The Lenkurt Demodulator

NEWS FROM LENKURT ELECTRIC

VOL. 6, NO. 6 JUNE, 1957

THE KLYSTRON

Most conventional vacuum tubes have little practical use at the higher microwave frequencies. Without some other means to generate and amplify these signals, all communications would be seriously limited to the already crowded lower bands of the spectrum.

One of the devices which opened up a vast new area of usable frequencies was the klystron tube. This article discusses the basic operating principles of klystrons and their applications.

A conventional vacuum tube conducts current by means of a stream of electrons which flows from a negative cathode to a positive plate. The electric field between cathode and plate controls the amount of electrons in the stream.

In a triode, a signal voltage on the grid changes this field and causes the electron stream to increase and decrease in density with the amplitude of the signal voltage. The resulting current flows through a load in the plate circuit to produce an output voltage whose amplitude is proportional to the signal and whose frequency is the same.

The distance between cathode and plate is short and the speed of the electrons is high. Therefore, the transit time between is very short compared to the time it takes for an audio-frequency or low radio-frequency signal to go through one cycle. But at frequencies in the microwave region, the transit time may be very long compared to the period of the signal. When this happens, the field between cathode and plate may reverse itself long before an individual electron has had time to go from cathode to plate. This upsets the phase relationship between plate voltage and current, limits the output power and frequency, and increases the plate dissipation.

Transit time effects are the most serious limitations of a conventional tube at microwave frequencies. These effects are counteracted in the klystron tube which actually makes use of transit time to amplify or generate microwave frequencies.

Klystron Operation

To understand the operation of a klystron, it is first necessary to know something of the basic mechanics of electron flow. First of all, the electron is a negatively charged particle with a definite mass. When it is in motion, it has a certain amount of kinetic energy. Increasing its velocity increases its energy. Decreasing its velocity decreases its energy.

A positive electric field attracts an electron and a negative field repels it. If an electron is moving toward a positive electrode, the attractive force will accelerate the electron. If it is moving away from a positive electrode, the force will exert a drag on the electron which decelerates it. A negative field has just the opposite effect.

But no form of energy comes into being or disappears spontaneously. So when an electron's speed is increased, the additional energy must come from somewhere. And when an electron's speed is decreased, the energy it gives up must go somewhere. In an electronic circuit, the energy supplied to or taken from the electron comes from or goes to the field.

Figure 1 shows the basic circuit of a klystron tube. A positive accelerator grid draws electrons from the cathode and shoots them in a high-velocity stream toward a pair of grids in a cavity resonator. These grids are called *buncher grids*. The cavity acts like a tuned LC circuit. A signal is fed into it through a waveguide, probe, or by a coupling loop as shown.

The signal voltage sets up an electric field between the buncher grids. On positive halves of the cycle, this field accelerates the approaching electrons and on negative halves it decelerates them. When the signal wave goes through zero, the field has no effect on the electrons. Therefore, the stream leaving the buncher grids consists of electrons moving at different speeds. Some are moving faster than when they entered the cavity, some are moving slower, and others are moving at the same speed.

The space between G_3 and G_4 in Fig. 1 is free of any fields and is called the *drift space*. In the absence of any accelerating field, the electrons will keep whatever speed they had on leaving the buncher gap. Since some are traveling faster than others, the faster ones will overtake the slower ones. Therefore, at some point in the drift space, the electrons will jam up and form bunches.

Another resonant cavity with a set of catcher grids (G_4 and G_5) is located at a point where the bunches of electrons form. The bunches induce an r-f voltage in the catcher cavity at its resonant frequency just as a current pulse excites a tuned LC circuit. With the proper phase relations between this voltage and the arriving bunches, the field will slow down the electrons as they pass through the catcher gap. The energy they give up goes into the resonator field and is taken out by another coupling loop. The slowed down electrons then go on to strike a collector plate which returns them to the cathode.

Since the electrons pass the buncher gap in a steady stream, the signal voltage speeds up as many electrons as it slows down. Therefore, neglecting losses, there is no net exchange of energy in the buncher cavity throughout a cycle of signal voltage.

But at the catcher, the electrons reach the gap in bunches when the cavity voltage is in its negative half of the cycle and very few electrons pass

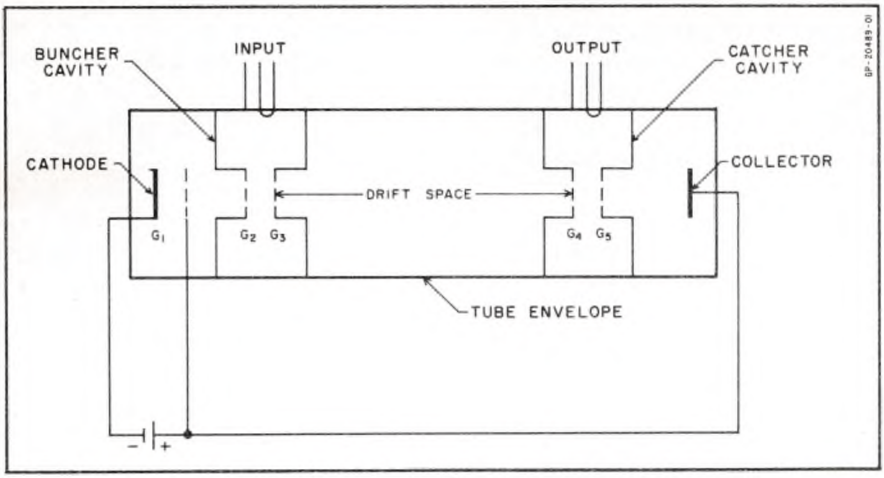

FIG. 1. Simplified diagram of a klystron amplifier. An actual klystron usually has a set of electrodes at the cathode which focuses into a narrow beam.

through on the positive half. As they pass through the gap, many more electrons are slowed down than are sped up. Thus, much more energy goes into the field than goes out. This extra energy represents an increase in power over the applied signal. In working terms, the klystron has amplified the signal.

Klystron amplifiers are often made with more than two cavities. These are called multi-cavity klystrons. They achieve greater efficiencies and higher outputs by cascading the power gain. Such amplifiers can supply output powers of the order of kilowatts.

Klystron tubes can also be used for oscillators and frequency-multipliers. The klystron oscillator simply feeds back some of its output power from the catcher cavity to the buncher cavity in the proper phase. In a frequency-multiplier, the catcher cavity is smaller than the buncher cavity and tuned to resonate at some multiple of the buncher cavity frequency.

The Reflex Klystron

Probably the most common form of klystron oscillator in use today is the reflex klystron. Its basic circuit is shown in Fig. 2. This form uses only one resonant cavity and one set of grids which act as both buncher and catcher for the electrons. In place of the collector of the two-cavity klystron, the reflex klystron has a repeller electrode. This has a negative voltage with respect to the cathode and turns the electrons back instead of returning them through the external circuit.

In operation, electrons from the cathode are drawn through the resonator gap and toward the repeller by the potential of the first grid. The positions of electrons in the beam are random in nature. Thus the beam will induce tiny noise voltages in the gap, and some of these will be in the resonant frequency range of the cavity. These voltages will velocity-modulate the electron beam just as the signal source does in the klystron amplifier of Fig. 1.

This means that some electrons will have greater speeds than others as they leave the gap and head toward the repeller. The repeller exerts a force similar to the force of gravity on an object thrown straight up in the air. At some point before an electron reaches the repeller, it will slow to a stop, reverse, and head back toward the gap. Electrons traveling at higher speeds will travel farther into the negative field of the repeller before reaching this turning point.

On the way back, the electrons will form bunches. This bunching process takes place in much the same manner as a number of balls thrown straight up in the air, one at a time, can be made to strike the ground at the same time. If each one is thrown up with a little less force than the one before and the time interval between throws is spaced properly, the balls will all reach the ground in a bunch.

In the reflex klystron, the electron bunches pass back through the gap toward the cathode and induce voltages in the gap which reinforce the original voltage. The reinforced voltage speeds up or slows down other electrons coming from the cathode and the cycle repeats itself. At some point, conditions will reach an equilibrium state where the amount of energy coming back just balances the circuit losses. Then the klystron oscillates at the frequency of a resonant mode of the cavity.

Both the frequency and power output of a reflex klystron depend on the time it takes for the electrons to leave the gap and return in a bunch. This time depends on the distance between gap and repeller and the supply voltage on the grids and repeller. When the dis-

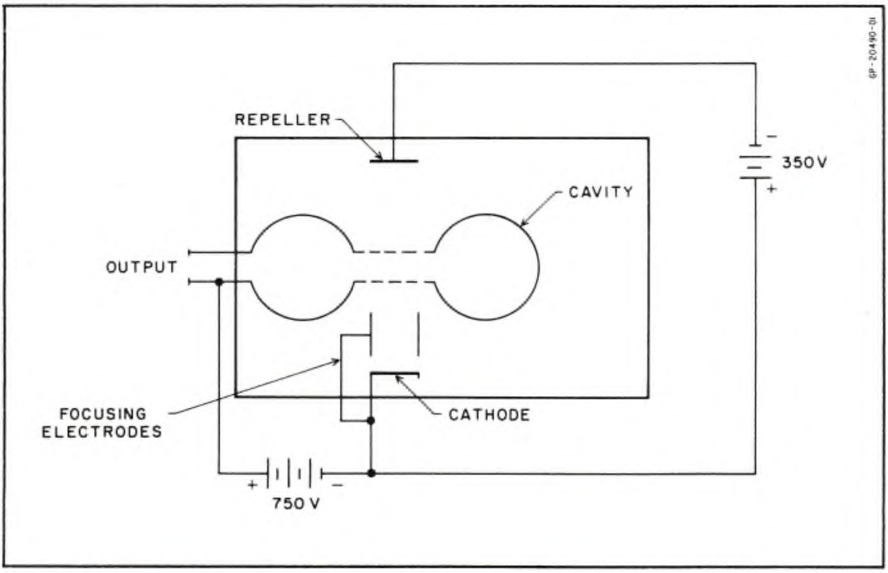

FIG. 2. Diagram of a reflex klystron. The output may be through a waveguide, coaxial cable or probe.

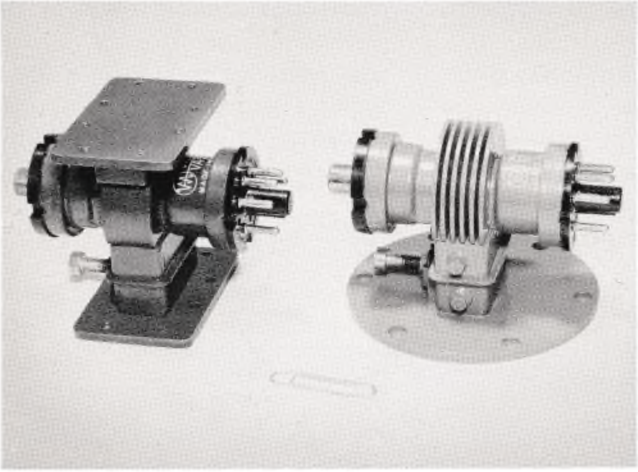

FIG. 3. Two typical reflex klystrons. The one at left is rated at one watt, and the one at right, at 35 milliwatts.

tance and the grid voltage are fixed, both frequency and power can be controlled by the repeller voltage.

To transfer power to the cavity, the r-f voltage across the gap must decelerate the electron bunches as they pass through. This happens when the repeller voltage is the proper value to get the bunches back to the gap at a time when the r-f voltage is going through a negative part of its cycle with respect to the arriving bunches. The energy given up by the electrons then transfers to the field.

Since the repeller voltage controls the time necessary for the bunches to get back to the gap, it also controls the frequency of oscillation. With a constant supply voltage on the repeller, the frequency will be the resonant frequency of the cavity. A more negative voltage will stop and turn back the electrons at a point farther from the repeller. Their travel time will then be shorter and the frequency will increase. A less negative voltage will have the opposite effect.

This ability to convert variations in voltage amplitude to variations in frequency makes the reflex klystron a very convenient oscillator for frequency-modulation systems. For the circuit of Fig. 2, the modulating signal can simply be placed in series with the repeller supply voltage. As the signal voltage varies in amplitude, the repeller voltage also varies and causes the output frequency of the oscillator to vary.

The reflex klystron has a low efficiency and so is not used to produce very high power outputs. But in many applications, not much power is needed and the reflex klystron makes a very effective oscillator. Two reflex klystrons are used in the new Lenkurt Type 74A 6,000-mc microwave radio system. One supplies the radio carrier frequency in the transmitter and another acts as a local oscillator in the receiver. Two typical low-power reflex klystrons are shown in Fig. 3.

Conclusion

The klystron overcame the serious frequency limitations of conventional vacuum tubes to open a new area of the microwave frequency spectrum. It operates with one or more resonant cavities and performs the functions of amplifier or oscillator. The most common form is the reflex oscillator which uses one resonant cavity. In all cases, an electron stream is velocity-modulated to form bunches of electrons which then induce voltage in a resonant circuit.

As a power amplifier, a klystron can deliver large outputs of power at microwave frequencies. As an oscillator, the power output is low but the principle of its operation makes frequency-modulation easy and natural.

CROSSTALK COUPLING TERMS

Telephone engineers use a number of terms to describe the crosstalk conditions between paralleling wire pairs. Each term has its own purpose. But they are all related and all stem from the same basic measurement—the amount of coupling that exists between two circuits separated in space. Each is just another way of stating how much a signal on one circuit will interfere with the operation of another adjacent circuit.

One of these terms is the *crosstalk unit*. This is a measure of the current that is induced on the disturbed circuit as a result of a current flowing in the disturbing circuit. In the usual case where the impedances of the two circuits are the same, the coupling can be expressed as a simple ratio of the induced current to the inducing current. Usually this is a very small figure. In order to give it an easy-to-handle dimension, it is multiplied by one million. The crosstalk coupling expressed in these terms is the coupling in crosstalk units (cu). If the impedances of the two circuits are different, the coupling in cu can be obtained by using the square root of the power ratio in place of the current ratio.

The tendency of two circuits to crosstalk is directly proportional to the coupling in cu between them. A high value of cu means a tight coupling and a greater tendency for one to interfere with the other.

The cu is a very handy unit for designing and laying out transposition schemes for open-wire lines. A great deal of valuable information is available in the form of tables which are keyed to a crosstalk coefficient in terms of cu per mile of circuit length, per kc of operating frequency.

Coupling can also be related in another way to the power of the signal in the disturbed circuit and the power of the disturbing signal. The ratio of these powers provides a basis for stating the coupling in db. The ratio of induced power to inducing power gives a negative value of power gain in terms of db. In practice, the usual procedure is to state the value as a positive number and call it a *coupling loss*. The coupling loss in db is therefore inversely proportional to the tendency of two circuits to crosstalk.

Another common method of stating crosstalk coupling is in terms of *dbx*. This is really a means of taking into

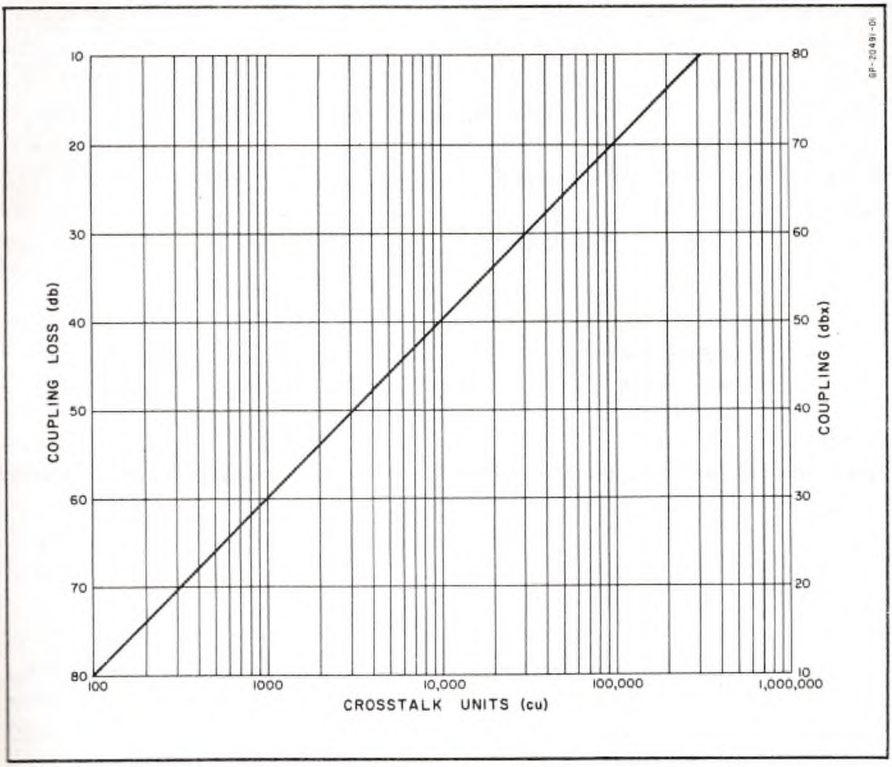

FIG. 1. Nomograph showing the relationship between cu, db and dbx.

account the different interfering effects of different frequencies. The dbx unit relates the actual power coupling between two circuits to the interfering effect by tying the measurement down to still another unit, the *dba.* The dba has been defined and discussed in a previous Demodulator article (January, 1954). In effect, the coupling in dba units adjusts the actual coupling to relate it to the interfering effect of a 1000-cycle tone.

The coupling in dbx must be referred to a reference coupling. This reference is the coupling that exists between two circuits when a test tone of 90 dba on the disturbing circuit gives a measurement of 0 dba on the disturbed circuit. The measurements of both circuits must be made with a Western Electric 2-type measuring set and at the same weighting. Under these conditions, the crosstalk coupling in dbx is 0.

At reference coupling, there is 90 decibels of loss between disturbing and disturbed circuits (from 90 dba to 0 dba). Therefore, coupling in dbx can be expressed as 90 minus the coupling loss in db. The coupling in dbx is directly proportional to the tendency of the circuits to crosstalk.

The relationships between crosstalk couplings in cu, db and dbx are given in the nomograph of Fig. 1.

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CHANNEL UNIT ASSEMBLY BELT

The photo at left shows a conveyor belt at work in one of the modern production shops at **Lenkurt's** San Carlos plant. The women are assembling and wiring channel units as the units pass along on the belt. Each channel unit arrives at the belt as a bare chassis and ends up at the far end of the belt as a finished assembly. From there, the units go on to testing and then to systems assembly.

The channel unit is one of the plug-in assemblies which are interchangeable among all Lenkurt 45-class systems.

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