The Lenkurt® Demodulator

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AMPLIFIERS

For Carrier Applications

The entire communications industry and many of the industries it serves depend on the existence of amplifiers. The nature and design of amplifiers used in carrier applications is important, for amplifiers have a profound effect on the cost and performance of a carrier system. This article considers some of the characteristics of amplifiers and how they are used in a modern carrier system.

Without the amplifier, vaudeville would still be restricted to theaters and showboats instead of illuminating millions of living rooms each Sunday evening. Long distance telephony would be impractical or impossible; indeed, all long distance communications would be reduced to the dots and dashes of telegraphy. The amplifier has similarly transformed many other industries, largely by improving their ability to communicate.

In communications, the amplifier's value stems from its ability to restore the strength of signals weakened by transmission loss. The basic characteristic of an amplifier is that it enables a very small electrical signal to control a much larger quantity of electrical energy. Thus, an amplifier can transform a weak signal to a large signal of the same form.

An ideal amplifier would produce an output signal exactly duplicating the original signal in all respects except magnitude. Practical amplifiers fall short of this ideal by introducing some form of distortion. Generally speaking, the greater the amplification required of an amplifier, the more likely it is to distort the signal. This may not be too important in amplifiers used alone, such as hearing aids, public address systems, or intercoms. But in applications where many amplifiers are used in tandem, such as long distance communications circuits for telephone and television, distortion becomes intolerable. In transmitting messages over long distances, amplifiers (repeaters) are spaced along the path at intervals as short as 2½ miles to restore lost signal strength. In crossing the country, a signal may pass through more than a hundred repeaters and be amplified in power billions of times.

If the first repeaters introduce distortion, even in very small amounts, this distortion receives the same amplification as the signal. Since each additional repeater adds its own distortion to that already imposed on the signal, the message might well be unintelligible by the time it reached its destination if strong measures were not taken to limit distortion.

There are numerous ways of obtaining amplification. The familiar electron tube and transistor are used in the great majority of all amplifiers. Until the last ten years, the electron tube was almost alone in performing the world's amplifying chores. Today, the transistor is enjoying a rocket-like climb as state-of-the-art technical improvements permit the transistor to replace the electron tube in more and more applications. Increased life and reliability, as well as reduced power and space requirements, provide a powerful motive for increased use of transistors in carrier equipment.

Other less well known types of amplifiers include the magnetic amplifier, parametric amplifiers, and the maser. Magnetic amplifiers have been around for years, generally used for control and regulation. Battleships in World War I used magnetic amplifiers to control the position of gun turrets, as did bombers in World War II. In communications, magnetic amplifiers are used principally in regulating the output voltage of power supplies.

The newest amplifiers are the parametric or variable-parameter amplifiers. The parametric amplifier obtains its operating power, not from the conventional d-c source, but from a continuous-wave frequency, usually at some multiple of the signal frequency. This "pump" frequency continuously varies a reactance in the amplifier circuit in such a way that pump-frequency power is converted to signal-frequency power, thus producing signal amplification. This type of amplifier provides a great reduction of noise in UHF and microwave radio service.

The maser is a special form of parametric amplifier that takes advantage of

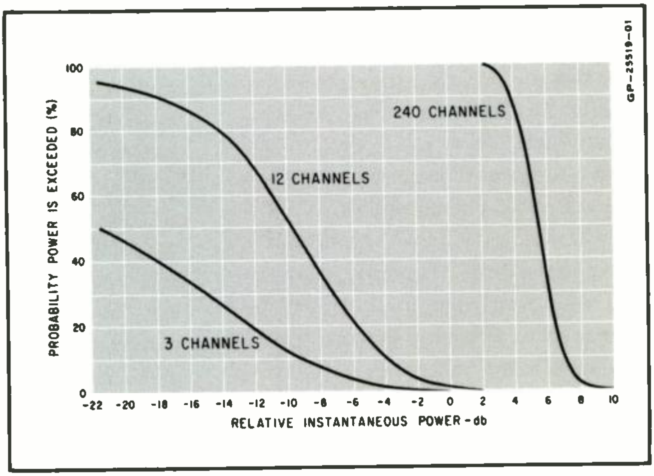
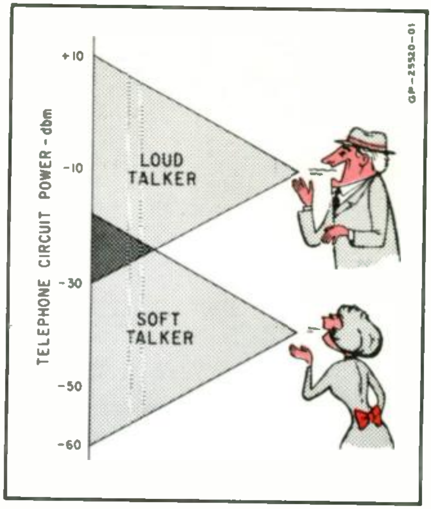


Figure 1. Probability of signal power being exceeded for different numbers of channels. Note that 3-channel system has 22-db range, while 240 channel system has less than 8-db range.

the special properties of certain substances at very low temperatures. Under the right conditions of temperature and magnetic field, these substances will absorb energy from a very high pump frequency and release it to the signal frequency, thus achieving amplification. In this particular type of amplifier, thermal noise is reduced to levels which, until recently, were believed impossible to achieve. Despite the inconvenience of using liquid nitrogen or liquid helium to keep the maser properly cooled, the spectacular reduction in noise makes this type of amplifier appear very promising for applications in radio astronomy, radar, and "scatter" communications.

Despite the enhanced performance and reduction in size and power of some of these "solid-state" amplifiers, electron tubes still maintain a lead over other types of amplifiers because of their higher state of development.



Channel amplifiers must accommodate 70-db power range without losing soft speech or distorting high levels.

Amplifier Design Considerations

Distortion is the principal enemy of the amplifier designer. An important cause of distortion in amplifiers is inadequate power capability. This is particularly important in carrier amplifiers because of the tremendous range of signal level that may be encountered. Since most carrier systems are operated under low impedance conditions to maintain compatibility with telephone systems or related radio equipment, considerable power may be required to develop the required signal voltage.

In a single carrier channel, there may be a tremendous power level range imposed on the amplifier. During listening periods, there is almost no signal power on the line. When the telephone user begins to talk, power jumps dramatically, varying over a range of about 30 db or 1,000 to 1, for an individual talker. The range for all talkers is 10,000,000 to 1, or 70 db!

When several channels are combined into a group, power variations tend to average out, so that in groups of 64 or more channels, the difference between average power and probable peak power is greatly reduced, and may be predicted on the basis of statistical probability. Careful attention to this fact in designing carrier amplifiers permits considerable savings in complexity, space, and power required for carrier systems. Figure 1 shows how power level range varies for various numbers of channels.

The question might well be asked, "Why not design for maximum possible loading based on all channels being used simultaneously by loud talkers?"

Such a system would require amplifiers to have much greater capacity than actually required. Equipment would require more input power, additional heat would be generated (a serious consideration in large, high-density terminals), and the system would cost more, for no significant improvement in performance. Consequently, modern carrier systems are designed to accommodate average load at the time of greatest traffic. To prevent a few loud talkers from upsetting the balance between probable maximum instantaneous load and the power capacity of the system, individual channel amplifiers are usually provided with peak limiters to prevent excessive levels from entering the system.

Amplitude Distortion

Amplitude distortion is the greatest single cause of poor amplifier performance. Amplitude distortion occurs when the amplifier is operated in a non-linear portion of its dynamic characteristic. Signal voltage variations in the output

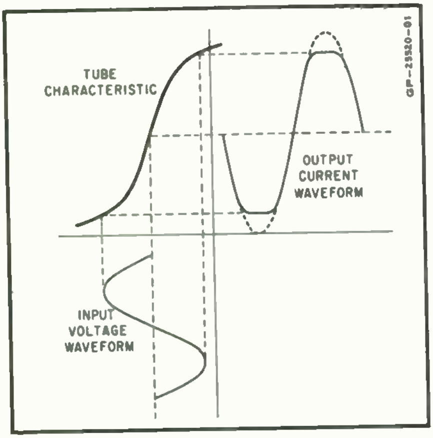


Figure 2. Distortion caused by excessive input voltage. Tube is driven into non-linear operation.

are not proportional to input signal voltage changes. In such a case, the amplifier tends to act like a modulator, producing harmonics and multiples of the various input frequencies. These intermodulation products cause inter-channel crosstalk and noise which interfere with the desired signal.

Negative Feedback

A powerful technique for correcting amplifier deficiencies was discovered by telephone researchers in 1927. This technique, called negative feedback or inverse feedback, reduces distortion, improves frequency response, and essentially frees the amplifier from the effects of power line variations and changes occurring within the amplifier itself.

Negative feedback gives an amplifier a great "reserve" which is used automatically to correct distortion and amplifier irregularities of all sorts. As an example of negative feedback, assume that an amplifier is required to have 60 db gain. If the amplifier is designed with 100 db gain, a portion of the output voltage may be applied to the input in such a way as to partially cancel the input signal. When the cancellation obtained in this way reduces the amplifier gain from 100 db to 60 db, the amplifier is said to have 40 db negative feedback.

The signal applied to the input of an amplifier represents the difference between the original input signal and the negative feedback signal. This difference is rather small if large amounts of feedback are employed. Now, if the amplifier has a tendency to amplify one frequency more than others within its passband, this frequency appears more strongly in the feedback signal. When applied to the input signal, that particular frequency is reduced more than are the other frequencies, thus giving it a relative strength reduction just about equal to the excess amplification at that frequency. As a consequence, frequency response will tend to be uniform. Similarly, if amplification is reduced for any reason, the feedback signal is reduced, permitting the input signal to enter the amplifier at a higher level.

For a given output voltage, distortion is reduced by a factor equal to the reduction in amplification by feedback. Thus, the above amplifier with 40 db feedback will provide an output in which intermodulation or distortion products will be 40 db below those in the output of an amplifier producing the same output level, but without negative feedback.

An amplifier employing negative voltage feedback tends to maintain uniform output voltage regardless of the load placed across the output. As more and more voltage feedback is employed, the output impedance of the amplifier approaches zero. If, instead of feeding back output *voltage*, negative feedback is derived from output *current*, the amplifier tends to maintain a constant current regardless of load impedance. This is equivalent to increasing the output impedance of the amplifier.

Since both current and voltage feedback are beneficial to amplifier performance, they afford the carrier amplifier designer a convenient tool for adjusting the amplifier output impedance, while at the same time improving the performance of the amplifier. By carefully adjusting the ratio of current feedback to voltage feedback, output impedance can be raised or lowered to suit the

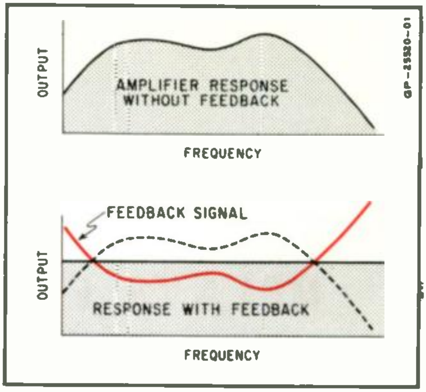


Figure 3. How negative feedback improves amplifier frequency response.

needs of the circuit. In carrier systems this is particularly useful where the amplifier operates into one or more filters.

Amplifiers and Filters

Carrier systems employ many filters to divide the frequency spectrum into channels and groups of channels. The more efficient the filters, the more tightly packed channels and groups can be before they interfere with one another. Since high-performance filters are extremely impedance-sensitive, optimum filter performance can be obtained only when proper circuit impedances are carefully maintained. Thus, judicious use of feedback in amplifier design contributes yet another benefit to overall performance of a carrier system.

By carefully designing filters and amplifiers to work together, designers of modern carrier systems achieve performance that not long ago was considered to be impractical for economical design. Not only do these modern designs improve performance, but they permit reductions in complexity, power requirements, and space.

RELAYS FOR TELEGRAPH CARRIER

Good or Bad?

After several years in disfavor as a loop keying device for carrier telegraph service, relays are now returning to good grace. Relays are normally preferred for loop keying because they provide maximum flexibility to the telegraph carrier system.

The principal objection to using relays for loop keying has been the excessive maintenance required by polar relays usually found in older types of telegraph systems. These relays are difficult to adjust and maintain. The fairly high voltages and currents in typical telegraph loops are hard on contacts, particularly since the contacts may operate more than a million times a day. In large telegraph switching centers, the great number of relays in service may require several full-time technicians just to keep the relays adjusted and in service.

Most telegraph relays require many types of adjustment. There are adjustments for contact travel and sensitivity. Pole pieces and stationary contacts are separately adjustable. And since contacts are rather small and made of precious metals subject to pitting, they must be frequently cleaned and adjusted. Such adjustments may be required as often as once a month, depending on circuit traffic.

Although electronic keying eliminates these difficulties, some rather rigid restrictions are substituted. Electron tube keyers introduce considerable voltage drop into the loop, thus restricting the length of the loop that may be keyed. Special tubes for keying applications are expensive and merely reduce the magnitude of the problem instead of correcting it. Transistor keyers permit operation under conditions of loop length and voltages not practical with electron tube keying. However, transistors introduce problems of complexity and cost. In addition, loop polarity and voltage is restricted by the circuit design, severely reducing the number of applications in which the telegraph keyer might be used. In such cases, the loop must conform to the equipment, rather than the opposite.

In 1951 a new polar relay was designed specifically to overcome the maintenance problems inherent in previously available types. Operation in thousands of telegraph channels has proven the success of the design. This relay, known as the Type PTW, has been repackaged for use in the Lenkurt 23A Telegraph Carrier System.

The relay design departs from the concepts employed in many of the older types in common use. Contacts are 3/16 inch in diameter, sixteen times the contact area of the older relay. Contacts are of tungsten carbide, an extremely hard substance that wears very slowly. Unlike contacts of precious metals, there is no pitting or contact build-up; contacts wear by powdering. To eliminate the gradual de-magnetization experienced by other polar relays, an Alnico permanent magnet is used. The magnetic flux remains essentially constant indefinitely. By contrast, magnets of other relays must be recharged from time to time.

Type PTW polar relay.

The design of the PTW relay has eliminated all field adjustment, except for the contacts. A single set screw for each contact is provided for bias and contact gap adjustment.

In laboratory tests at Lenkurt, several PTW relays were operated at 60 cps, keying a 70 ma, 130-volt polar circuit with a 2-henry load. There were no significant changes in bias or sensitivity after 100,000,000 operations! After 840,000,000 operations, equivalent to six months of continuous day and night service, these relays introduced 6 to 9% bias in a 100 word-per-minute neutral circuit (an amount of bias easily removed by the bias control in the 23A channel).

The relay manufacturer cites instances of PTW relays operating up to 18 months without trouble in high speed telegraph circuits averaging 5,000,000 operations a day. A PTW was installed in a full-time weather circuit to test relay life. After two years without adjustment, the relay was still operating properly before it was inadvertantly removed.

By employing a relay to key the receive loop, the Lenkurt 23A Carrier Telegraph provides much greater flexibility than would otherwise be possible. The system permits various polar arrangements without requiring an external repeater. The equipment allows back-to-back operation, either half- or full-duplex. There is no restriction on loop length introduced by the receive keyer. Thus, the use of a relay permits much greater equipment flexibility than would be possible using electronic keying, while the simplicity and reliability of the 23A Carrier Telegraph System is increased.

Lenkurt Electric Co.
San Carlos, Calif.

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Customer Training School Graduates 1,000th Student

Each week, many engineers and technicians learn the fine points of maintaining Lenkurt carrier and radio equipment in the Lenkurt Customer Training School. In five years, the school has trained personnel from 128 companies and government agencies, including representatives from many countries.

W. C. Johnson (standing, left), the 1,000th student, and associates L. I. Kunkle, R. E. James, and R. R. Collins from West Coast Telephone Company adjust carrier equipment in class.

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LYtell 1-8461 GLenburn 4000 24—46—50

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