The Lenkurt® Demodulator

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OSCILLATORS

For Carrier Systems

Oscillators for generating electrical waves are an important part of carrier and radio communication systems. The waves produced by these oscillators are used in the processes of modulation, demodulation, signaling, remote control, and regulation. Many different types of electronic oscillator circuits have been developed. All of these types can be resolved into one fundamental electrical circuit—an amplifier with a feedback path.

This article discusses the basic oscillator circuit, the conditions for oscillation, and considers briefly a typical carrier frequency supply circuit such as that used in Lenkurt's 45-class carrier systems.

The production of electrical waves for communication purposes is as old as the art itself. Morse generated such waves by interrupting a direct current with a telegraph key. Bell's original telephone transformed sound waves into electrical waves by the action of a reed vibrating in a magnetic field. The ordinary telephone transmitter generates electrical waves in response to sound waves acting on a diaphragm arranged to vary the magnitude of a direct current passing through carbon granules.

In carrier and radio communication, it is necessary to generate electrical waves of particular frequencies to facilitate modulation, signaling, and other necessary processes. In early work on carrier telephony, carrier frequency waves were generated through the use of rotating machinery. This method was not satisfactory, and was followed by the use of the vacuum tube oscillator and more recently, the transistor oscillator.

As the art evolved, various types of vacuum tube oscillator circuits were developed. Although physically different, these various circuits are fundamentally the same. They can all be considered in terms of an amplifier with a feedback circuit which permits some of the output energy to be returned to its input in such a manner as to produce and sustain oscillations.

The operation of an oscillator can be described by means of a simple arrange-

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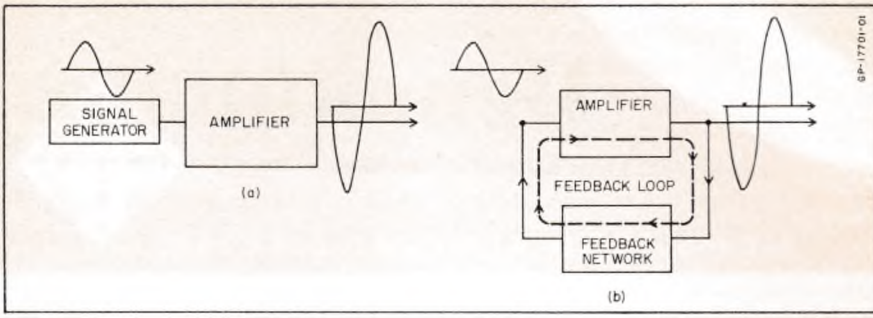


FIG. 1. An amplifier with and without a feedback path. Under certain conditions feedback will cause the system to oscillate.

ment consisting of an amplifier and a source of input energy, as shown in Fig. 1a. As long as the signal generator continues to supply input energy to the amplifier, the latter will produce energy of substantially the same waveform but of greater magnitude at its output—the increase of magnitude being proportional to the gain of the amplifier. If the source of input energy is removed, a wave will no longer be present at the output of the amplifier. In other words, the amplifier does not independently generate an electrical wave.

If, however, the output of the amplifier is connected to its input through a feedback network, as shown in Fig. 1b, the system will oscillate provided the loss and phase characteristics of the feedback network are such as to permit oscillation to take place. When this occurs, the system acts as an oscillator because it generates a wave without any external excitation.

Conditions for Oscillation

For sustained oscillation to take place in the circuit shown in Fig. 1b, two conditions must be satisfied. First, the total phase change through the amplifier and back to the input, via the feedback path, must be equal to 0°, 360°, or some multiple of the latter.

Second, the total gain of the system must be equal to or greater—but not less—than its total loss. To those who are familiar with the operation of two-way gain devices—2-wire telephone repeaters, for example—this will be recognized as a *singing* condition, useful in the case of an oscillator but to be avoided in repeater operation.

To satisfy the two conditions, it is necessary that, (1) the feedback network possess sufficient phase change to make the total phase change around the loop an integral number of cycles and that, (2) the system have sufficient gain to at least offset the total loop loss.

The preceding discussion is based upon the fundamental theory of the feedback amplifier, which is given briefly in Fig. 2 for reference purposes.

Frequency of Oscillation

Oscillators are usually required to generate a wave of one specific frequency and to be incapable of oscillating at any other frequency. To accomplish this, the feedback circuit must be phased correctly at only the desired frequency. A tuned circuit consisting of an inductance-capacitance combination, or a phase-shift network composed of resistors and capacitors meets this requirement.

In the case of the tuned circuit, which may be either series or parallel resonant, there is one frequency at which the inductive reactance completely neutralizes the capacitive reactance. At this frequency, the circuit is electrically a pure resistance. If it is sharply tuned, the range of frequencies over which the circuit behaves as a resistance is very narrow. A feedback loop can then be connected in such a manner that the oscillator phase requirements are satisfied at only the resonant frequency of the tuned circuit.

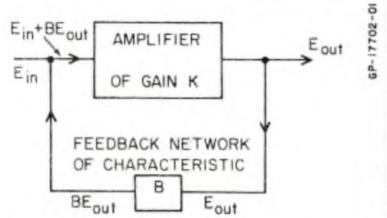
The operation of a phase-shift network is similar, except that inductors are not needed. This type of network uses a number of resistance-capacitance combinations to provide the required phase shift at some particular frequency. This method is especially useful in low cost or variable-frequency oscillators because the circuit components are relatively inexpensive.

Practical Considerations

Although an oscillator is potentially capable of producing oscillations, none will take place at the instant power is first applied to the circuit. However, as the vacuum tubes or transistors begin amplifying, the transients or other small voltages that are inherently present in all electronic circuits will be amplified. Since these disturbances occur over a wide frequency range, some portion will be amplified, returned to the amplifier input in the proper phase, and re-amplified (regeneration). Within a few micro-seconds the circuit starts to oscillate at its operating frequency.

The process of regeneration continues after oscillation has started, and will further increase the amplitude of oscillation. Unless some provision is made to hold the amplitude constant at a suitable level, it will continue to build up until the amplifier is operating beyond the linear portion of its characteristic. This nonlinear operation will limit the amplitude of oscillation because the amplification of the tube decreases as its operation becomes nonlinear. Therefore, the circuit will find some amplitude at which there is a balance between regeneration and the decreasing amplification.

Unfortunately, permitting the amplitude of oscillation to be controlled in this manner causes a distorted output wave. This distortion can be reduced to tolerable magnitudes by using high Q feedback circuits, or by the addition of a circuit designed to maintain the amplitude of oscillation at the desired value.



$$E_{out} = KE_{in} + KBE_{out}$$

$$E_{out} - KBE_{out} = KE_{in} = E_{out}(1-KB)$$

$$\text{TOTAL CIRCUIT GAIN} = \frac{E_{out}}{E_{in}} = \frac{K}{1-KB}$$

FIG. 2. A feedback amplifier. When KB equals plus one at an angle of 0° or multiples of 360°, the system becomes oscillatory and E_{out} can exist without E_{in}.

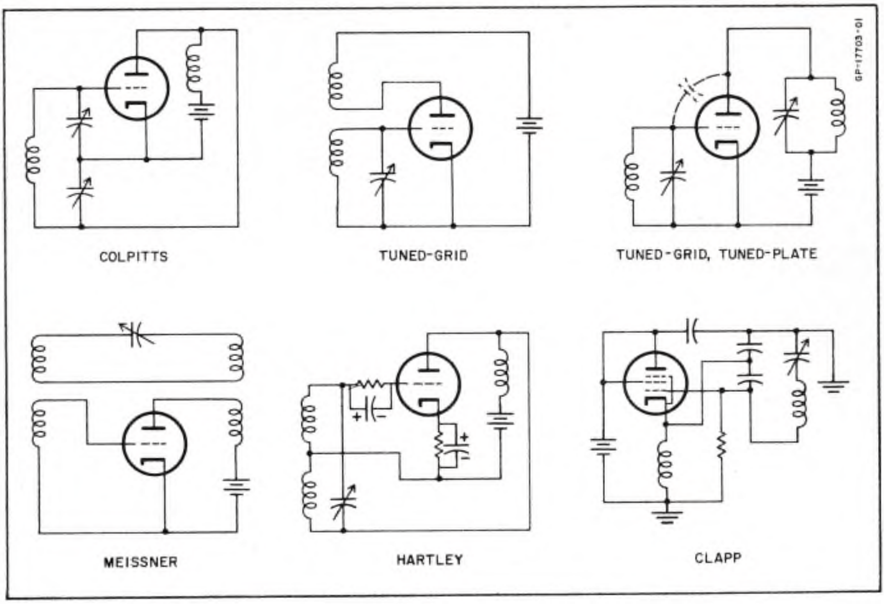


FIG. 3. Six typical LC oscillators. Although the configurations are different, the theory of operation is the same.

LC Oscillators

Before oscillator theory was fully developed, much attention was given to the various methods of obtaining the necessary feedback. It was at this time that each type of oscillator circuit was designated by the name of the individual associated with its development. Among these are the Hartley, Colpitts, Meissner, and Clapp oscillator arrangements. All of these circuits have certain advantages and disadvantages because they are arranged differently, but in every case the basic requirements of an oscillator are fulfilled.

Fig. 3 shows six of the more common types of oscillators. Each circuit has a tube to provide the necessary amplification, and a feedback loop to furnish connection from the plate to the grid circuit. A tuned circuit is in the feedback loop to establish one frequency at which the output is returned in phase with the input.

The operation of the Hartley oscillator is typical of all other types of LC oscillators. This oscillator consists of an amplifier tube and a tuned circuit. The coil in the tuned circuit has a tap near its center for connection to the cathode of the tube. Whenever one end of the coil is positive with respect to the cathode tap, the other end of the coil is negative, and vice versa. This arrangement provides a 180° phase shift through the tuned circuit. Because the tube adds another 180°, the 360° phase shift requirement is satisfied. The operating frequency of the oscillator is determined by the resonant frequency of the tuned circuit because the system has the proper phase relationship at only this frequency.

The resistor-capacitor combination in the cathode circuit of the tube supplies grid bias. A similar combination in the grid circuit, known as a grid-leak, provides a certain amount of amplitude control. As the amplitude of the wave increases with regeneration, the grid becomes positive at some point and draws current. A voltage drop of the polarity shown will develop across the grid-leak resistor, and will increase the negative bias on the tube preventing further regeneration.

The bias across the resistors, which is held constant over the period of one cycle by the capacitors, will maintain the output amplitude of the oscillator relatively constant. However, the output will still contain harmonics because the high negative bias prevents the tube from conducting for a large part of each cycle. This causes short bursts of tube current to flow into the tuned circuit. For high Q circuits, these bursts of tube current appear in the output as fairly well filtered waves of the desired frequency.

Oscillators utilizing LC or RC circuits are relatively simple and inexpensive. Their primary limitation is the effect of most of the variables in the circuit upon the operating frequency. Any change in the value of the inductance, capacitance, tuned-circuit resistance, plate voltage, filament voltage, tube characteristic, temperature, loading, or humidity causes a change in the frequency.

The frequency of LC oscillators can be controlled to a substantial degree by using highly stable components, well-regulated power supplies, and compensated vacuum-tube circuits. These methods of control are usually adequate in the voice and lower carrier frequency ranges. However, at the higher carrier and radio frequencies, more effective control is needed than can be obtained with LC circuits. This has led to the use of crystal-controlled oscillators.

Crystal Oscillators

To achieve a high degree of stability at higher frequencies, piezoelectric crystals are commonly used as frequency controlling elements in electronic oscillators. Such crystals are able to exert a stabilizing influence on an oscillator because of their highly sensitive frequency characteristics. This sensitivity, or high Q, is evident from the equivalent circuit and typical values of a crystal shown in Fig. 4a. The Q of this crystal, at its resonant frequency, is over 10,000 —or enormously higher than can be obtained from any conventional LC circuit.

The effectiveness of a crystal in controlling frequency results from the fact that, as shown in Fig. 4b, its impedance

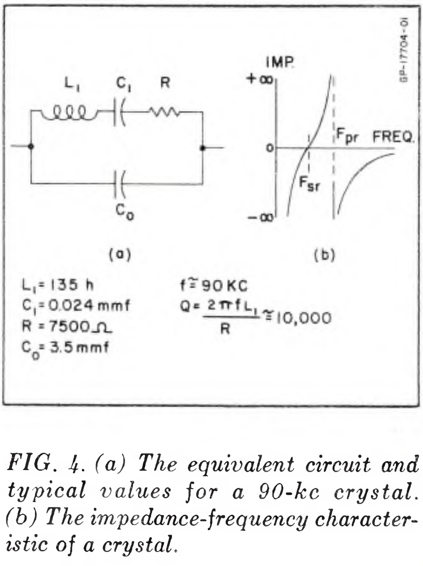


FIG. 4. (a) The equivalent circuit and typical values for a 90-kc crystal. (b) The impedance-frequency characteristic of a crystal.

varies rapidly in the regions adjacent to its resonant points. Thus, if an oscillator circuit is designed to operate at the resonant frequency of the crystal, any slight shift from that frequency will make a great change in the crystal's impedance and phase characteristics. Such a change returns the oscillator frequency to the desired value.

For example, a crystal designed to operate at its series-resonant frequency has a very low impedance and little phase shift because it is nearly a pure resistance at that frequency. Any change from the series-resonant frequency will cause the crystal to present a large inductive or capacitive reactance to the feedback circuit. This greatly changes the phase characteristics, and prevents any appreciable deviation from the series-resonant frequency. Because crystals are so sharply resonant, it is practicable to obtain oscillators which will maintain a constant frequency to within one part in a million. At 50 kc, this means a frequency deviation of only 0.05 cps or 0.0001 percent.

Fig. 5 shows two typical crystal oscillator circuits and their LC equivalents. The Miller oscillator, employing a crystal in the grid circuit and an LC combination in the plate circuit, is electrically identical to a Tuned-Plate Tuned-Grid LC oscillator. Coupling, or a feedback loop, is established through the grid-plate capacitance of the tube.

The Pierce oscillator utilizes the highly inductive property of a crystal which is operated slightly off its parallel-resonant frequency. This inductance is applied between the grid and the plate of the tube. The inter-electrode capacitances between the grid and the cathode, and the cathode and the plate complete the equivalent circuit which is identical to the Colpitts LC oscillator.

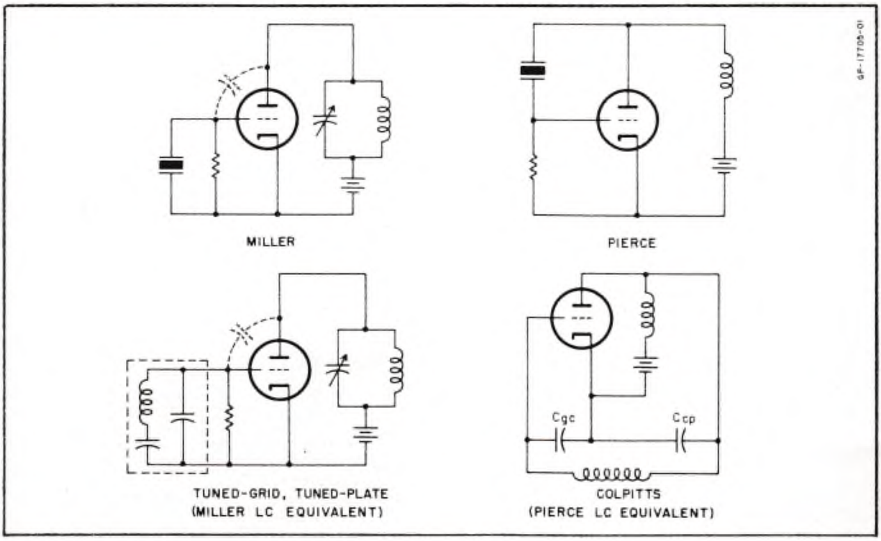


FIG. 5. Two crystal oscillators and their equivalent LC circuits.

Carrier-Frequency Oscillators

Multi-channel carrier systems, such as Lenkurt's 45-class equipment, require the generation of electrical waves of a number of frequencies. Usually one carrier frequency wave is needed for each channel, and several other high-frequency carriers are required for group modulation. Although a number of frequencies are needed, it is impractical to use separate crystal-controlled oscillators to produce each one. For this reason, specially designed circuits are used to produce all the necessary frequencies from one precise wave generated in a master oscillator.

The circuit of a typical master oscillator is shown in Fig. 6 and pictured in Fig. 7. This oscillator is basically the same as an LC Hartley oscillator, except that a crystal is connected between the center tap of the coil and the cathode of the tube. Also, in this case the oscillator tube drives a second tube connected as a modified cathode follower. The cathode follower has no effect on the action of the oscillator, but provides isolation and coupling between the relatively high impedance output of the oscillator and the low impedance into which it works. The oscillator generates a virtually pure sine wave of 96 kc at an amplitude of 6.5 volts. Harmonics are reduced to a very low level by the action of the crystal.

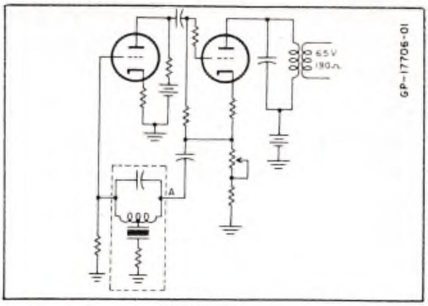


FIG. 6. The circuit of a typical master oscillator for use in a carrier communication system.

The circuit is designed to operate at the series-resonant frequency of the crystal. At this frequency, the crystal appears as a very small pure resistance. Voltage from the output of the tube appears across one-half of the coil and the crystal. As long as the impedance of the crystal is small, most of the feedback voltage is impressed across the coil. In the second half of the coil a voltage is induced which is nearly equal in amplitude to the voltage at point A, but is 180° out of phase. Therefore, the voltage induced in the second half of the coil satisfies the condition for sustained oscillations.

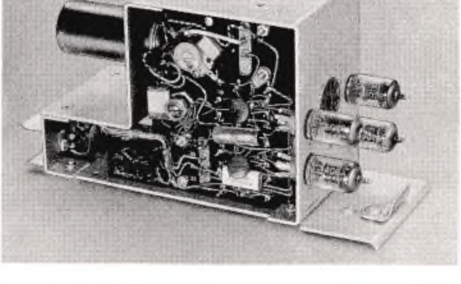


FIG. 7. The master oscillator unit used in Lenkurt 45-class carrier systems. This unit contains two crystal-controlled oscillators; one supplies a 96-kc wave for use in the carrier frequency supply units, the other supplies a high frequency carrier for group modulation.

At other than the resonant frequency, the crystal presents a much higher impedance to the feedback loop. When this is the case, most of the feedback voltage appears across the crystal and little is returned to maintain oscillations. The operating frequency of the oscillator is therefore self-compensating and does not deviate appreciably from the desired value of 96 kc.

To maintain still greater accuracy and prevent the influence of external effects such as temperature changes from affecting the operating frequency, the crystal is enclosed in an oven. The oven (Fig. 8) is electrically heated and thermostatically controlled to maintain the crystal temperature constant at 55° C.

Carrier Supply Units

In Lenkurt 45-class equipment, the pregroup carrier supply and the channel carrier supply units are driven from the output of the master oscillator. The block diagram of these two units is shown in Fig. 9. Both units operate on the same principle, except that they provide different frequencies.

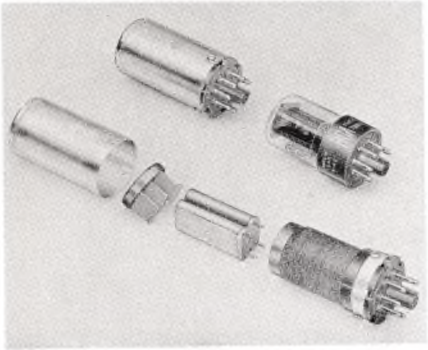


FIG. 8. An exploded view of a crystal oven, an assembled oven, and a conventional vacuum tube to illustrate relative size. The oven contains two crystals—one for each of the two oscillator circuits in the master oscillator. The oven is electrically heated and thermostatically controlled.

The pregroup carrier supply has a feedback loop that is resonant at 80 kc. The 80-kc wave is initially produced by oscillations within this unit, and then modulated with the 96-kc crystal-controlled wave. The output of the modulator contains modulation products such as 80 kc plus 96 kc, 96 kc minus 80 kc, 2x80 kc minus 96 kc, and many more. The 64-kc lowpass filter, however, permits only the 16-kc and the 64-kc waves to pass.

The 64-kc wave is separated by an appropriate filter. The 16-kc wave is selected by the lowpass filter and clipped. The clipper consists of a pair of biased diodes which remove the peaks of the wave. At this point the original sine wave approximates a square wave—a wave very rich in odd harmonics.

The fifth harmonic of the 16-kc wave is selected by the 80-kc bandpass filter and used to modulate the 96-kc crystal-controlled wave. Once the system becomes stabilized, the 80-kc wave is independent of the characteristics of the feedback loop and is as accurate as the crystal-controlled wave. Therefore, this unit provides a 16-kc, a 64-kc, and an 80-kc wave—all accurate to a fraction of cycle.

A similar process takes place in the channel carrier supply. In this case the 16-kc wave is the controlling element and is supplied by the pregroup carrier supply unit. A feedback oscillator begins supplying a 12-kc wave, which is then maintained by the products of the

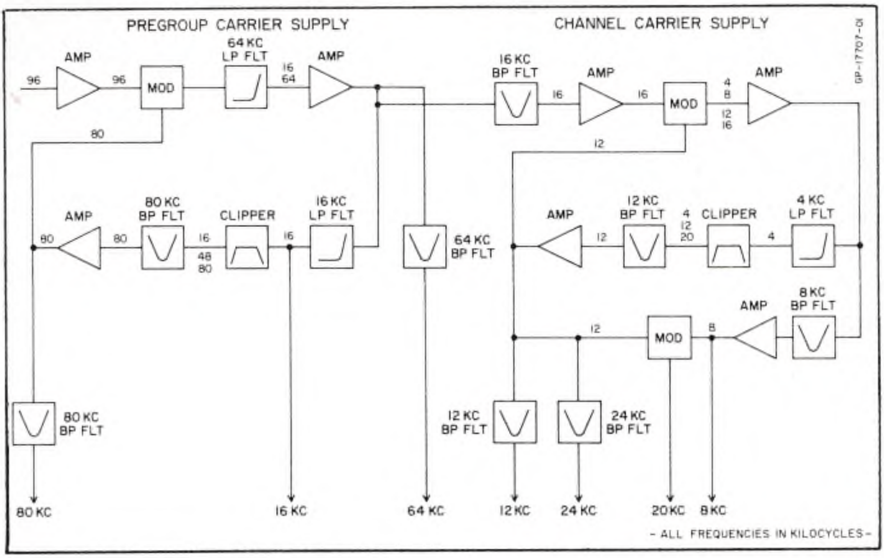


FIG. 9. Block diagram of the pregroup and channel carrier supply units of Lenkurt's 45-class carrier equipment.

modulation and the selected harmonic of the clipper. This unit produces 8-kc, 12-kc, 16-kc, 20-kc, and 24-kc waves—all as accurate as the output of the 96-kc crystal-controlled master oscillator.

Conclusion

The preceding discussion can be summarized briefly by stating that the various types of electronic oscillators used in carrier and radio communication conform to the fundamental theory of a feedback amplifier having (1) sufficient gain and (2) the proper over-all phase characteristics to permit sustained oscillations. Oscillation at the particular frequency desired is obtained by making the characteristics of the feedback path suitable for that frequency only.

Resonant circuits, phase-shift networks composed of resistors and capacitors, or crystals are used in the feedback path for frequency control. Arrangements employing the first two types of control are generally known as LC or RC oscillators, and those using crystal control are usually termed crystal oscillators.

LC and RC oscillators find their principal field of use in the voice and lower carrier frequency ranges because they can be made sufficiently stable in those ranges and are economical for the purpose. They can, of course, be used for the generation of higher frequency waves in situations where stability is not a factor of outstanding importance.

At the higher carrier and radio frequencies, stability is a consideration of prime importance. Because of their very stable frequency characteristics, crystal oscillators are peculiarly suitable —and economical—for these fields of application. This is particularly true in the case of radio and of suppressed-carrier communication systems.

COMPREHENSIVE TECHNICAL INFORMATION

on Lenkurt Products

The ultimate success and usefulness of a product depends, in part, upon (1) a clear understanding of what is available, (2) its arrangement and its performance characteristics, (3) how it can be obtained, and (4) how it can be applied to the user's best advantage.

The technical information on Lenkurt's products is designed to provide comprehensive information of the above types. The first of these involves product information; the second, general and detailed description and performance; the third, precise ordering information; and the fourth, engineering considerations, installation, operation, and maintenance. The manner in which this is accomplished and typical items of information furnished are outlined in this article.

A "Drawing and Publication Information Service" is also provided to enable customers to keep up-to-date files of nearly all technical product information.

PRODUCT INFORMATION LETTERS

Serially numbered letters (such as PIL-20) are issued to announce the development of a new product and to give preliminary information, from time to time, as the development progresses.

CONDENSED SYSTEM DESCRIPTION

Generally termed a "P4"—designed to provide a brief and condensed description of the particular item. Useful in over-all preliminary consideration of a product's suitability for a particular field of application.

GENERAL SYSTEM DESCRIPTION

Bulletins describing the arrangement and performance of complete systems. They show the electrical position and the more important circuit details involved in the over-all system operation. General System Description bulletins are coded with the system type number followed by the suffix "DES." Example: Form 45A1-DES.

ORDERING INFORMATION

Bulletins giving information on standard equipment assemblies and detailed procedures for ordering the particular equipment desired. Ordering Information bulletins are coded with the system type number followed by the suffix "ORD." Example: Form 45A1-ORD.

ENGINEERING CONSIDERATIONS

Bulletins outlining the general engineering considerations for the application of a particular system. These bulletins are coded with the system type number followed by the suffix "ENG." Example: Form 45A-ENG.

ENGINEERING LETTERS

Serially numbered letters (such as EL-37) used to provide engineering information of a temporary character, information of a general character which may relate to several specific systems, or any other type of information which can be covered appropriately by a letter.

ENGINEERING BULLETINS

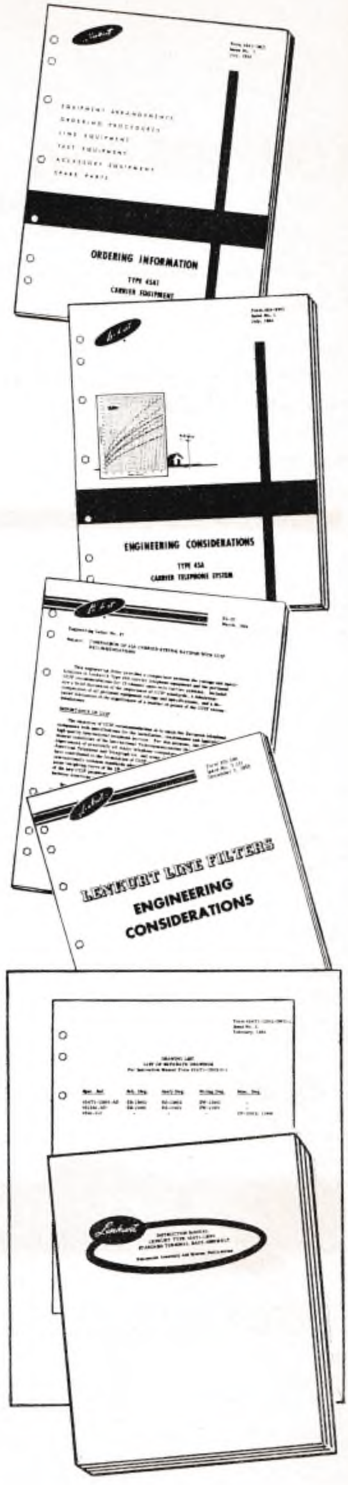
Serially numbered bulletins (starting at 100) containing information that may apply to several different types of systems—usually of a somewhat more permanent form than that contained in Engineering Letters.

INSTRUCTION MANUALS

Detailed manuals are furnished with complete system assemblies, and are coded for the particular assembly supplied.

Each instruction manual contains general and specific descriptive information; installation instructions; lineup and maintenance instructions on a system basis; specific operating instructions for the assembly covered; and detailed specifications for individual shelves, panels, and units comprising the equipment. For the more complex assemblies, this material is usually assembled in two separate books and the associated drawings are supplied separately in envelopes.

Comprehensive system instruction manuals containing all the information on a particular system and its assemblies are also available for detailed engineering and training purposes.



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45BN System	—Descriptive	**45BN-DES**
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72C System	—Descriptive	**72C-DES**
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Included in these bulletins is information on the arrangement and performance of the systems, the more important circuit details, and procedures for ordering various equipment arrangements.

Copies of these bulletins can be obtained from Lenkurt's distributors.

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Editor . . . . P. C. DeMuth

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