The Lenkurt® Demodulator

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Rapid Microwave Switching

Increasing congestion of microwave frequency allocations, plus greater need for protection against transmission failures as system capacities increase, is placing new emphasis on so-called "hot-standby" techniques for assuring continuous microwave transmission. This article reviews some methods of microwave switching, essential to hot-standby protection.

The conventional way of protecting against the failure of a microwave communications system is *frequency diversity* transmission, a method which requires two fairly well separated frequency allocations. This method protects against fading, since the most common type of fades rarely occur simultaneously on separate frequencies. Equipment failure is guarded against by the duplication of radio equipment. Unfortunately, two separate frequencies are required, and these are becoming increasingly scarce in some areas due to the burgeoning growth of microwave communications. For this reason, frequency diversity transmission may not be permissable.

When only a single transmission frequency is available, complete protection is more difficult. *Space diversity* provides some protection against fades, but is much more costly than frequency diversity. Two well-separated antennas, and a receiver for each, are required to receive the same transmission. The separation of the two transmission paths prevents most fades from occurring on the two simultaneously. The extra antennas, reflectors, greater tower height, and additional land may make the cost of space diversity prohibitive.

Nevertheless, some means of protecting the system against equipment failure is required. This is often achieved by some form of "standby" transmission equipment. In some older systems, the standby equipment sat idle without power applied until there was an equipment failure. When a failure or loss of power was sensed, the standby equipment was turned on and soon took over the communications load. In more recent times, however, even brief interruptions of service during the period required for the standby equipment to warm up, have become intolerable, with the result that so-called "hot-standby" transmission is gaining much wider usage.

In hot-standby systems both the operational and the standby equipment are energized ("hot") at all times. If some part of the system fails, or if power drops below some arbitrary value, transmission is immediately turned over to the standby equipment. Service is interrupted for the time required to switch from one transmitter to the other. Early hot-standby switching arrangements required one or more seconds for the switching operation. In many operations today, the large volume of communications carried over microwave make even this brief interruption extremely undesirable, if not intolerable. As a result, greater emphasis is being placed on reducing the time required for switching.

Problems of Switching

The problem of microwave switching is fairly old. In even the earliest radar systems, the sensitive receiver had to be effectively disconnected from the antenna while the transmitter sent its brief, powerful pulse, then re-connected quickly to listen for echoes. The problem was generally solved by the use of gas discharge tubes, thyratrons, and the like. Although speed of switching was fairly important, the degree of isolation required was not great, since it was only necessary to protect the receiver from damage caused by the high-powered transmitter pulses.

In a communications system, however, it is necessary to have a high degree of attenuation of the undesired signal. This would not be required if both the standby and operating transmitter signals were precisely in phase with each other. If there are slight discrepancies in the phase or frequency of the two transmitters, destructive interference of the two signals results, causing a large increase in system noise.

Although klystron oscillators can be phase-locked very easily, practical considerations of equipment design make this approach undesirable. Accordingly, all presently-available hot-standby methods allow only one signal to be present at a time. This is accomplished by the use of some sort of switch which, in one state, can connect the transmitter to the antenna with very little loss, or, in the other state, block the RF signal and provide a high degree of isolation. The actual amount of isolation required depends on the nature of the microwave system. Basically, the switch should reduce the standby RF carrier enough that noise caused by mutual interference is less than the "idle noise" of the system. This, of course, varies with the bandwidth of the system, its loading, crosstalk performance, and similar factors. In general, isolation or attenuation of the standby carrier should be about 80 db for most microwave equipment used in this type of service.

Switching Requirements

In data transmission, the loss of a single symbol can have expensive consequences. The data transmission speed determines how fast the transmitter switchover must be made in order to avoid errors.

In general, switching time should be less than one-half the duration of a single data pulse—as much less as possible—thus reducing the likelihood of that pulse being lost at the instant of switchover. In the case of 100-speed (100 words-per-minute) teletypewriter

Figure 1. Carrier equipment like shown above enables hundreds of channels to be transmitted over a single radio beam. Increasing traffic density makes it imperative that some sort of standby protection be provided for microwave equipment.

signals, about 80 bits or pulses are transmitted each second. Accordingly, the switchover should take place in less than 1/160 second—that is, about 6 milliseconds. Similarly, 60-speed teletypewriter signals must be switched in less than 10 milliseconds to avoid loss of characters. For higher speed data transmission, faster switching speeds are required.

Microwaves are considerably more difficult to switch than lower frequencies because they are almost always transmitted through waveguide instead of wire. The problem is not only physical but also electrical. Microwave signals are propagated through the waveguide as electrical and magnetic fields, instead of a simple flow of current, as in a wire. Slight imperfections or discontinuities in the waveguide cause the signal to be reflected instead of just being interrupted. When the signal is reflected back towards its source, it affects the

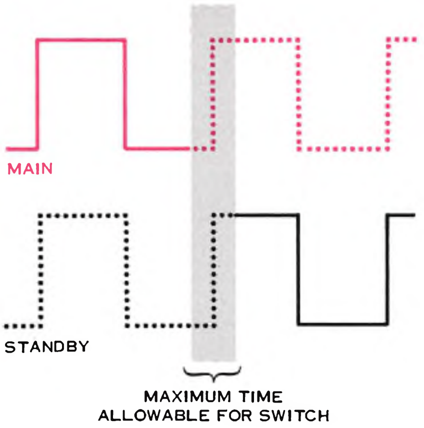


Figure 2. Maximum switching time of half the pulse length is required to permit switchover with little chance of causing data errors. Shorter switching time is desirable.

voltage and power distribution in the waveguide, thus providing wrong indications at measurement points.

In telecommunications, it is very desirable to maintain the standby equipment in a condition which duplicates actual transmission. This allows the standby equipment to be monitored continuously, thus revealing any need for maintenance and providing positive indications of the state of the system.

Methods of Switching

The switching technique used has an important bearing on the behavior of the standby microwave equipment. Thus, a microwave switch that reflects the radio energy back to the klystron sets up standing waves. These interfere with klystron operation, and tend to give a misleading power indication. This can be avoided by using an isolator, a device for transmitting energy in one direction but absorbing that returning from the opposite direction. However, an isolator may not be necessary if a switch is used which absorbs the energy rather than reflects it.

The earliest method of switching microwave transmitters was by the use of a so-called waveguide switch, such as diagrammed in Figure 3. In this device, the antenna is directly connected to the operating transmitter-receiver by means of a movable waveguide section. The output power of the standby transmitter is connected to an absorptive load. After a fault or equipment failure, a motor-driven mechanism operates a movable waveguide section that removes the absorptive load from the standby unit and connects it to the other unit (now disconnected from the antenna). At the same time, the antenna is physically connected to the output of the standby unit. With the exception of switching time, this method of switching can have very good performance characteristics. If the switching machinery is well built, so that mechanical tolerances are exceptionally close, a very high degree of isolation is obtained, and there is very little "forward loss" in the transmitting condition. The disadvantages of this method are that it is mechanically complex, and switching time is extremely slow—sometimes requiring several seconds to complete the switch.

In an effort to improve switching time, simpler versions of the mechanical waveguide switch have been produced which are able to switch from one transmitter to the other in from 25 to 100 milliseconds. However, losses are somewhat higher. At best, these rotary switches provide from 40 to 60 db reverse isolation. Large amounts of power are required for rapid switching—on the order of about 50 watts typically.

Waveguide Plungers

A very popular method of waveguide switching, and one that is still widely

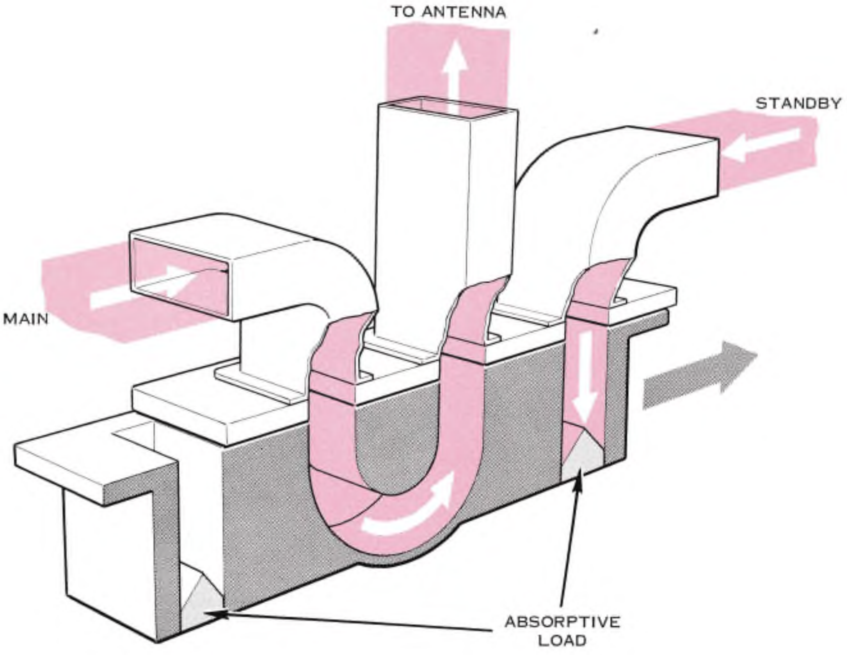


Figure 3. Early systems used mechanical waveguide switch like shown here. When switchover is required, electric motor drive slides shaded portion sideways; waveguide loop connects antenna to the operating equipment. Absorptive terminations are provided for the disconnected transmitter.

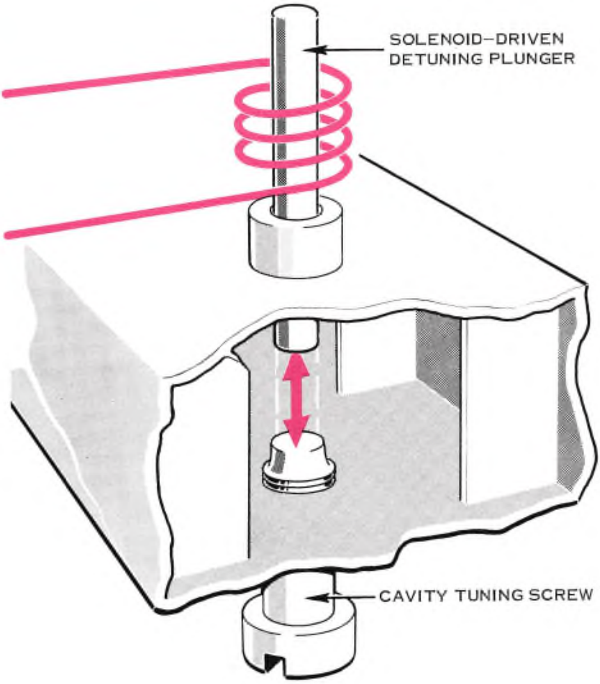
used, is the solenoid-driven waveguide plunger. In this method, a thin rod is inserted through the waveguide to stop the signal. Although the rod actually blocks only a very small area of the waveguide, it almost totally reflects the signal, thus providing an attenuation of about 40 db. By using two plungers appropriately spaced, additional attenuation is possible.

The plungers are driven by solenoid magnets so that the plunger is completely withdrawn from the waveguide of the operating transmitter and inserted through the waveguide from the standby transmitter. If the operating transmitter fails or loses power, one plunger is withdrawn and the other inserted in about 30 or 40 milliseconds. This is faster than the waveguide switch because less mass must be moved in the switching operation.

The mechanical plunger switch is still used by some manufacturers because it is reasonably reliable and provides effective switching action. It is stable and has good power handling capacity. Its bandwidth is relatively limited — only about 1% — because it is essentially a form of waveguide filter. However, this is still quite adequate for most communications applications.

The disadvantage of the plunger switch is that it is mechanical, and therefore inherently limited in its potential speed. Typical plunger switches

Figure 4. One form of waveguide plunger switch, still used in some equipment. When plunger is withdrawn, energy passes with little loss. With plunger inserted in cavity, microwave energy is mostly reflected.



operate at 1/5th the speed required to avoid loss of teletypewriter characters. If only voice circuits are to be carried over the microwave system, the mechanical plunger is entirely adequate, and this is also true for slow telemetering and control signals.

Electronic Switching

In order to avoid the limitations of mechanical switches, engineers have turned to fast-acting electronic devices. Special versions of some commonly-used ferrite devices have proved to be extremely effective as microwave switches. For instance, ferrite isolators make excellent high-speed switches. Microwave circulators have been successfully used as two-way switches.

The "Faraday" rotation type of ferrite isolator is widely used to absorb microwave reflections in waveguide, and thus reduce distortion. When microwaves travel through a ferrite slab lying in a magnetic field, the plane of polarization of the microwave signal is rotated. Signals coming from the other direction are also rotated. By designing the device carefully, each signal can be made to rotate exactly 45°; the signal traveling in one direction passes through with hardly any attenuation, while the opposite-going signal is rotated until it is at an angle of 90° with the outgoing waveguide, but is aligned with a vane of "lossy" or resistive material which absorbs its energy. Since the signal traveling in the desired direction is polarized at right angles to the lossy vane, little energy is absorbed.

In the switching isolator, *two* 45° sections are used, and the permanent magnet of the fixed isolator is replaced with electromagnets. By reversing the magnetic fields, it becomes possible to rotate the plane of polarization of the microwave signal parallel to the output waveguide and perpendicular to its vane of absorbing material—thus letting the signal pass through—or perpendicular to the waveguide and parallel to the vane, thus blocking passage of the microwave energy.

The switching isolator has no moving parts and thus can switch much faster than devices which depend on the mechanical motion of a mass. The only basic limitation to the speed of a switching isolator is the time required to overcome and reverse the magnetic fields of the electromagnets. In the Lenkurt 74B hot-standby equipment, this problem is easily overcome by storing a large amount of "reserve" electrical energy in a series inductance. In the 74B arrangement, the effect of the standby RF carrier is reduced more than 80 db, insertion loss is 0.5 db to 1 db, and switching time is about one millisecond—five time as fast as necessary for teletypewriter service. The switching isolator provides an attractive solution to the problem of rapid switching because it is also able to serve as a conventional isolator to prevent waveguide reflections from reaching the transmit klystron.

Other ferrite devices have been used for switching microwaves. In one arrangement a rod of ferrite is suspended in the waveguide, but without an applied magnetic field. Normally, it has very little effect on the microwave signal passing through. When it is subjected to a magnetic field, however, the

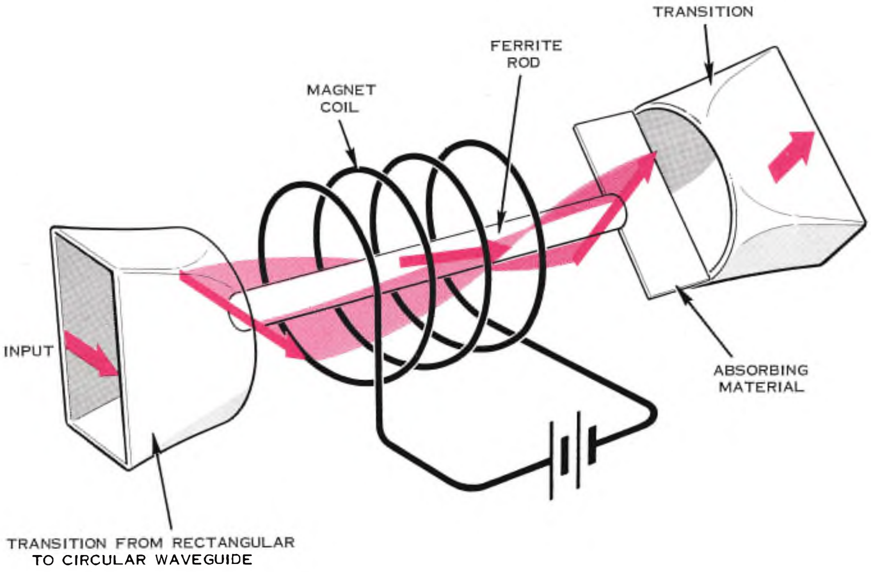
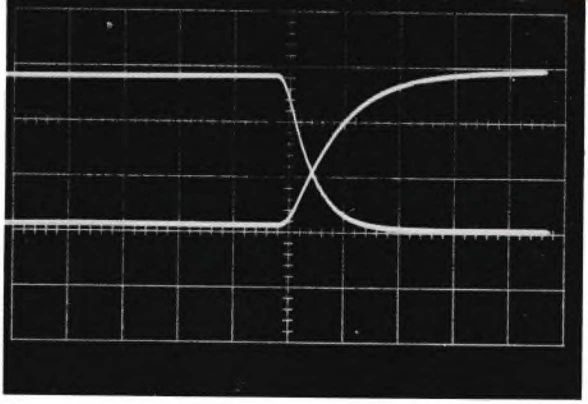


Figure 5. Faraday rotation switch uses property of ferrite in a magnetic field to rotate microwave plane of polarization. In one plane, signal is passed through with minimum attenuation; in other plane, signal is absorbed in vane of resistive material. In practice, two 45° sections are used to achieve 90° rotation.

Figure 6. Unretouched photograph of Lenkurt 74B "Hot Standby" switching action, using Faraday rotation switch. Time scale is one millisecond per division. Ninety percent of power is transferred in first millisecond.



ferrite magnetic permeability becomes saturated, and the microwave signal is strongly reflected. This technique can provide 60 db isolation, with about 0.5 db forward loss in the "on" condition.

Diode Switching

The rapid growth of computer technology has led to considerable work on the switching of microwave energy with semiconductors. One form of semiconductor microwave switch is diagrammed in Figure 7. In this device, a microwave diode is placed across the narrow dimension of a section of waveguide. When the diode is biased so that current flows through it, microwave energy is attenuated only about one db. When the diode bias is reversed, microwave energy is strongly reflected, thus providing up to 25 db attenuation. Essentially this occurs because the diode introduces a capacitive reactance when non-conducting—the equivalent of a short circuit across the waveguide.

Another version, shown in Figure 8, employs a probe into the waveguide. When the probe is just ¼ wavelength long, it is "series resonant" and reflects the microwave signal. If the probe is physically contacted by another probe at right angles to it, it is necessary to readjust the length of the vertical probe to achieve series resonance and block the signal. If the side probe is retracted slightly so that electrical contact is broken, the structure is detuned, and the microwave energy passes freely. Now, if a biased diode is used to make and break electrical contact, the device becomes an electrically-operated microwave switch which provides about 20 db isolation and 0.2 db insertion loss.

In most diode switches of the type described, not more than about 25 db isolation can be obtained by a single switch section. By spacing two or more diodes in tandem, greater isolation becomes possible. Such tandem switches are sensitive to the spacing between diodes and to applied voltage since the voltage determines the effective capacitance of each diode. In general, the most effective switching is obtained when diodes are spaced approximately a quarter wavelength apart in the waveguide, thus effectively creating an antiresonant cavity.

The use of diodes in this fashion has suggested still other ways of switching. In one configuration, a diode is used to shunt each cavity of a multi-cavity tuned filter like those commonly used in the output of a microwave transmitter to suppress extreme modulation sidebands.

Such diode switches can provide extremely fast microwave switching—one microsecond or less. Isolation is typically 20 to 25 db per section, thus permitting very effective suppression of the carrier for hot-standby applications.

Two major difficulties must be overcome, however. The most effective location for the shunting diode is in the center of the cavity where the electric component of the microwave transmission is strongest. In this location, however, the microwave diode is subjected to strong fields which overload the diode and shorten its life considerably. If the diode is moved away from the center of the resonant cavity, it is subjected to less overload, but produces poorer switching action. Another disadvantage of this particular method is the relatively high insertion loss. In addition to the losses inherent in the filter cavity, each diode provides between 0.5 and 1 db loss per section, depending on its placement within the cavity. Thus, a compromise must be found between adequate isolation and excessive loss of transmitted power.

Surprisingly enough, the *type* of diode used may have an important bearing on the switch performance. In most switching arrangements, germanium and silicon diodes behave quite differently. Usually, expensive microwave diodes are required, and these are quite delicate and sensitive to overload. The nature of the semiconductor and the amount of bias used to obtain switching action can affect insertion loss, isolation, and power handling capabilities. Typically, this type of microwave switch has relatively low power handling capability. Because of this and the compromise between isolation and insertion loss, these switches are used more in laboratory applications and certain types of radar modulators than in practical communications applications.

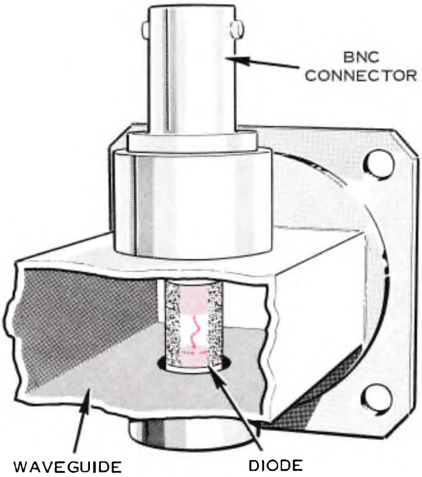


Figure 7. Semiconductor diode may be substituted for plunger to pass or block microwave energy. This switch configuration requires special, high-performance diodes, and is limited in power-switching capability.

A related device, developed by Lenkurt for its new 76B microwave system, overcomes most of these objections. The 76B hot-standby switch provides 75 db isolation at the worst frequency (but effectively infinite isolation at the best frequency), while introducing 0.5 db loss. Switching time is somewhat less than 1 microsecond. This does not, however, include the time required to detect the need to switch and energize the control circuit. The 76B switch does not require microwave diodes, but uses rugged switching diodes of the type used in computers. In tests, the new switch was able to control 8 to 10 watts of microwave power without harm to the diodes.

Possible Trend

In the United States, hot-standby arrangements have been required only in private and industrial microwave systems. Despite the inherent privacy of a microwave link (due to the narrow beams employed) it is becoming more and more difficult to find frequency allocations that do not interfere with other systems.

Frequency diversity is, of course, the preferred method of achieving system reliability because of the inherent protection it provides against both equipment failures and propagation fades. However, as microwave continues its present growth, an increasing shortage of frequency allocations may make hot-standby necessary even in services where it is not required today. Under these circumstances, protection against fading will depend upon the use of larger fade margins—obtained by the use of greater transmitting power, larger antennas, and shorter path lengths. Faster hot-standby switching will be increasingly important to minimize loss of information—a vital consideration as the capacity of the systems increase. ●

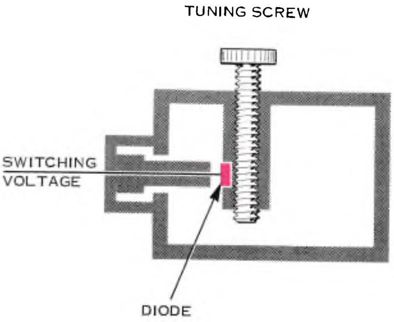


Figure 8. Alternate version of switch uses semiconductor diode to detune vertical probe in waveguide. Electrical "contact" between horizontal probe and tuned vertical probe is made by biasing diode "on" or "off."

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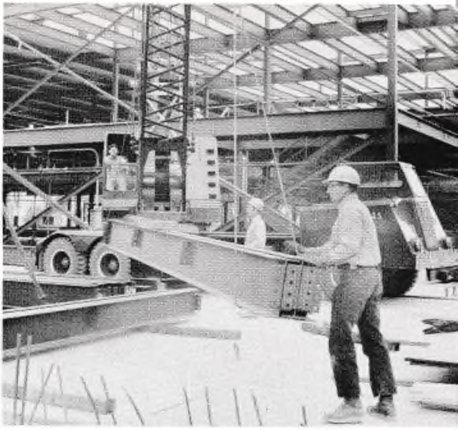
DRAMATIC LENKURT EXPANSION



Burgeoning engineering activity, increased new product development, and selection of Lenkurt Electric by the U.S. Air Force to develop and produce its standard high-capacity AN/FCC-17 carrier system, are all contributing to a dynamic surge of Lenkurt growth. At San Carlos alone, employment has increased from about 1640 in early 1961 to more than 3000 currently. Research and development is increasing rapidly, and is expected to result in even more rapid growth in the future.

Plant facilities are growing to match. Our new Engineering Research and Development Laboratories, shown in these pictures, is nearing completion. The new building, which will be devoted entirely to engineering and related sciences, is the fourth completed this year at Lenkurt. Many special facilities have been incorporated to help Lenkurt engineers design better equipment: much larger digital computer installations, laboratories for metallurgy, crystal development, and chemistry, and many types of environmental test facilities. A roomy engineering library with separate study rooms is included. More than 10,000 square feet are devoted to prototype construction, including printed circuits and waveguide components. Lenkurt's engineering expansion is expected to continue at an increasing pace at least through 1964. ●

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The equipment is described in Bulletin No. 927A-P4, available on request from Lenkurt or Lenkurt Field Offices.

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