The Lenkurt® Demodulator

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FREQUENCY MEASUREMENTS

in Communication Systems

An important factor in the development of modern carrier telephony has been the ability to generate electrical waves of precise frequencies. This ability has evolved from the further ability to measure electrical frequencies with great precision.

In this article, some of the methods currently used for the measurement of electrical frequencies are discussed and some of the more commonly used frequency measuring devices are described.

Frequency is the rate at which a cyclic event occurs. Its measurement, like the measurement of all quantities, ultimately involves a comparison with a fundamental unit. For frequency, this unit is an interval of time determined by the rotation of the earth on its axis. Hence the basic unit of measurement is one revolution of the earth per day.

Since a day—or even an hour or a minute—is too awkward an interval to use as a time base, one second is universally accepted as the fundamental unit of time for electrical measurements. Thus electrical frequency is normally expressed in cycles per second, kilocycles per second, or megacycles per second.

For purposes of discussion, the various methods of measuring frequency may be separated into five general categories: (1) comparison methods, (2) tuned circuit methods, (3) balanced bridge methods, (4) wave-length measuring methods, and (5) pulse counting methods. Each of these, in turn, encompasses a variety of different approaches to the same general method. Regardless of the approach or the method, however, every measurement of frequency involves either directly or indirectly a comparison with a standard interval of time.

Frequency Standards

Any stable oscillator whose frequency has been accurately determined may be used as a reference to measure other frequencies and is known as a frequency standard. Two important classes of these are primary and secondary standards. A primary standard is one whose frequency has been determined directly in terms of time. A secondary standard is one whose frequency has been determined by comparing directly with a primary standard.

A typical primary standard might consist of a high-quality, crystal-controlled oscillator which drives a very precise clock. A time interval as measured by the clock is compared with the same time interval as determined by astronomical observations. The number of seconds measured by the clock, multiplied by the frequency at which the clock is designed to operate, gives the total number of cycles which occurred in the astronomically determined interval of time. Thus the frequency of the primary standard is determined directly in terms of astronomical time.

A secondary standard is one whose frequency has been determined by comparing directly with a primary standard and thus indirectly with the frequency of the earth's rotation. Like primary standards, secondary standards are usually high-quality, crystal-controlled oscillators. However, some standards for the audio range use tuning fork control.

With suitable equipment, any person or organization can maintain a primary or secondary standard. The U.S. Naval Observatory transmits extremely precise time signals daily on several different radio frequencies for the purpose of calibrating primary frequency standards. Among the best known and most accurate primary standards are those maintained by the National Bureau of Standards of the United States Government.

The Bureau of Standards operates two radio stations, WWV in Washington and WWVH in the Hawaiian Islands, which transmit signals for measuring and calibrating the frequencies of secondary standards. The signals from WWV and WWVH are derived from the Bureau's very precise

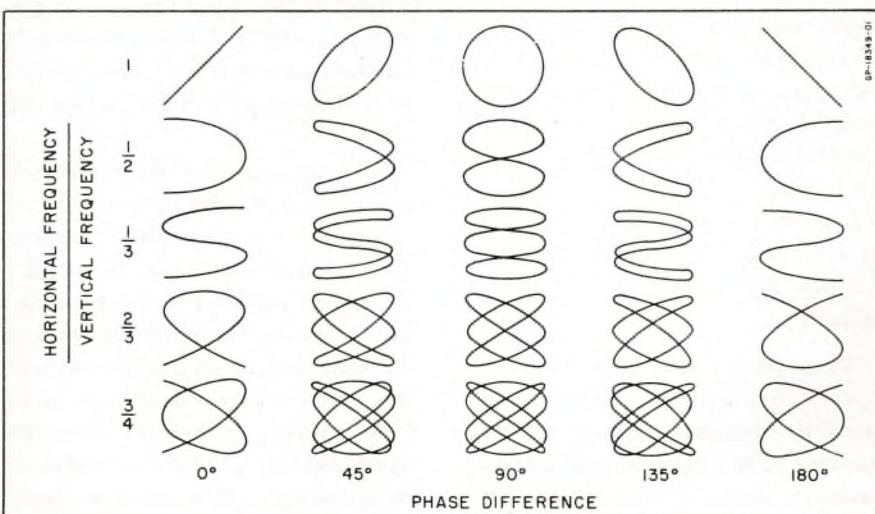

FIG. 1. Typical Lissajous figures for various frequency ratios and phase differences.

primary standards. They are transmitted daily in accordance with established schedules and provide a very convenient and highly accurate standard for measuring frequency. The average error of WWV is about one part in 100 million.

For many measurements, the high degree of accuracy provided by WWV and WWVH is not required and is, in fact, beyond the measuring capabilities of most instruments available. For such measurements, the carrier frequencies transmitted by commercial broadcast stations may often be used as standards. Broadcast stations in the United States are required by law to maintain their assigned frequencies within ± 20 cps and, as a matter of practice, usually maintain them much closer than that. Where such accuracy is tolerable, these frequencies furnish a standard of comparison that is easily accessible and almost continuously available.

To make possible the precise frequency measurements necessary in the manufacture of carrier equipment, the Lenkurt factory at San Carlos maintains both a primary and a secondary frequency standard. The primary standard is a crystal-controlled oscillator whose 100-kc output is divided down to 1 kc to drive a clock. The clock has facilities for comparing its time directly with time signals from the U.S. Naval Observatory.

The secondary standard is also a 100-kc crystal-controlled oscillator calibrated by comparison with the primary standard. The output frequency of the secondary is then divided down to provide frequencies of 10 kc, 1 kc, and 0.1 kc in addition to its fundamental frequency of 100 kc. These precise frequencies are "piped" throughout the factory and engineering laboratories to provide highly accurate standards of comparison for measuring the frequency characteristics of the various oscillators, filters, and amplifiers used in Lenkurt carrier equipment.

Measurement by Direct Comparison

Since frequency standards are so readily available, one of the most obvious methods of measuring frequency is the direct comparison of the unknown frequency with a known standard frequency. One method in common use is comparison by means of a cathode ray oscilloscope.

In this method, a voltage at the unknown frequency is applied to one set of deflection plates of the oscilloscope while a voltage at the known frequency is applied at the same time to the other set of deflection plates. When the relationship of the known to unknown frequency is a ratio of whole numbers, a stationary pattern called a Lissajous figure will be formed on the oscilloscope screen.

The configuration of the pattern will be determined by the ratio of the two frequencies and their phase relationship to each other. For the simpler ratios, the figures can be easily identified. When the ratio of the known and unknown frequencies is a fraction with large whole numbers in the numerator or denominator or both, the Lissajous figures are very complicated and difficult to identify. More involved methods are then necessary. Some typical Lissajous figures are shown in Fig. 1.

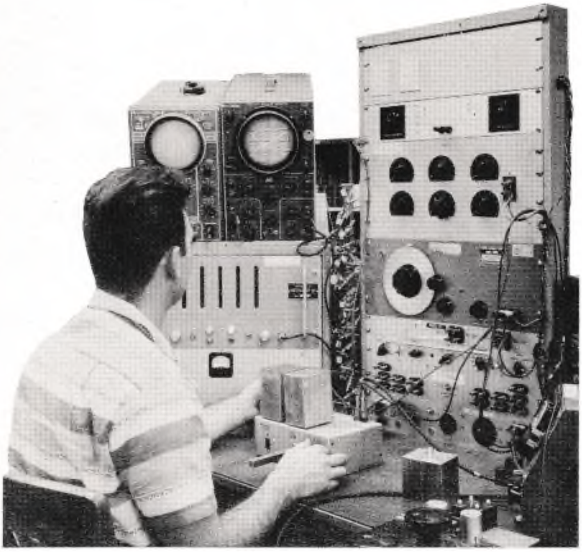

FIG 2. A test bench in the Lenkurt factory where frequency is measured by oscillographic comparison.

The measurement of frequency by means of oscillographic comparison has its most useful application when the unknown frequency and a known frequency are simply related to each other. Lenkurt production departments use large numbers of oscilloscopes for frequency measurement. Figure 2 shows frequency being measured by oscillographic comparison. The known frequency is derived from the precise Lenkurt frequency standard.

Another common form of comparison makes use of the *beat frequency* which is produced when two different frequencies are mixed. The beat frequency is the difference between the two original frequencies. An unknown frequency may be measured by mixing it with a known frequency and varying the known frequency until the beat frequency is zero. The unknown frequency is then equal to the known frequency.

One application of the beat frequency technique is used in heterodyne frequency meters. A heterodyne frequency meter is an instrument which produces a beat frequency by the non-linear mixing (or heterodyning) of two frequencies, one of which is of a known value. The basic instrument consists of a stable local oscillator, a mixing device, and a monitoring device. The output of the oscillator is mixed with the unknown frequency and the beat frequency is monitored by headphones, a meter, or other device. The local oscillator is variable and usually has its tuning control calibrated in terms of frequency. In operation, the variable oscillator is tuned until a zero beat is obtained.

The accuracy of a heterodyne frequency meter is dependent on the ability of the user to detect the zero beat point, the precision of design of the oscillator and associated circuitry, the aging of circuit elements, and the accuracy to which the instrument can be calibrated. In general, it is possible to obtain an accuracy in the vicinity of a few parts in a million, stable over short periods of time, with frequency meters of this type.

Heterodyne frequency meters are often used in the measurement of the frequencies associated with microwave systems. Figure 3 shows a type that is used for the lineup and maintenance of Lenkurt Type 72 microwave radio equipment.

Tuned Frequency Methods

Among the simpler methods of frequency measurement are those using the principle of electrical resonance in tuned circuits which are series or parallel combinations of capacitance and inductance. By holding the inductance at a fixed value and varying the capacitor (or vice versa), the resonant frequency of a tuned circuit can be varied over a relatively wide frequency range.

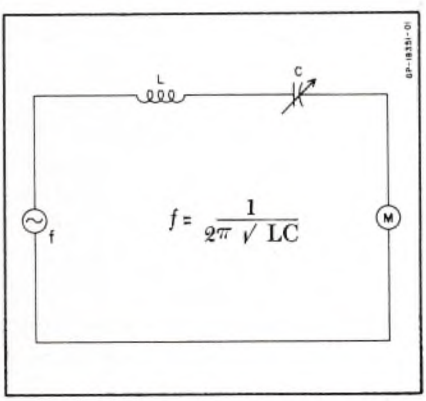

FIG. 4. Simple circuit to illustrate basic principle of a series wavemeter. Variable capacitor, C, is adjusted until meter, M, reads maximum current.

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FIG. 3. Gertsch heterodyne frequency meter. This instrument has a conservative range of 20 to 640 megacycles and can be used for some purposes for frequencies as high as 1,000 megacycles.

The variable capacitor (or inductor) can be calibrated to read directly in terms of frequency.

One of the simplest of tuned circuit frequency measuring devices is called a wavemeter. Wavemeters which read directly in terms of frequency may employ either a series or parallel circuit. A sensitive current-reading instrument is usually incorporated in the circuit as an indicating device. The source of the unknown frequency is connected to the wavemeter and the circuit is tuned through resonance as indicated by a maximum current reading for a series circuit or a minimum current reading for a parallel circuit. A rudimentary series wavemeter is shown in Fig. 4.

Many different types of measuring devices use the tuned frequency principle. Common among them are grid-dip meters, Q meters, and sharply tunable radio-like instruments, such as frequency selective voltmeters. In fact, a well designed radio receiver makes a frequency measuring device suitable for many purposes.

Balanced Bridge Method

Audio frequencies may be accurately measured by means of various bridge networks. A typical circuit for this application is the Wien bridge shown in Fig. 5. The circuit elements are so arranged that when a signal of unknown frequency is applied to the input, the bridge will be balanced for only one particular setting of two variable resistors. The point of balance is determined experimentally, usually by connecting a telephone headset or vacuum tube voltmeter across the output and

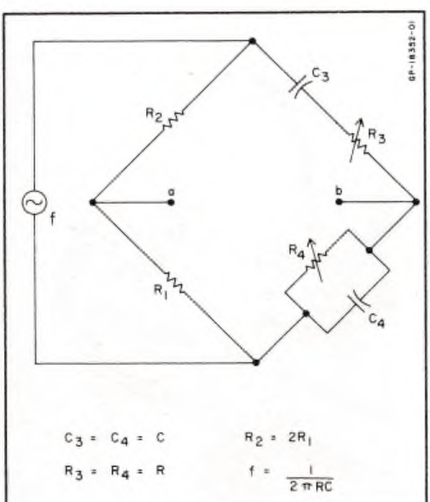

FIG. 5: Schematic diagram of a Wien bridge circuit for measuring frequency. Output of the bridge is across a-b.

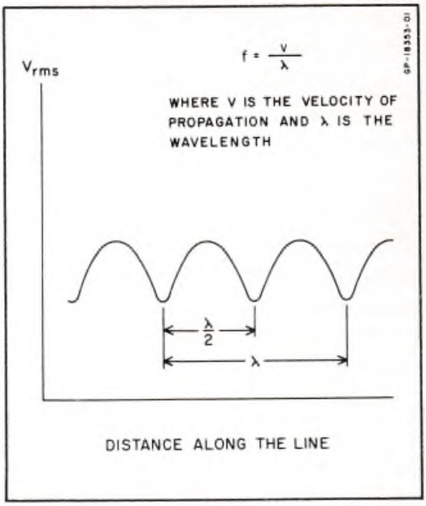

FIG. 6. Variation of amplitude of a voltage standing wave along a transmission line.

adjusting the variable resistances to obtain a null indication. The two variable resistances are normally constructed so that they can be adjusted to the same value simultaneously by means of a common dial. The dial can then be calibrated to read frequency directly.

An accuracy of less than 1 percent is not uncommon with carefully designed frequency - measuring bridges of this type. However, harmonics of the unknown frequency sometimes prove troublesome in the measuring process as they tend to be conspicuous in the output and may mask out the null point being sought.

Wavelength Measurements

An indirect method of frequency measurement involves the principle of resonance and the use of standing wave patterns on transmission lines. Since frequency and wavelength bear a fixed relationship to each other, frequency may be computed readily when the wavelength is known. Mathematically, frequency is equal to the velocity of wave propagation divided by the wavelength. The velocity of wave propagation is usually taken as the velocity of light, 300 million meters per second. At microwave frequencies, measurements may be made by measuring the wavelength along a transmission line.

The actual measurement consists of connecting a sensitive current-reading instrument across the line and adjusting its position along the line until a point of minimum voltage (maximum current) is obtained. The distance between any two such successive points when multiplied by two is equal to the wavelength. Figure 6 is a graphical representation of a voltage standing wave pattern on a transmission line.

The measurement of frequency by directly measuring wavelength has certain distinct advantages. One of these is the directness itself. The measurement obtained is a measurement of length and is independent of any comparison with a frequency standard. Also, since resonant lines normally have a high Q, the accuracy of such methods is quite good and may reach a precision that is accurate to within ± 0.1 percent. The basic principles of this method apply both to open-wire lines and coaxial cables. In the latter case, a slotted cable is used.

A variation of the above method uses a slotted waveguide. In this application, a probe is shifted along the length of a waveguide to determine the minimum voltage points of the standing wave pattern. The distance between these points is then read from a calibrated scale along the side of the waveguide. Figure 7 shows a slotted waveguide used to measure microwave frequencies. The scale on this type of instrument is usually equipped with a vernier and may be capable of measuring accurately to 0.1 millimeter.

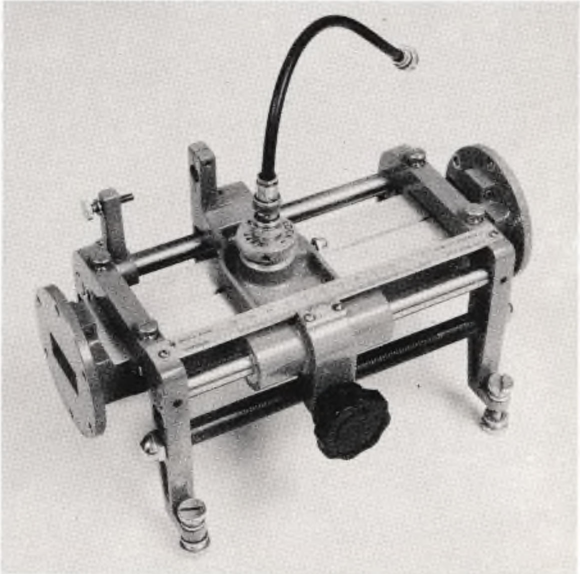

FIG. 7. Slotted waveguide used to measure frequency in the 5.85 to 8.2 megacycle range.

Pulse Counting Method

Perhaps the most modern and one of the most convenient frequency measuring instruments is the electronic counter or scaler. The basis of such a device is a network which converts the signal to be measured into pulses and then counts these pulses against an accurate time base.

A circuit commonly used in such frequency measuring applications is the Eccles-Jordan circuit shown in Fig. 8. A circuit of this type has two stable conditions with a large area of unstable operation between. In one of these stable states, Tube 1 is conducting and Tube 2 is non-conducting and biased beyond cutoff. In the other stable condition, Tube 2 is conducting and Tube 1 is non-conducting and biased beyond cutoff. The shift from one stable state to another is almost instantaneous and is brought about when the grid of one of the tubes is excited by a voltage pulse of the proper polarity and sufficient amplitude. For this reason, such circuits are often referred to as trigger or flip-flop circuits.

When operating in one of its stable states, the circuit is triggered if a negative pulse of sufficient amplitude is applied to the grid of the conducting tube or a positive pulse to the grid of the non-conducting tube. The circuit will then jump suddenly to its other stable state. When another pulse of the proper polarity is applied to the proper grid, the circuit will jump suddenly back to its original stable state. Such a system therefore completes one cycle for every two pulses fed to it and may be said to count or scale by a factor of two.

Each cycle of the trigger circuit may then be converted to a pulse and fed to another trigger circuit. Thus, for two such trigger circuits, four original

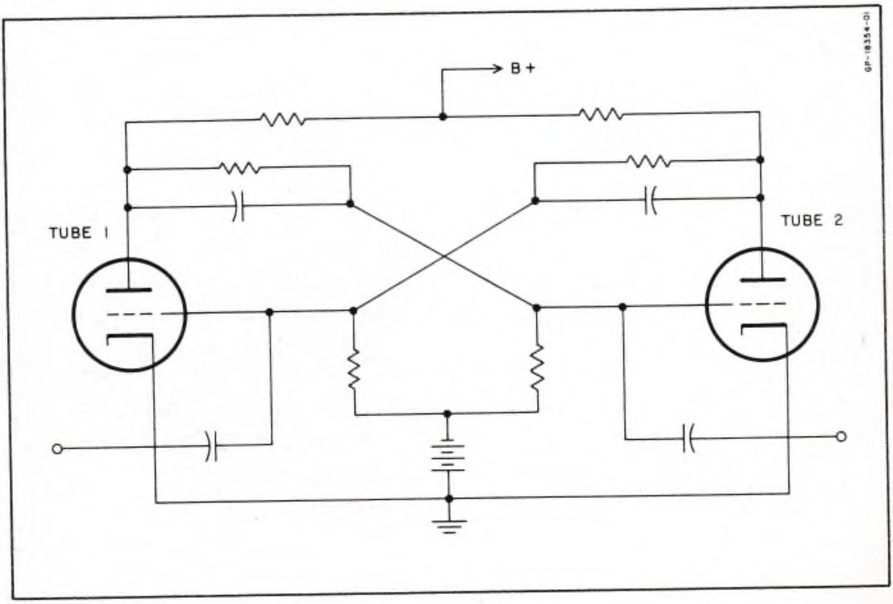

FIG. 8. Basic Eccles-Jordan trigger or flip-flop circuit.

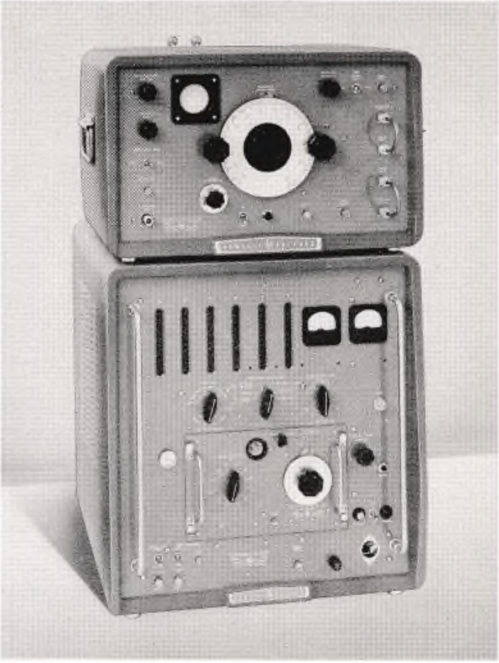

FIG. 9. A frequency-counting system covering a very wide range. The counter is capable of measuring from 0 to 10 megacycles. With a frequency converter (shown mounted in front panel of counter) and transfer oscillator (top), the range can be extended to cover from 0 to 12,400 megacycles.

COURTESY OF HEWLETT-PACKARD CO.

pulses are required to complete one cycle of the second circuit. This process can be extended through several stages until the desired division factor is obtained. When used to generate lower frequencies than the original input frequency, this process is known as frequency division or subharmonic generation.

When such a circuit is used to measure frequency, the signal of unknown frequency is first converted to pulses which are then used to trigger the counting circuit. This count is then compared against an accurate time base furnished by a frequency standard which may be incorporated either in the counter instrument itself or external to it. Thus the counting circuit gives the number of pulses which occur in a given interval of time as determined by the standard. The result is the frequency of the signal being measured. Most frequency counters of this type are designed to display the reading by means of rows of neon lights which are energized in the correct order to provide a direct reading of the measured frequency at the end of each discrete sampling period. An electronic counting system covering a wide range of frequencies is shown in Fig. 9.

The accuracy of frequency counters cannot be any higher than the accuracy of the oscillator used as a standard to determine the time base. With high-quality oscillators for internal standards, instruments of this type can be designed to have an accuracy approaching one part in a million over short periods of time. Frequency-counting instruments may be used to cover a range of a fraction of a cycle to thousands of megacycles.

JACKFIELDS

For Carrier Telephone Terminals

An accessory often used with carrier installations is a jackfield installed at a convenient location on the equipment rack. A jackfield provides quick access to different equipment units and line circuits. Depending on its specific purpose, a jackfield may be arranged in a number of different ways and may use any of several different types of jacks. Fig. 1 shows a Type 45A carrier terminal equipped with a typical jackfield.

There are two basic ways in which jackfields improve the operating efficiency and reliability of a communications plant:

1. They simplify routine maintenance and testing of equipment and circuits.
2. They provide a means for temporary switching of circuits by the use of patch cords.

For maintenance purposes, jackfields permit test equipment to be connected to different units and circuits within the carrier terminal for making transmission measurements and testing equipment performance. They also permit test equipment to be conveniently connected to external circuits such as the voice frequency drops, signaling circuits, and the high-frequency carrier line. This use of jackfields for maintenance is particularly helpful in large installations where many carrier circuits must be tested on a periodic basis. Transmission level, noise, and other quantities can be measured in a matter of seconds.

Although there are many different types of jacks which can be arranged in many different ways, a common arrangement used in Lenkurt equipment provides two pairs of jacks at the desired circuit junction. The jacks are usually wired so that the insertion of a double plug into one of the two jack pairs connects the plug to the circuit in one direction and opens the circuit in the other direction. This arrangement is traditional in the telephone industry.

For example, if the circuit junction is at the point where the two-wire subscriber drop connects to the carrier

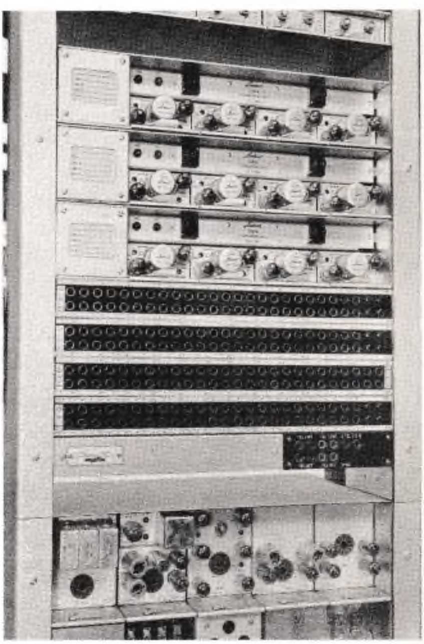

FIG. 1. A typical jackfield arrangement in a 45A carrier terminal.

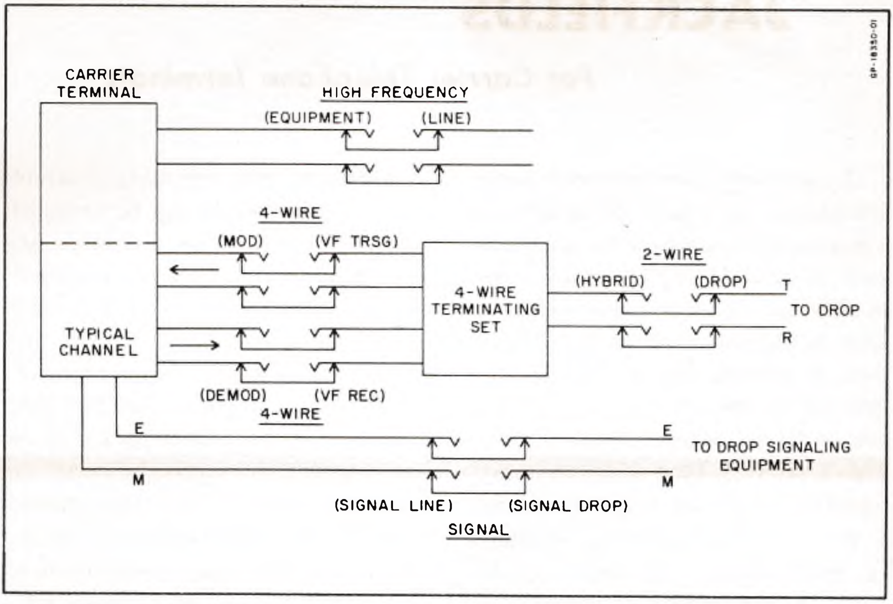

FIG. 2. Block diagram of a typical carrier terminal jackfield arrangement.

channel hybrid, a test equipment plug inserted in the pair of jacks marked "hybrid" would connect the test equipment to the carrier channel unit through the hybrid but would disconnect the subscriber drop. Similarly, inserting the plug into the jack pair marked "drop" would connect the test equipment to the subscriber drop and disconnect the hybrid. A typical jack arrangement is shown in Fig. 2.

In addition to their use as a testing accessory, jackfields also provide a very convenient means for patching circuits and equipment. Carrier systems can be transferred quickly from one line to another, or voice circuits can be transferred from one channel to another by patching cords plugged into appropriate jacks. This ability to transfer circuits and equipment quickly is of great benefit when there is trouble in regularly assigned circuits or equipment. It is also very convenient when temporary changes in circuit layout are required to handle changing traffic patterns.

The jackfields optionally available with Lenkurt carrier systems can be arranged to provide nearly any degree of flexibility desired for testing and patching operations in a carrier bay. Where desirable, Lenkurt jackfields can be integrated into other jackfields already existing in a toll terminal office. For example, a toll terminal office already equipped with a patching jackboard may not require jacks in the voice-frequency circuits but may require carrier-line jacks.

Jackfields are optionally available with all types of Lenkurt carrier equipment. Advice and information on the jackfield requirements for any particular installation can be obtained from Lenkurt's distributors and from appropriate ordering information bulletins.

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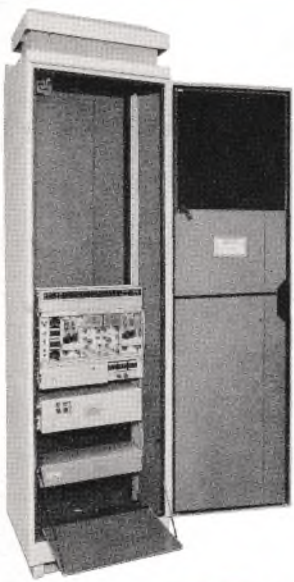

Recently Issued Publications

The development of new equipment to extend the frequency allocations of 45C open-wire carrier systems is discussed in **Product Information Letter No. 21.** The new equipment together with the existing 45CB allocation will provide four four-channel groups covering the frequency range from 2 to 156 kc and coordinating with Western Electric Type O systems.

Product Information Letter No. 22 describes new pole-mounted repeater arrangements for use with 45A open-wire carrier systems. Up to four repeaters can be housed in a single weatherproof cabinet. A one-repeater arrangement is shown opposite.

Copies of these letters may be obtained from Lenkurt's distributors.

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