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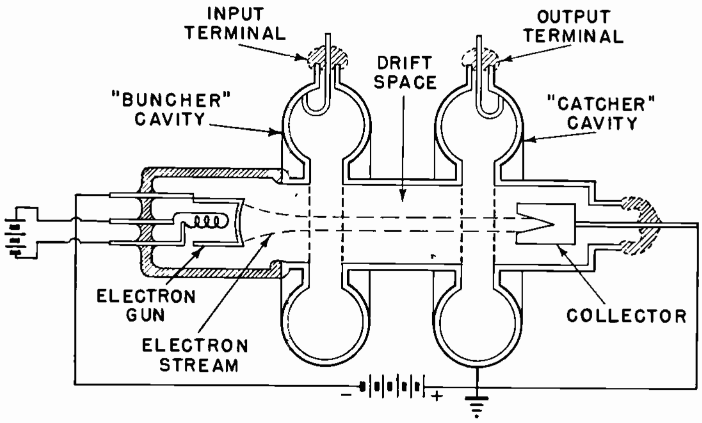
Understanding the New Microwave Tubes

Part 1: The Traveling Wave Amplifier

By the Engineering Department, Aerovox Corporation

THE advent of radar during World War II lent tremendous impetus to the development and application of vacuum tubes capable of generating, amplifying, and detecting the very short wavelengths employed. Notably, the magnetron and klystron oscillators (See AEROVOX RESEARCH WORKER, November, 1951 and January, 1952.) underwent very extensive development between 1942 and 1945, and in that brief span progressed from the status of laboratory curiosities to that of mass-produced tube types having annual procurement rates in the millions of dollars. These microwave tubes continue to enjoy paramount importance in military electronic equipment and, in addition, have begun to appear in commercial usage such as marine radar, diathermy, electronic cookery, communications equipment, and test equipment.

Since 1946, however, what might be called a *renaissance* has been taking place in the microwave tube field; the narrow band magnetron and klystron tubes are being replaced or supplemented by a new family of tubes having broadband or electronically tunable features. Since these new devices are characterized by the interaction of electrons with *traveling* waves rather than *standing* waves, as in magne-



TWO-CAVITY KLYSTRON AMPLIFIER

FIG. 1

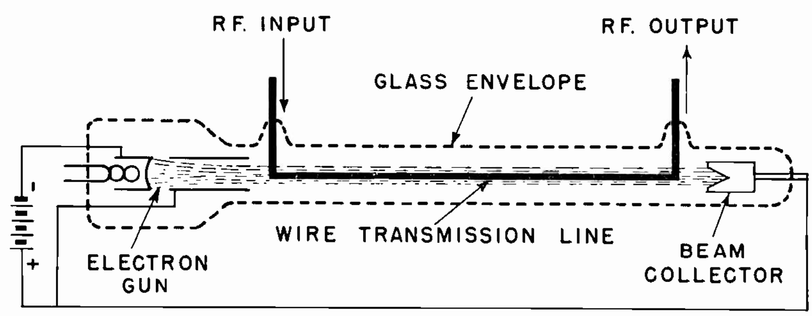
trons, klystrons, and triodes, they are called traveling wave tubes. This issue of the RESEARCH WORKER will discuss the traveling-wave amplifier. Subsequent issues in this series will describe the two varieties of *backward-wave oscillators* which make electronically tuned signal generation possible.

To understand the functioning of the traveling-wave amplifier, it is helpful to first review the operation of a two-cavity klystron when used as an amplifier. Fig. 1 illustrates schematically the elements of such a tube. An electron gun, similar to that used in cathode ray tubes, but capable of greater emission densities, provides an electron beam which travels through apertures in an "input" and an "output" resonant cavity and is ultimately captured by a "collector" electrode.

When the input cavity is tuned to the frequency of an input signal to be amplified, an r. f. voltage is concentrated across the first aperture or "gap". Since this alternating r. f. field has a direction parallel to the direction of the electron stream, it either adds to or subtracts from the velocity imparted to the electrons by the voltage between the cathode and the first resonator. Electrons passing through the gap during one-half of the r. f. cycle are *accelerated*, while those passing through the opposite half-cycle are *decelerated*. Thus, the uniform electron velocity imparted by the d. c. voltage is *velocity modulated* at a radio frequency rate by the input r. f. signal. The net result of this velocity modulation is that faster electrons catch up with the slower ones at specific distances beyond the input cavity to form dense packets or "bunches". For this reason, the input cavity is frequently called the "buncher". The frequency of arrival of these bunches of electrons at points beyond the buncher cavity corresponds to the frequency of the input r. f. signal; one bunch arriving each cycle.

If, now, another cavity tuned to the same frequency, sometimes called the "catcher" cavity, is placed at a point along the velocity modulated electron stream where these dense bunches are arriving in synchronism, oscillations will be induced in it which follow faithfully the input signal. High gain amplification results because the power required to bunch the beam is much less than the power that can be derived from it — the additional energy coming from the kinetic energy imparted to the beam by the d. c. accelerating voltage.

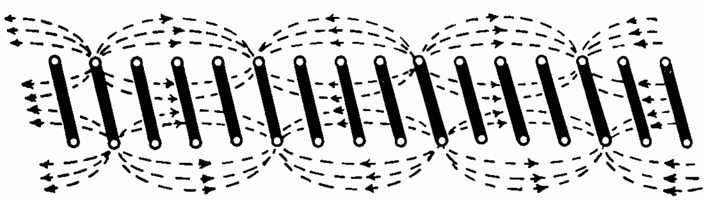
The interaction between the electron stream and the r. f. fields in a klystron is highly localized, taking place only in the gaps of the cavity resonators. This means that the "Q" of the cavities must be high in order to build up the r. f. voltages across the gaps to values high enough for efficient interaction. This results in the klystron being a narrow band device which can only oper-



HYPOTHETICAL TRAVELING-WAVE TUBE
WITH STRAIGHT WIRE LINE

FIG. 2

mode is shown qualitatively in Fig. 6. Note that there are longitudinal fields both inside the helix and outside. Because the fields are usually more concentrated on the inside, the beam is usually sent through the center of the helix. In the case of very small helics, such as might be used for very high frequency amplification, a hollow electron beam may enclose the entire helix and interact with the external fields.



ELECTRIC FIELD CONFIGURATION ON HELICAL WIRE LINE

FIG. 6

Since the traveling-wave amplifier is capable of high gains, any signal reflection from the output end which reaches the input would be re-amplified and result in spurious oscillation. To prevent this, a lumped attenuation is included near the mid-point of the helix delay line, as indicated in Fig. 5. For low power tubes this may consist of a lossy material applied to the delay line, or a split cylinder of graphite placed around the helix. This provides enough isolation between the input and output sections to stabilize the operation and prevent oscillation. This stabilization is achieved at the expense of some of the forward gain, however. Traveling-wave tubes have been built in which separate sections of properly terminated helix are used for the input and output functions — making the tube more closely analogous to a two-cavity klystron amplifier.

Because traveling-wave tubes utilize long electron streams which must be confined within the helix, or in close proximity to other types of delay lines, some means of focussing the beam is commonly employed. The focussing system most generally used is a long wire-wound magnetic solenoid which completely encompasses the delay-line portion of the tube. The weight of this electromagnet and it's associated power supply add greatly to the bulk and complexity of traveling-wave tubes and has prevented their use in some instances. Some weight reduction has been effected through the use of solenoids wound with aluminum foil instead of wire. Another approach is the use of a focussing field produced by permanent magnets. This system, although not fully exploited, eliminates the power drain of the electromagnet and the weight of the supply.

Performance and Applications

Low power traveling-wave tubes have been used principally in the frequency range between 1000 and 10,000 megacycles/second. A single tube will give relatively uniform amplification over a bandwidth of about 20-30% of the center frequency. This bandwidth limitation is largely imposed by the bandwidth of the transition sections which match the input and output transmission lines to the delay line. Gains are characteristically 20-30 decibels. A large amount of the development effort in traveling-wave amplifiers in recent years has gone into reducing the noise figure. The rather high noise figure of the early tubes was a serious deterrant to low level applications. Recent advances have resulted in this property being reduced to where the use of traveling-wave tubes in the front-ends of radar receivers is practical.

In the high power field, traveling wave tubes have been developed which deliver kilowatts of CW power or hundreds of kilowatts of pulse power at frequencies as high as 3000 megacycles. Because of heat dissipation problems, such tubes use water-cooled helices or more rugged delay lines capable of greater heat dissipation.

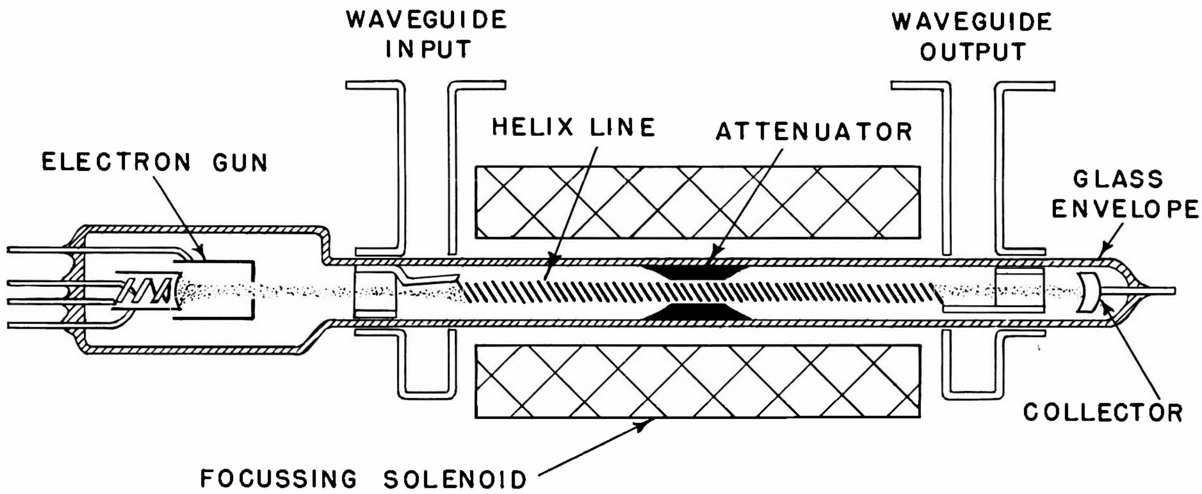
As mentioned above, the unfortunate form factor and bulk of traveling-wave amplifiers, as well as the noise performance, has somewhat retarded widespread usage. However, in addition to military electronic equipment, these tubes are now finding acceptance in telephone radio relay equipment, and even in commercial UHF signal generators. It is probable that the future will find this new device in such widespread application that at least a general understanding of it's principles will be required of service technicians, amateurs, military technical personnel, and engineers.

electronic fields along such a line for two frequencies varying by a factor of 2:1 are shown in Fig. 3. Note that a large component of the electric field is parallel to the direction of travel of the wave and also parallel to the direction of the electron stream in our hypothetical tube. Thus, interaction between the electromagnetic wave on the wire and the electrons in the stream would be possible over the entire length of the system and for a wide range of wavelengths of the traveling wave.

If the electrons which constitute the electron stream can be made to travel at a velocity which is slightly faster than that of the wave on the wire, the electrons will become bunched due to the effect of the longitudinal electric field on the wire. Some of the electrons which are in a retarding field will be slowed down, while others in an accelerating field are speeded up. The result is a grouping of the electrons in the "troughs" behind the retarding portions of the traveling wave, where they can deliver part of their kinetic energy to the wave continuously over the latter part of their travel. See Fig. 4. The result is that the traveling wave "grows", or is amplified, as it travels along the wire toward the output terminal. The action is essentially the same for a wide range of wavelengths, so that the traveling-wave tube has the unique property of uniform amplification over broad bands of frequencies.

Actually, of course, the hypothetical tube of Fig. 3 is not a practical amplifier because the traveling wave on a straight wire would travel at the velocity of light and no means is known which will accelerate an electron stream to such velocities. (Electrons in the worlds largest electron accelerators only *approach* the speed of light. To equal or exceed that velocity is theoretically impossible due to relativistic effects.) For this very good reason, practical traveling-wave tubes must employ a *delay-type* transmission line which slows the velocity of the r. f. wave on it to some value which can be matched by an electron stream accelerated by practical voltages.

The most usual type of delay line for low and medium power traveling-wave tubes is a wire wound helically, as depicted in the practical tube shown in Fig. 5. The helix pitch and diameter are chosen so that the wave progresses along it at about one-tenth the velocity of light. At phase velocities of this order, only a few hundred of volts are required to accelerate the electron stream to synchronism. The helix is a successful delay line for this application because, for the mode of propagation employed, there is a large component of the electric field parallel to the direction of propagation. The field configuration for this principal



PRACTICAL TRAVELING-WAVE TUBE

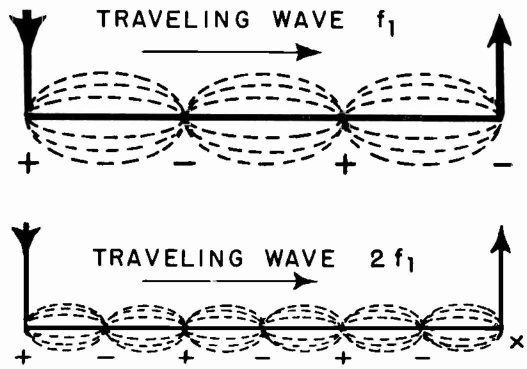
FIG. 5

ate on other frequencies by mechanically tuning both the input and output cavities.

Traveling Wave Interaction

The traveling-wave amplifier was first introduced in 1946 as a result of independant research both in this country and abroad. It differs from the klystron amplifier principally in that the electrons interact with a traveling wave, rather than with a standing wave, and the interaction is *distributed,* rather than localized as in the klystron. There are no high "Q" resonant circuits, so that amplification can occur over relatively broad frequency ranges.

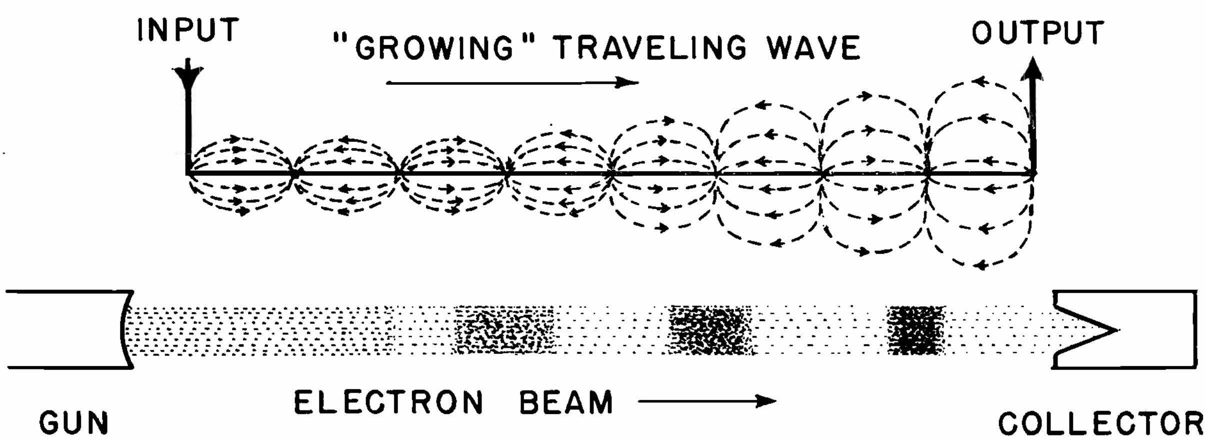
To see how broadband amplification can come about, let us examine the purely hypothetical traveling-wave tube of Fig. 2. Here an electron gun produces a beam similar to that used in the klystron amplifier. This electron stream is passed along, or around, a transmission line consisting of a simple wire having an input terminal at one end, and an output terminal at the other. As in the klystron, the electrons are gathered at the far end by a "collector" electrode.



SHOWING SIMILARITY IN TRAVELING FIELDS ON WIRE FOR 2:1 FREQUENCY RANGE

FIG. 3

If the output terminal is terminated in a load impedance equal to the characteristic impedance of the line, radio frequency energy of a wide range of frequencies will travel along the line in a similar manner, i. e., the line is *aperiodic,* or non-resonant. The configurations of the



SIMPLIFIED CONCEPT OF TRAVELING WAVE AND ELECTRON-STREAM INTERACTION.

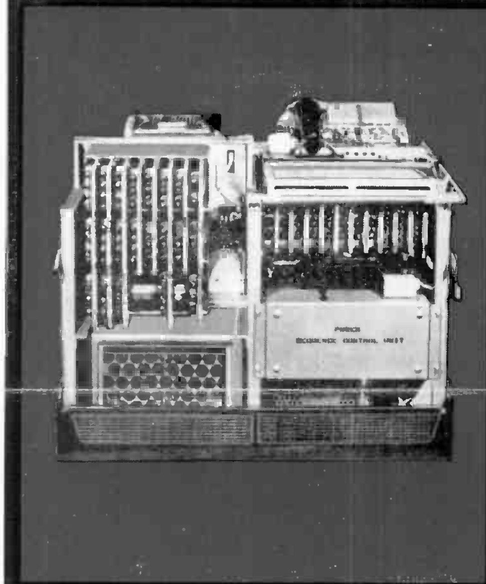
FIG. 4

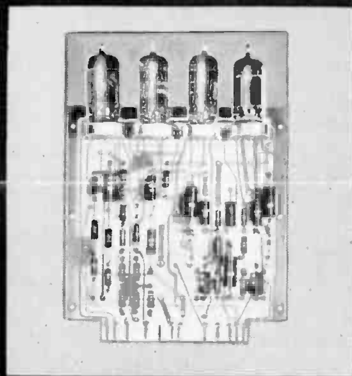
ANOTHER

SPACE-SAVING

APPLICATION FOR

AEROVOX RIGHT-ANGLE TUBE SOCKETS





The Royal Precision Corporation LGP-30 Computer fulfills the need for a small size, highly reliable and low-priced scientific computing device. Its large memory capacity is comparable to that of many computers much greater in size while its general physical configuration offers a new approach in computer design philosophy.

AEROVOX RIGHT-ANGLE TUBE SOCKETS are used in the plug-in cards of the LGP-30 contributing to the overall compactness of the computer. The plug-in cards contain all tubes and associated components and are easily removable for quick check-out.

This Space-Saving feature is just one of the many advantages offered by the use of right-angle tube sockets. Other advantages include: Increased shock resistance . . . lower position of tube mass reduces strain on socket caused by acceleration in the plane of the mounting surface; Ease of mounting . . . ideally suited for hand or mechanical insertion into printed-wiring boards using simple, in-line punched round holes; Versatility . . . long terminals allow use of sockets on wide range of board thicknesses.

Available in 7-pin and 9-pin types in four styles these sockets are designed to meet existing MIL specifications. Active contacts are silver-plated and non-fatiguing contact pressure provides proper insertion and withdrawal pressure with a minimum of contact resistance. Send today for complete technical details on these extremely versatile tube sockets.

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