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# Introduction to Radar Techniques

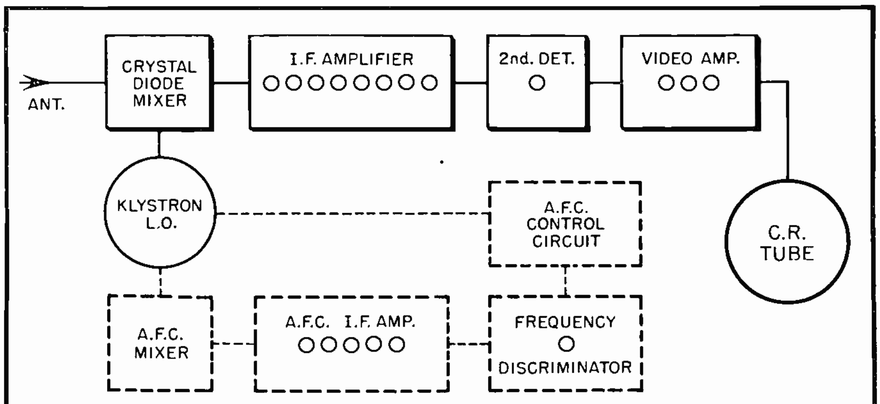
## Part 4. The Radar Receiver

*By the Engineering Department, Aerovox Corporation*

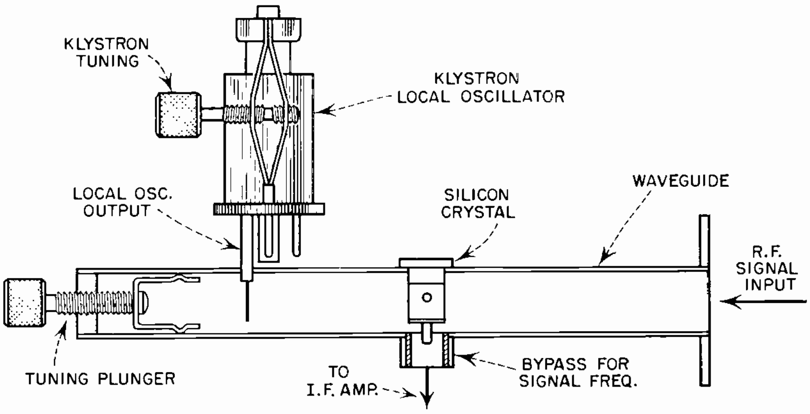
THIS is the fourth in the series of RESEARCH WORKER articles dealing with the special components of the microwave radar equipment. It consists of a discussion of the receiving portion of the generalized radar set - - especially the microwave parts such as the crystal mixer and the klystron local oscillator. The other components are covered in less detail since they have been discussed here previously or are standard practices in fields other than radar.

The function of the radar receiver is to detect the very weak echo signals returned by the target and to greatly amplify them so that they can be visibly displayed on the screen of an oscilloscope to convey information regarding the range and azmuth of the target. As was indicated by the "radar equation" given in Part 1, the range of a radar system is inversly proportional to the *fourth root* of the minimum signal which the receiver will detect. The minimum detectable signal is determined by the noise figure of the receiver, so that any improvement in the receiver noise characteristics result in improved range. Since a three decibel improvement in the receiver sensitivity would have the same effect on set performance as doubling the transmitter power, and at considerably less expense and power consumption, much effort has been expended toward this end. It is probable that added range can be obtained more economically by receiver improvements than elsewhere in the radar system, with the possible exception of the antenna. And, since typical radar receivers exhibit noise figures about 13 to 50 times greater than that of a theoretically perfect receiver, there is still sufficient room for improvement.

For reasons of greater sensitivity and selectivity, the superheterodyne type of receiver is almost universally used in modern radar practice. A block diagram of its component parts is given in Fig. 1. The input stage




CONVENTIONAL RADAR RECEIVER
FIG. 1




TYPICAL WAVEGUIDE CRYSTAL MIXER
FIG. 2

is usually the mixer, or frequency converter, in which the echo signal from the target is heterodyned with the local oscillator signal to produce a difference frequency which is amplified by the i.f. amplifier. The output of the i.f. amplifier is rectified by a second detector and fed into a video amplifier and thence to the cathode-ray viewing tube.

### *The Crystal Mixer*

For microwave radar, the mixer is usually a silicon crystal diode. An r.f. amplifier is seldom employed since microwave amplifier tubes having sufficiently low noise figures do not exist in practical form at present. The crystal mixer, on the other hand, has good noise and transit time characteristics and permits the signal to be converted immediately to a lower frequency where the state of the art affords low-noise amplification. The most serious disadvantage in the use of the crystal mixer lies in its susceptability to accidental burn-out by the high power transmitter pulses. It is the function of the "duplexing system", to be described in the next issue of this series, to protect the crystal from such burn-out while the transmitter is operating.

The details of a typical crystal mixer are shown in Fig. 2. The silicon semiconductor diode is mounted in a socket across the waveguide into which is coupled the r.f. signal and the local oscillator signal. The amount of local oscillator injection is regulated by a tuning element such as tuning screws or a plunger. The i.f. difference signal is taken out at one end of the crystal by a coaxial coupler which is by-passed for the signal frequency but not for the lower i.f. frequency. The *conversion loss* of the crystal mixer circuit may be as much as 10db. This loss is easily made up in the i.f. amplifier stages, however.

### *The Local Oscillator*

The local oscillator, or "beating oscillator" as it is sometimes called, must be a stable, continuous-wave signal source which will tune over the range of frequencies covered by the radar set. It is usually the only vacuum tube in the receiver which operates at a microwave frequency. Although triode oscillators of the "lighthouse" type have been used in some cases up to about 3000 megacycles, the klystron or *velocity modulation* tube is more universally employed.

The klystron oscillator is a special form of microwave vacuum tube which, like the magnetron, was developed largely during World War II for use in radar. The kind most commonly used for receiver local oscillators is the reflex klystron illustrated in Fig. 3. In this tube a thin beam of electrons, like that in a cathode-ray tube, is projected from an electron gun through two apertures in a cavity resonator. If oscillations are assumed to exist within this resonant circuit and the r.f. electric field associated with this oscillation is concentrated between the apertures, some of the electrons passing through the cavity will be slowed down while others will be accelerated. This process is known as *velocity modulation.* It occurs because some of the electrons traverse the gap while the r.f. field adds to the d.c. accelerating potential applied between the cathode and the cavity, while others cross while the r.f. field is retarding. The net result of this is that the slow electrons are overtaken by the fast ones at some finite distance beyond the cavity, so that dense packets or "bunches" are formed.

In the reflex klystron, a *reflector,* or *repeller,* electrode is used to turn the bunched electron beam around and send it back through the cavity. By adjusting the negative d.c. potential on this reflector, the distance the electrons travel between the cavity and the reflector may be controlled so that the dense bunches of electrons form just as they are traversing the gap in the r.f. cavity for the second time. If these bunches of electrons, which are spaced the period of one r. f. cycle apart, are timed to cross the gap while the r.f. field there is retarding, they will be slowed down and some of their kinetic energy will be converted into r.f. energy to reinforce the oscillation. As in the magnetron, or any other oscillator, the original oscillation may be initiated by a noise voltage or other random fluctuation.

The reflex klystron is characterised by relatively low efficiency (½ to about 2%) but ease of tuning and simplicity. Although only a few milliwatts of power must be supplied to the crystal mixer for efficient conversion, most klystron oscillators are designed to deliver many times that much so that the oscillator may be loosely coupled to the mixer. This is done to improve the operating stability of the oscillator. Also in connection with frequency stability,

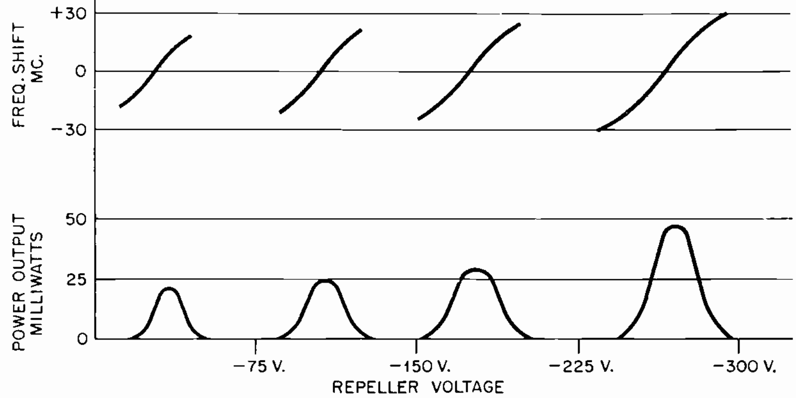
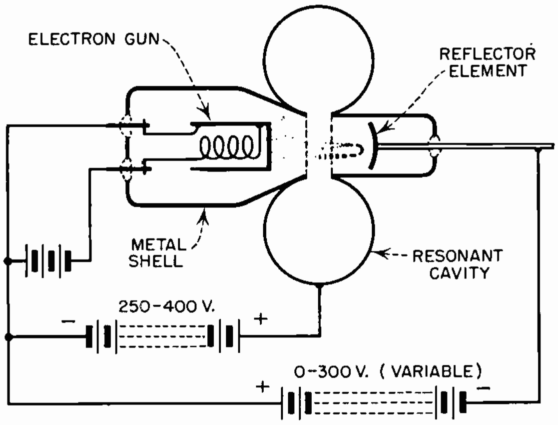
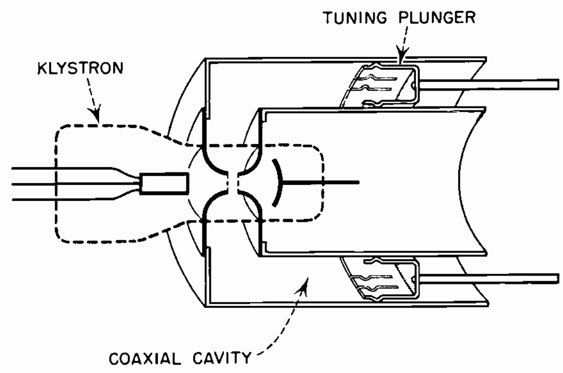



FIG. 5




ESSENTIALS OF REFLEX KLYSTRON TUBE

FIG. 3




USE OF EXTERNAL COAXIAL CAVITY WITH KLYSTRON FOR WIDE TUNING

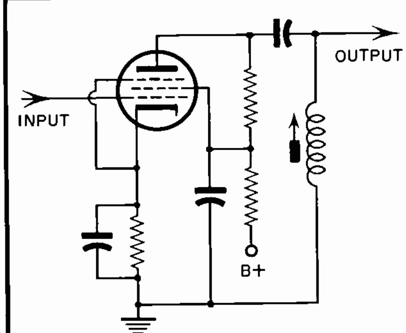
FIG. 4

the d.c. voltages applied to the cavity and repeller of a reflex klystron as shown in Fig. 3 must be well regulated. An electronically regulated power supply of the type described in the September, 1950 RESEARCH WORKER is usually employed, although in some cases simple VR tube regulation will suffice.

Mechanical tuning is usually accomplished in the reflex velocity modulation tubes by deforming one or both walls of the cavity resonator in a manner such that the gap spacing, and hence the capacity of the resonant circuit, is varied. In other types, the resonant cavity is not an integral part of the klystron tube but is clamped around it so as to make good electrical contact to disc seals which connect to the internal gap. Tubes of the "external cavity" type are usually tunable over greater frequency ranges than "integral cavity" tubes, especially when the external tuner is a coaxial type like that illustrated in Fig. 4. Tubes exist which will tune over a 2:1 range of frequencies in a circuit of this type in contrast with a maximum of about 20% tuning for the integral cavity types. To maintain oscillation, the reflecter voltage must be changed with the tuning on all reflex klystron types.

Another feature of velocity modulation reflex tubes which is important in radar applications is *electronic tuning*. The operating frequency of most reflex klystrons may be varied as much as 1% by changing the repeller voltage slightly about the value which gives maximum power output. The electronic tuning and power output characteristics of a typical 10,000 megacycle reflex klystron, plotted versus repeller voltage, are shown in Fig. 5. Note that the tube oscillates at several discrete values of repeller voltage. These are called "repeller modes". They correspond to different repeller voltages at which the electrons are reflected into the cavity in the right phase to sustain oscillations. The average velocity electron may take ¾, 1¾, 2¾, or 3¾ r.f. cycles in the "drift space" between the cavity and reflector, and still return in the right phase.

Electronic tuning by varying the repeller voltage is important for radar receivers since it allows the use of a system of *automatic frequency control* to keep the receiver tuned to the frequency of the transmitter in spite of variations due to thermal drift or load impedance changes. The parts of a representative AFC circuit are shown as dotted lines in Fig. 1. It consists of an extra crystal mixer and i.f. strip which sample the transmitted signal and apply it to a frequency discriminator. If the transmitter frequency varies, the discriminator develops an error voltage which is applied through appropriate control circuitry to the repeller of the klystron. The local oscillator is thus automatically retuned to the transmitter frequency as long as it remains within the klystrons range of electronic tuning.




TYPICAL SINGLE-TUNED RADAR I.F. AMPLIFIER STAGE

FIG. 6

*The I.F. and Video Stages*

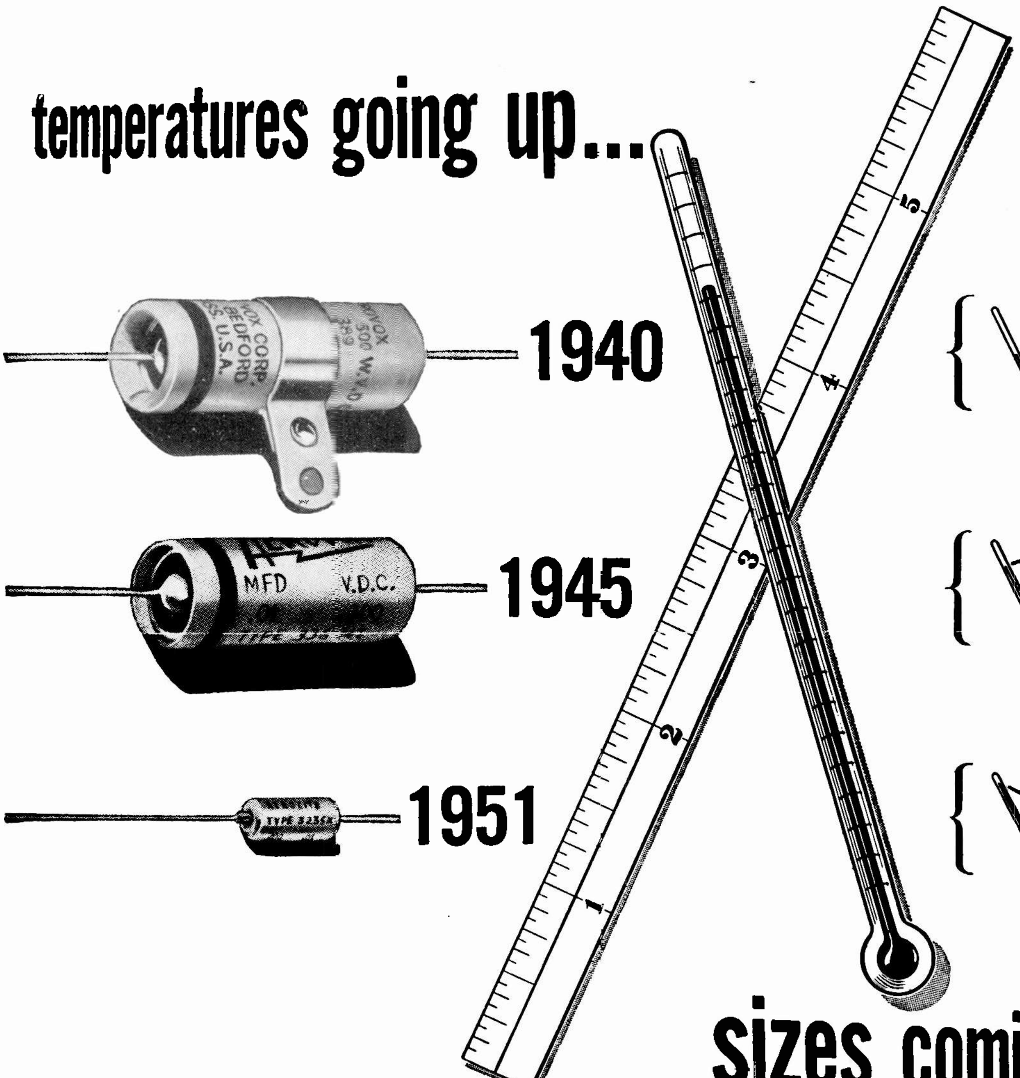
The remaining circuits of the radar receiver, that is, the i.f. and video amplifiers and the second detector, are quite similar to those encountered in television practice.

Most of the gain of a typical radar receiver, which is usually about 120 db., is obtained from the i.f. amplifier, which may consist of as many as ten stages. The selectivity of the receiver is also determined by the band-pass of the i.f. amplifier. Since the spectrum width of the transmitted signal is considerable for the transmission of very short pulses, the i.f. bandwidth must usually be several megacycles. A figure sometimes used by system designers for receiver bandwidth is 1.6/t, where t is the transmitter pulse duration in micro-seconds. To obtain such bandwidths, double-tuned or stagger-tuned i.f. stages of the kind treated in detail in the January, 1949 RESEARCH WORKER are employed. A typical single-tuned radar i.f. amplifier stage is shown in Fig. 6. Such stages depend upon high gm tubes like the 6AK5 or the 6AC7 for high gain-bandwidth products. The resemblance to conventional television i.f. stages (minus the sound traps) is evident.

Since the crystal detector contributes no gain, the noise characteristics of the first i.f. stage are very important in determining the overall noise figure of the receiver. For this reason, much work has been devoted to the development of low-noise i.f. input stages. Special low-noise triode circuits such as the *cascode* amplifier (See March, 1949 RESEARCH WORKER) are widely used in radar practice.

*(The preceding installments of this series on radar techniques were presented in the October, November, and December, 1950 issues.)*

# temperatures going up...

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