The Lenkurt® Demodulator

NEWS FROM LENKURT ELECTRIC

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CAPACITORS

For Carrier Systems

Modern communication equipment uses large numbers of different types of capacitors. At Lenkurt, most of the commercially available types are used in the carrier and microwave radio equipment, and in addition, some special types are manufactured to provide the characteristics needed in electric wave filters.

This article describes the properties of capacitors in general and discusses the applications and characteristics of the more common types used in carrier equipment.

Capacitors are required in electronic equipment to perform numerous functions such as filtering, coupling, and bypassing. Because of their wide applications and various uses, many different types of capacitors have been developed—each type having certain characteristics which permit it to meet the requirements of any specific application.

The requirements placed on capacitors for use in carrier, microwave and other electronic equipment are many and varied and have resulted in the design and manufacture of many different types. Figure 1 shows the many types of capacitors used in a typical carrier terminal. There are differences in size, appearance, and application; however, the operation of all of them is fundamentally the same.

Operation of a Capacitor

In essence, a capacitor consists of two conducting surfaces separated by an insulating material. A steady current cannot flow *through* the capacitor because there is no direct connection between the conductors. However, when a voltage is applied, a certain amount of current will flow *into* the capacitor causing it to become charged.

Figure 2a shows a capacitor connected to a source of direct current through a switch. When the switch is closed, current flows, charging the capacitor until the voltage across it equals the applied d-c potential. The

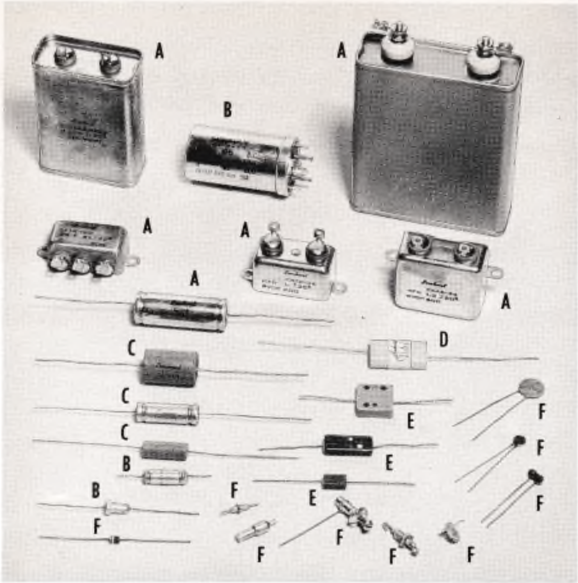

FIG. 1. *Types of capacitors used in Lenkurt carrier and microwave radio equipment. Letters indicate dielectric as follows:*

A. Oil-paper

B. Chemical film

C. Polystyrene

D. "Mylar"

E. Mica

F. Ceramic

capacitor is then fully charged and the circuit is, in effect, completely open and no further current can flow. If, however, the polarity of the d-c source is reversed, current will again flow, discharging the capacitor and charging it in the opposite direction.

When an alternating current is applied to a capacitor, the polarity of the voltage source is constantly being reversed. If the frequency is high enough, current will flow in and out of the capacitor freely, and the circuit will behave almost as though the capacitor represented a direct connection. At such frequencies, therefore, the capacitor presents very little impedance to the circuit. *Impedance* may be defined as the ratio of the alternating voltage across a capacitor to the alternating current flowing through it.

The impedance characteristic of a capacitor is shown in Fig. 2b. At zero frequency, or direct current, a capacitor theoretically has infinite impedance. The impedance becomes less as the frequency is increased and gradually reaches a very small value. The exact relationship between frequency and impedance depends upon the electrical size of the capacitor, or its capacitance.

The amount of capacitance depends upon the surface area of the two conductors forming the capacitor, the spacing between them, and the nature of the insulating material separating the conductors. Increasing the area of the conductors or decreasing the spacing causes the capacitance to increase. Also, using an insulating material with a high dielectric constant increases the value of capacitance which can be obtained from a particular arrangement of conductors.

Dielectric constant is a measure of an insulator's ability to store electricity. Insulators with a high dielectric constant produce more capacitance for a given arrangement of conductors. Vacuum has a dielectric constant of one and is used as the standard of comparison.

The dielectric constant of air is only slightly more than that of vacuum, and all other liquid or solid insulators have greater values. For example, high-grade mica has a dielectric constant of over five, which means a capacitor having a mica dielectric has five times the capacitance it would have if the dielectric were vacuum.

The unit of capacitance is the farad, which is the capacitance that will store a charge of one coulomb (approximately 6.24×10^{18} electrons) when a potential of one volt is impressed across the conductors. Because the farad is a very large and unwieldly unit, it is commonly subdivided into microfarads (a millionth of a farad—abbreviated μf) or micromicrofarads (a millionth of a millionth of a farad—abbreviated $\mu\mu f$). Commercially manufactured capacitors are available in a size range that extends from less than 1 $\mu\mu f$ to over 4000 μf.

Electrical Properties

Although the most important property of a capacitor is its capacitance, several other properties are also significant. Figure 3 shows the complete equivalent circuit of a capacitor, which includes the normal capacitance, leakage resistance, inductance, capacitance to ground, and series resistance.

The leakage resistance, R_2, represents a shunting current path through the capacitor dielectric and across the insulation between the capacitor terminals. This resistance permits a very small, usually undesired, direct current to flow through a capacitor. The magnitude of this current depends upon the type and condition of the dielectric and the method of capacitor manufacture. When necessary, a leakage resistance of millions of megohms can be achieved by using a very high grade of dielectric and hermetically sealing the capacitor in metal or glass.

Like almost every other electrical device, a capacitor has a certain small amount of inductance. In the lower frequency ranges the effect of this inductance is insignificant. However, since inductive reactance increases with rising frequency, beyond a certain frequency the inductance of a capacitor will become electrically important. In fact, at some frequency, the inductance of a capacitor will be resonant with the capacitance, and the capacitor itself will appear as a resonant circuit.

In some cases, the stray capacitance between either or both conductors of a capacitor and other nearby conductors may be important. This is especially true in the higher frequency ranges or in high impedance circuits because this capacitance then becomes a virtual short circuit. This capacitance exists between the outside conductor of the capacitor and any other nearby conductor—usually the chassis at ground potential. The magnitude of the effect can be minimized by using capacitors which are physically small, by allowing a large air space between the capacitor and ground, and by connecting the outside conductor of the capacitor to a low impedance circuit whenever possible.

The last property, the series resistance, has very little effect on the characteristics of a capacitor and can be neglected except at very high frequencies. This resistance represents the inherent resistance of the dielectric, terminals, leads, and conductors composing the capacitor.

Operating Characteristics

In addition to the electrical properties of a capacitor, there are a number of operating characteristics which are of importance. Among these are the voltage rating, the losses, and the stability with respect to temperature, frequency, and age.

The voltage rating of a capacitor is specified either in terms of maximum voltage or working voltage. Maximum voltage is the highest electric stress a dielectric can withstand. If a potential is applied to a capacitor in excess of the maximum voltage rating, the dielectric will probably rupture and cause a short circuit. The voltage at which this rupture occurs is called the *ultimate dielectric strength.*

Working voltage is the potential at which a capacitor can operate continuously without excessive deterioration. It is often only a fraction of the ultimate dielectric strength. If the working voltage is exceeded very often or by any great amount, there may be a considerable reduction in the life of the capacitor.

The voltage rating of a capacitor depends upon the insulating strength of the dielectric and the way in which the insulating strength is affected by factors external to the capacitor, such as temperature, moisture, and chemical impurities. Temperature, especially, causes great variations in the permissible working voltage of a capacitor since elevated temperatures lower the insulating strength of a dielectric. The usual practice is to reduce the voltage rating (derating) by a specified percentage whenever a capacitor is to be used for a high temperature application.

The losses of a capacitor are due primarily to the dissipation of power in the dielectric. The importance of this power loss depends upon the application of the capacitor. For example, the losses of a capacitor may be insignificant when it is used for coupling or bypassing, but if it is used in a tuned circuit, the losses may lower the Q and make the circuit unusable.

The amount of power dissipated in a capacitor is determined by the type of dielectric used and the frequency at which it is operated. Consequently, a capacitor which is satisfactory at low frequencies may be completely unusable for higher frequency applications. The variation of power dissipation with frequency indirectly affects the voltage rating of a capacitor since, as the losses increase with frequency, more heat is generated in the capacitor. This raises its temperature and causes a reduction in safe voltage rating for the higher frequencies.

Capacitance varies slightly with all the environmental conditions such as temperature, frequency, humidity, and age. This instability is caused by changes in the structure of the dielectric and consequently cannot be completely avoided. For most applications these small variations do not adversely affect the operation of the circuit in which the capacitor is used; however, in highly precise circuitry, compensation for these variations is sometimes needed.

Capacitor Types

The stability of a capacitor, as well as most of its other electrical properties

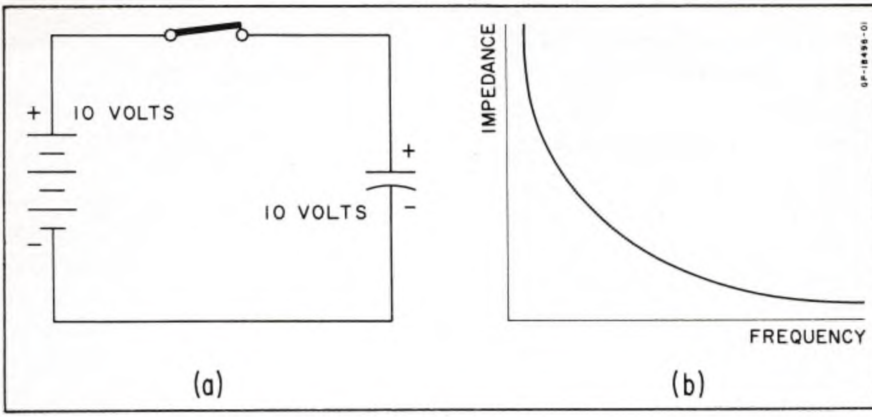

FIG. 2. *(a) A circuit in which electric charge has built up in a capacitor opposing the flow of current from the d-c source. When steady state has been reached, no current can flow. (b) The impedance-frequency characteristic of a capacitor.*

and operating characteristics, depends upon the kind of dielectric used and the type of construction. Many kinds of dielectrics have been developed to enable production of capacitors suitable for the widely different applications in modern electronic equipment.

The dielectrics commonly in use today are air, mica, plastics, ceramics, paper, and chemical films. The first four dielectrics in this group are generally used in capacitors for resonant circuits, while the last two types have primary application in capacitors for a-c coupling circuits.

Capacitors for Resonant Circuits

Almost every electronic device includes one or more resonant circuits for purposes of filtering, tuning, and establishing sinusoidal oscillations. A capacitor is always a necessary component in this type of circuit. Because of the precise nature of most resonant circuits, a capacitor is required which is stable, has low losses and high insulating strength, and can provide the required capacitance in a reasonable size. Low losses at the frequency of operation are especially important because the dissipation of power in a capacitor reduces the Q of the resonant circuit. Capacitors with the lowest possible high frequency loss utilize air as the dielectric.

Air capacitors, in addition to their low losses, are valuable because of the relative ease with which the capacitance can be continuously varied over the operating range. Variable air capacitors are commonly used in resonant circuits to facilitate changing the frequency or resonance (tuning), or in parallel with larger capacitors to adjust the total capacitance to the desired value.

Because of the necessary mechanical arrangements and the low dielectric constant of air, a variable capacitor has the greatest size per microfarad of any other type. However, when carefully manufactured, it provides a precise capacitance with good stability and very high Q.

Mica Capacitors

Mica was one of the first dielectrics used for capacitor manufacture and is still one of the most important. It has electrical characteristics which few other materials can surpass, such as excellent stability, very low losses, and high insulating strength. The main disadvantage of mica capacitors is the large physical size necessary to obtain high capacitances.

A mica capacitor consists of flat metal conductors separated by thin sheets of mica. The conductors are connected in parallel to increase the capacitance of the unit, and are then sealed in a molded plastic, ceramic, or metal casing. Flat construction of this nature must be used because mica is relatively inflexible and cannot be bent or rolled. Mica capacitors are also manufactured by silver-plating the conductors directly on the mica dielectric. This type of capacitor is called a "silver mica" and is used for highly critical applications.

Mica capacitors find their greatest application where a high degree of stability is required because they are only slightly affected by temperature, moisture, frequency, and aging. They are also valuable for high-frequency applications because of their very low losses, and consequently high Q. Since the smaller sizes of mica capacitors are relatively inexpensive, they are often used in applications where other types of capacitors would be equally satisfactory from the electrical standpoint.

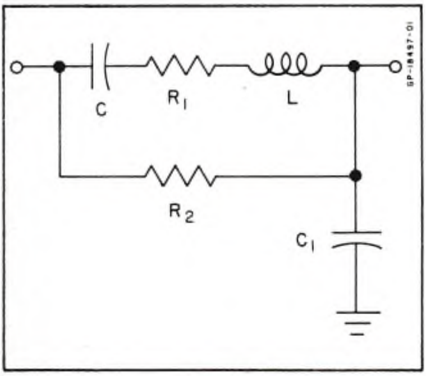

FIG. 3. *The equivalent circuit of a capacitor.*

Polystyrene Capacitors

In recent years, shortages of mica and the need for smaller and smaller size capacitors have led to a search for suitable dielectric materials from the many types of plastic films that have been developed. One of the more successful plastic films has been polystyrene.

Polystyrene was developed prior to and during World War II as a result of research by German chemists to find a substitute for mica. It had been known for years that polystyrene had suitable electrical characteristics for communications applications, but it was not until German scientists discovered a technique for making it into thin, flexible sheets that it became a practical capacitor dielectric.

In some respects, polystyrene has characteristics that are superior to those of mica. It has less leakage resistance, a higher Q over a wider frequency range, and greater flexibility. It also has a negative coefficient of capacitance which is very useful in filters and other resonant circuits as it tends to make the resonant frequency of a coil-capacitor combination remain constant despite temperature variations. In the values needed for electric wave filters (about 5,000 to 75,000 $\mu\mu f$), polystyrene ca-

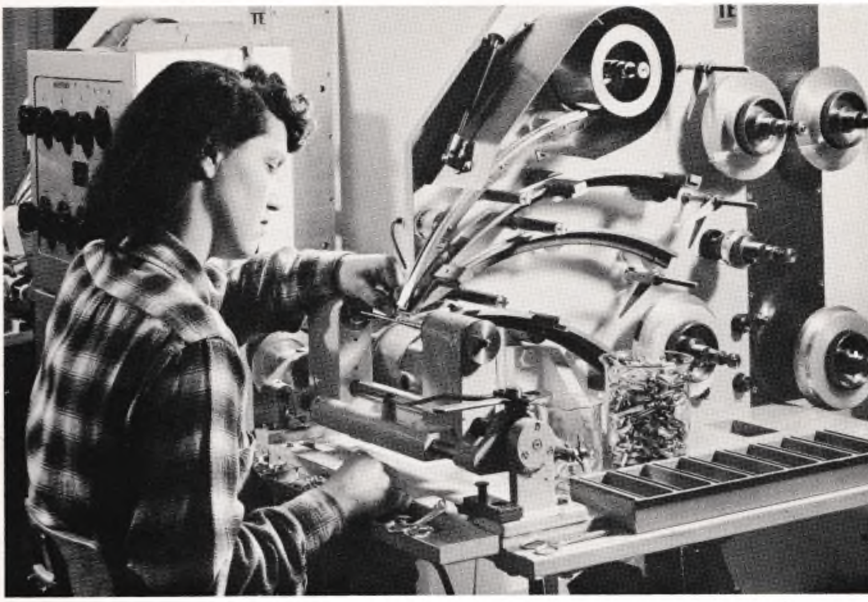

FIG. 4. *Automatic machine used for winding polystyrene capacitors at Lenkurt.*

pacitors are smaller and less expensive to manufacture than mica.

Lenkurt manufactures polystyrene capacitors for use in the electric wave filters of its carrier equipment. Special machines (Fig. 4) in air-conditioned rooms automatically wind long strips of polystyrene and tin-lead foil on fiber forms to any desired value. An attached blade severs the foil and plastic strips at precisely the right length. Manufactured in this manner, sizable yields of capacitors within 1 to 2 per cent tolerance are obtained. By padding (connecting in parallel) with small mica capacitors, tolerances within ¼ of 1 per cent can be achieved.

Ceramic Capacitors

The first capacitor using ceramic as a dielectric was the Leyden jar, invented in 1745. It was used by early scientists to investigate the properties of electricity. Modern ceramic capacitors use a wide range of insulating materials that often have unique characteristics. They are made in a wide range of temperature coefficients, either positive or negative, and some have very high dielectric constants.

Because they can be made with different temperature coefficients, ceramic capacitors are often used in tuned circuits to compensate for variations of resonant frequency with temperature. They are also used for coupling and bypassing at high frequencies because they can be manufactured in convenient shapes. (Shape is important at high frequencies.) The high dielectric constant results in a relatively large capacitance in a small space which makes ceramic capacitors useful in miniaturized equipment. They are used extensively in Lenkurt's miniaturized 45-class equipment.

Capacitors for A-C Coupling

There are many applications in electronic equipment where a direct current must be blocked while alternating currents must be conducted from one circuit to another, or from one point in a circuit to ground. The type of capacitor used for these applications depends upon the frequency, size limitations, and the nature of the circuit in which it is used.

For coupling in high-frequency circuits, small capacitances are satisfactory; consequently, capacitors suitable for resonant circuits, such as micas or ceramics, can be used. However, in low-frequency or low-impedance circuits, relatively large capacitances are necessary so that the impedance of the capacitor is low with respect to the rest of the circuit at the operating frequency. Three types of capacitors usually meet these requirements: paper (dry or oil impregnated), polyester film, and chemical film capacitors.

Paper capacitors are the most widely used and can be found in most electronic circuits. Their values lie in the large capacitances available in a reasonable size at a relatively high voltage rating. However, their electrical characteristics are somewhat poor. That is, the losses are high so that a paper capacitor cannot be used in precision electric wave filters at high frequencies. Also, the capacitance varies widely with changes in temperature, frequency, and age so that they cannot be used in critical circuits.

The main applications for paper capacitors are in low-frequency circuits for coupling and bypassing, in power filter networks, in power factor correction networks, and for contact protection in relays and other interruption devices.

In miniaturized equipment, paper capacitors are often so bulky that ceramic or polyester film capacitors are used. One polyester film is a plastic produced by Du Pont under the trade-name "Mylar." Capacitors made with a Mylar dielectric have characteristics similar to those of paper capacitors except that they are usually smaller, operate at higher temperatures, are easier to manufacture, and have fairly good stability. They range in capacitance from 0.001 to 1.0 μf and are primarily used for bypassing. Like ceramic capacitors, they are also used extensively in Lenkurt's 45-class carrier systems.

Chemical Film Capacitors

There is need for a type of capacitor which is capable of providing very large amounts of capacitance within a small space. A capacitor of this nature is obtained by using an extremely thin chemical film as the dielectric. Since this film is but a few millionths of an inch thick, very high values of capacitance can be obtained. This type of capacitor is usually called an *electrolytic.*

An electrolytic capacitor is manufactured by building up a very thin film of oxide on the surface of a conductor by electrolysis. This film then acts as the dielectric of the capacitor. Capacitors of this type can be reduced to very small sizes. For example, an electrolytic capacitor has been developed for low voltage applications which uses tantalum for the electrode. This capacitor is 5/16 of an inch long and 1/8 of an inch in diameter, and has a capacitance of

4 μf with a working voltage of several volts.

Because the oxide film has the characteristics of a rectifier (a relatively high resistance in one direction and a low resistance in the other), electrolytic capacitors can be used only in circuits where current flow is always in the high resistance direction. For this reason, they are only used in d-c circuits, or in applications where low amplitude a-c is superimposed on the d-c. The proper polarity of the capacitor is always marked so that it can be connected in the high resistance direction.

Since electrolytic capacitors have high losses, a relatively large leakage resistance, and very poor accuracy and stability, they are applicable only in non-critical circuits which need large values of capacitance in a form that is inexpensive and occupies little space. Their typical applications are in power supply filters and for cathode and screen by-pass in vacuum tube circuits.

Conclusion

An important element in the design and maintenance of carrier and radio equipment is the correct selection of the type of capacitor to be used for a specific purpose. This requires careful consideration of the requirements to be met, and the economy and quality of operation which can be obtained. Only by understanding the capabilities and limitations of the many types of capacitors presently available can the requirements of the equipment be completely fulfilled.

Table 1. Characteristics and Applications of Various Capacitor Types

TYPE OF CAPACITOR	CHARACTERISTICS	PRINCIPAL APPLICATIONS
Air	Lowest possible a-c loss Continuously variable High stability Precisely adjustable Low values of capacitance	Tuning of resonant circuits Padding of larger capacitors
Mica	Low a-c loss (high Q) Good temperature stability Little change in capacitance with age High insulating strength Low values of capacitance	Resonant circuits Coupling and bypassing at high frequencies High voltage circuits Padding of larger capacitors As standard capacitors
Polystyrene	Low a-c loss (high Q) Very high insulation resistance Larger values of capacitance than readily available with mica Stable with temperature and aging	In resonant circuits Coupling and bypassing at medium to high frequencies As standard capacitors In high-quality circuits
Ceramic	Positive or negative temperature coefficient Low values of capacitance Stable with aging Available in many sizes and shapes Low losses	Compensating for temperature variations in resonant circuits Coupling and bypassing at high frequencies
Paper	Available in larger values of capacitance Can be built for high voltage operation Large losses at high frequencies Medium stability	Coupling and bypassing at low frequencies Power factor correction Contact protection
Electrolytic	Large capacitance in small sizes Low cost per microfarad Poor stability Operation in d-c circuits only Deteriorates during shelf life or at high temperatures	Power supply filtering Cathode and screen bypassing
Mylar	Better than paper at high temperatures Smaller, more stable and easier to manufacture than paper	Bypassing primarily

Additional Frequency Allocations for

TYPE 45C CARRIER SYSTEMS

In October 1955, Type 45C, a new member of the Lenkurt 45-class of carrier telephone systems, was introduced at the United States Independent Telephone Association Convention. The 45C system has four stackable channel groups, each having four channels. The groups are designated Type 45CA, 45CB, 45CC, and 45CD. The group introduced last fall was the 45CB allocation operating in the frequency range from 40 to 76 kc.

Development work is now in progress at Lenkurt on equipment for the additional allocations which will extend the frequency coverage of the system from 2 to 36 kc, 80 to 116 kc, and 120 to 156 kc. Figure 1 shows the allocations of the 45C system in relation to other existing types of open-wire carrier. Equipment for the CA, CC, and CD allocations will be available during 1957.

Type 45C equipment is similar in construction and appearance to other Lenkurt 45-class miniaturized carrier. Further economies in space and power consumption are achieved by the use of transistors in circuits where they have proved to render reliable service. To reduce spare parts requirements and increase flexibility, most of the basic plug-in units and subassemblies of the terminals are interchangeable between allocations.

The system arrangement of the new 45C equipment lends itself readily to convenient, economical expansion. Since each block of four channels is essentially an independent system, the cost of an installation can be tailored to fit the immediate traffic demand. Thus, an initial installation might consist of four channels which could be expanded as the need arises to eight, twelve, and sixteen channels. The expansion involves no readjustments for power or level and makes use of the existing open-wire pair which serves the initial installation. On pairs transposed for 30 kc or less, application of the higher frequency groups may require some additional line treatment.

Although designed primarily to supplement each other, the various Type 45C allocations may also be used to increase the facilities of other existing systems. For example, the CA allocation may be used to provide an additional four channels on the same open-wire pair already carrying twelve channels of the Lenkurt 45A system. Similarly, the CB, CC, and CD allocations may be added above an existing Lenkurt Type 33A or 32A system or Western Electric Type C system to provide an additional twelve channels. The Type 45C system will also co-ordinate throughout its range in levels and frequencies with corresponding allocations

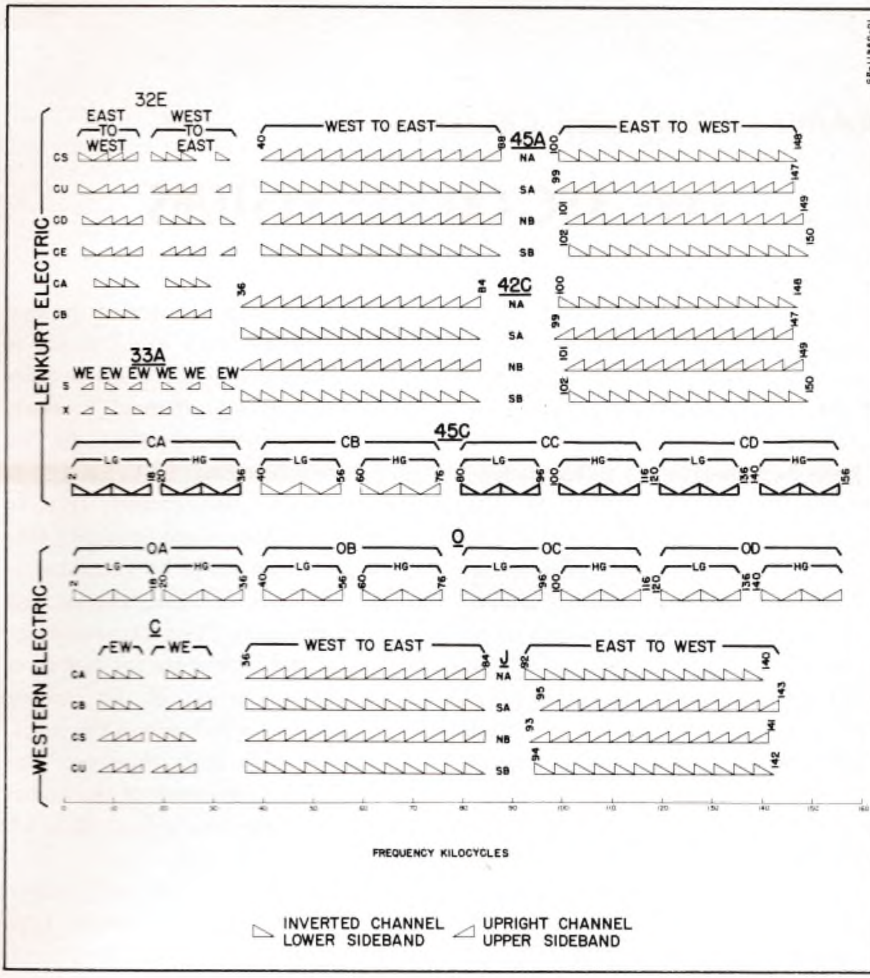

FIG. 1. *Frequency allocations of open-wire carrier systems. Heavy lines indicate new Type 45C allocations.*

of the Western Electric Type O system. Thus, through the use of proper line and directional filters, Type 45C carrier may be added to wire leads already partially equipped with Type O equipment.

The general operating and performance characteristics of the Type 45C system are described in two Lenkurt publications, 45CB1-DES and 45CB-ORD. These publications pertain specifically to the existing 45CB allocation but contain general information applicable to the future allocations of the system. Another publication, PIL-21, contains more detailed information on the expansion of allocations for the Type 45C system. These publications are available from Lenkurt and its distributors.

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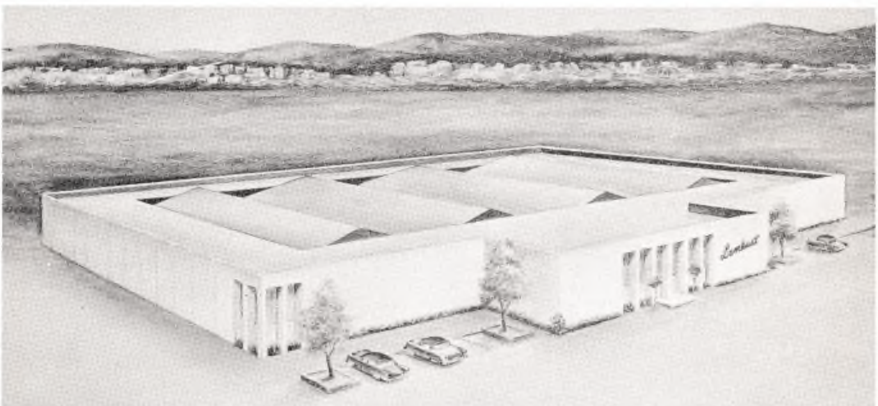

NEW FACTORY BUILDING—Using one of Lenkurt's existing buildings as a core, this new factory building will have a total of 88,000 square feet of manufacturing and office space. Under the present building program, which started in 1955, Lenkurt's San Carlos plant is being expanded to 225,000 square feet by the end of this year.

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