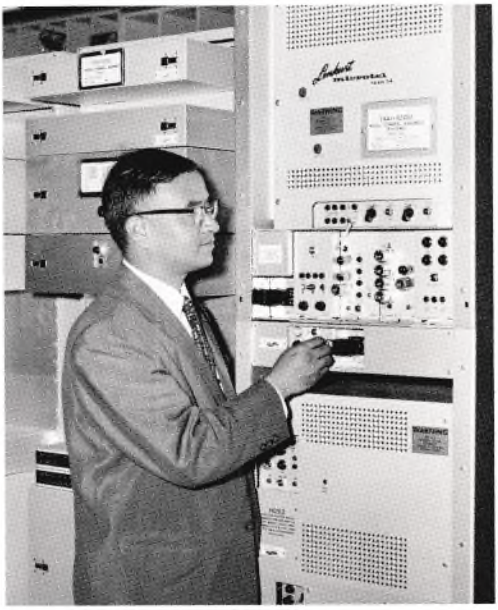
Taiwan Microwave Installation

Lenkurt 74A Microtel has been selected for the first microwave network to be installed in commercial telephone service on the island of Taiwan (Formosa).

The 6,000 megacycle system will link the Taiwan Provincial Government capital at Ying-Pan-Kow with the city of Taichung and the island telephone network. Initially, the system will carry 48 voice channels.

To prepare for this installation, Taiwan engineers Leon Y. Chen (shown) and Arthur Y. Huang recently attended the 74A Operation and Maintenance Course conducted at Lenkurt's San Carlos plant.



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