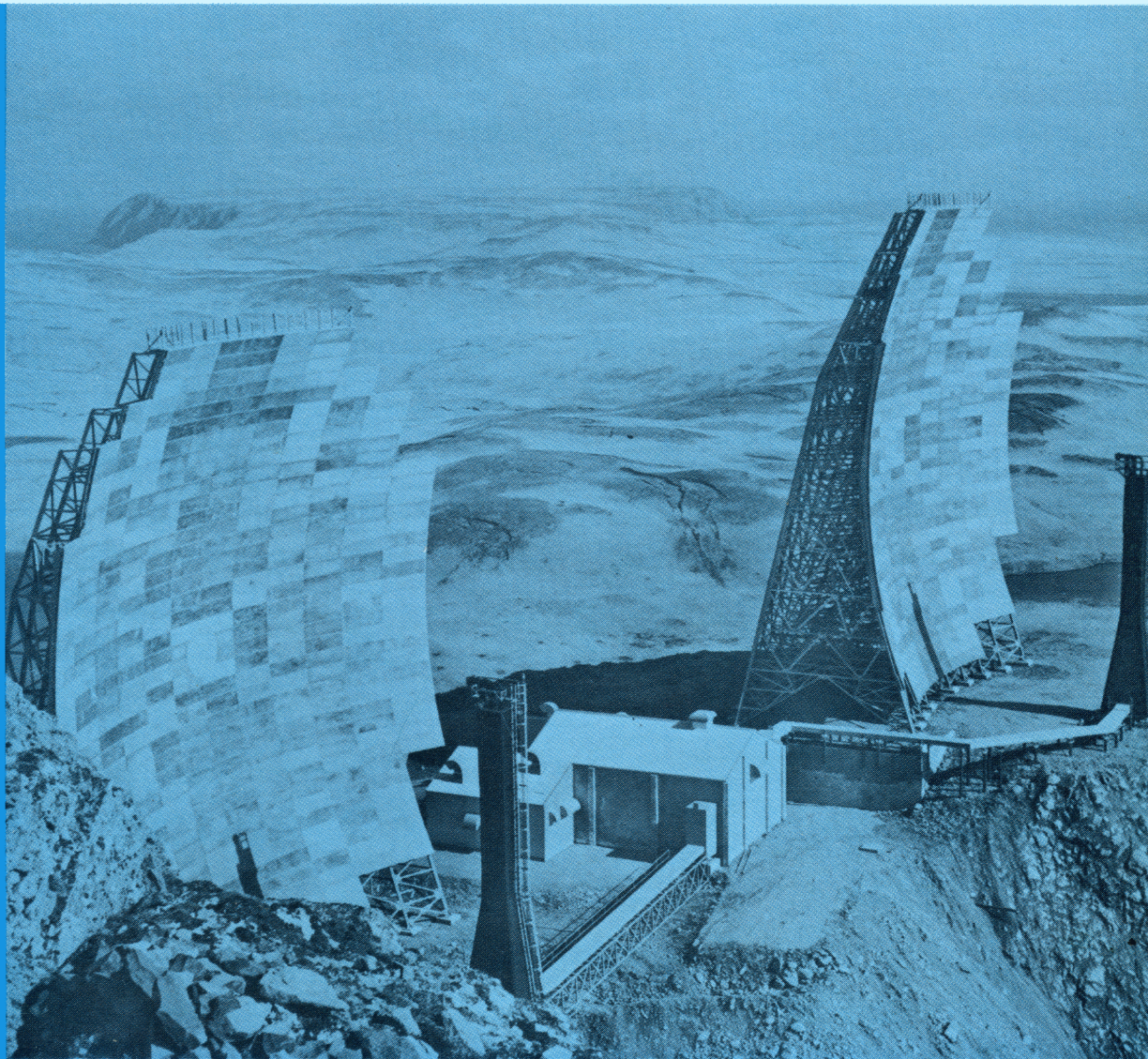
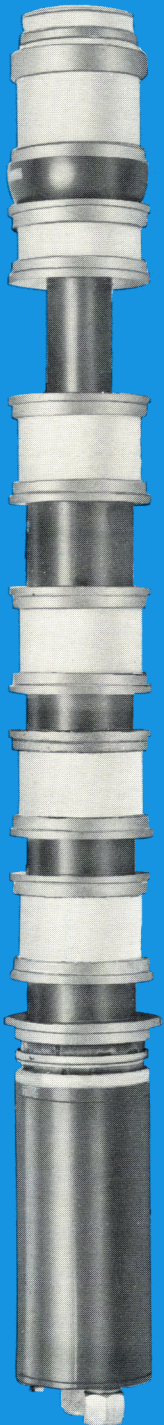


The Care and Feeding of

EIMAC EXTERNAL CAVITY

POWER KLYSTRONS

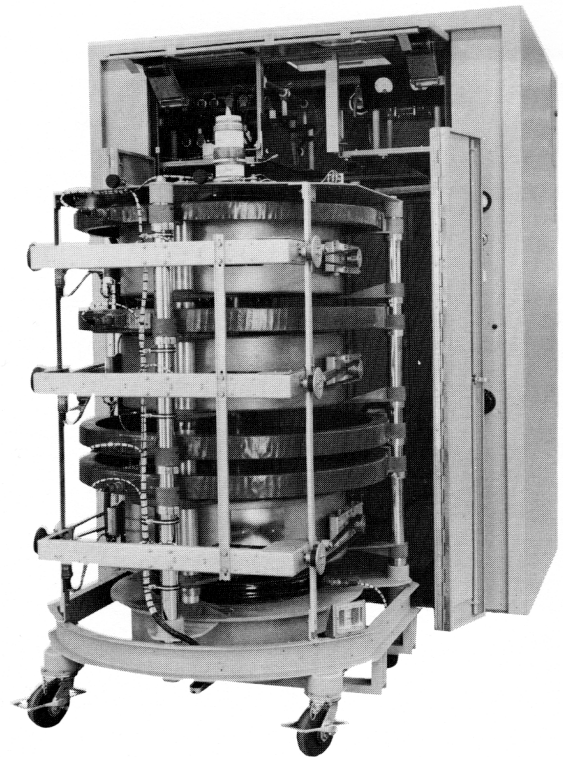


APPLICATION BULLETIN 10



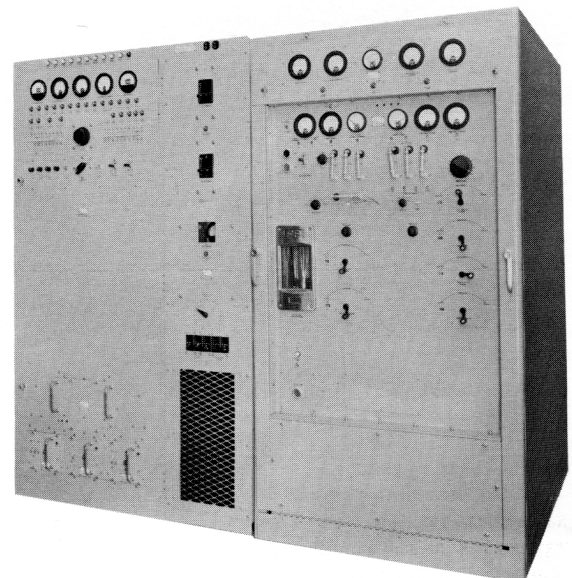
EITEL-McCULLOUGH, INC.
SAN CARLOS, CALIFORNIA

20 kW power amplifier built by ITT Federal Laboratories. This amplifier, using the Eimac 3KM50,000PA klystron, operates from 225 to 400 Mc. The klystron carriage is shown removed from the amplifier cabinet.



Collins Radio Company's 240D-2 amplifier, which uses an Eimac 10 kW power klystron. These power amplifiers are part of the ground command control network used for control of Project Mercury manned space capsules. Additional 240D-2 amplifiers will be used to control Project Gemini two-man space flights.

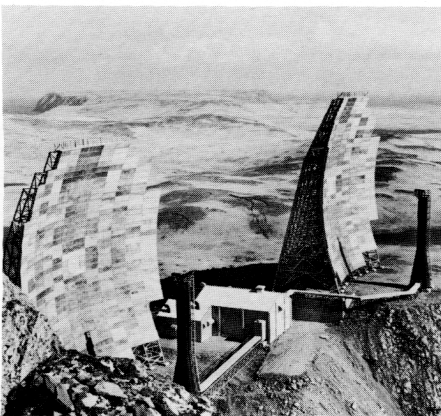
REL 10 kW power amplifier using the Eimac 4KM50,000LR klystron. This amplifier covers the frequency range of 755 to 985 Mc.



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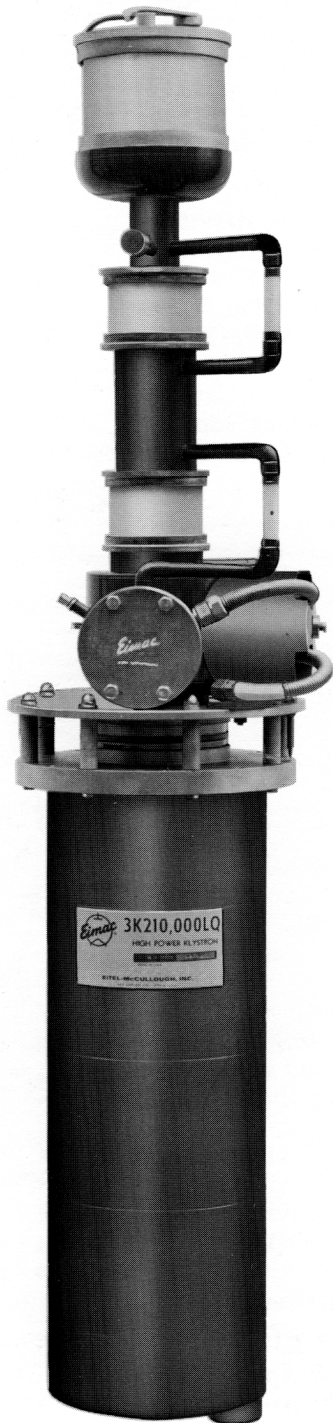
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On the Cover—120-foot antennas used at one of the tropospheric scatter sites in the Aleutian Islands. This is one of the many tropospheric scatter installations using Eimac power amplifier klystrons. The transmitters at this site were manufactured by Radio Engineering Laboratories, and the installation was engineered and directed by Western Electric Company.

FOREWORD



Eimac 3K210,000LQ. This 75 kW klystron is used in many tropo-scatter systems spanning distances up to 440 miles. This klystron is unique in that its input and penultimate cavities are external but its output cavity is integral.

Eimac external cavity power klystrons, operating at frequencies from 225 to 985 megacycles, have earned a unique position in high power radio communications. They were used in the very first tropospheric scatter communications systems and proved to be so successful that they are now found in approximately 90% of all such systems in the free world. They are also used extensively in fixed radar installations and in UHF television.

Because external cavity klystrons are so generally used, almost everyone associated with high power radio communications will at some time be concerned with equipment using these tubes. For this reason Eitel-McCullough, Inc. believes that an application bulletin dealing exclusively with external cavity power klystrons will serve a useful purpose.

Eitel-McCullough, Inc. also manufactures a complete line of integral cavity power klystrons operating throughout the UHF and microwave spectrum. Information on these Eimac integral cavity klystrons will be found in other publications.

The information in this bulletin is arranged in six sections:

1. Introduction to the Klystron.
2. Mechanical Considerations.
3. Electrical Considerations.
4. Operating and Tuning.
5. Application of the Power Klystron.
6. Miscellaneous.

This application bulletin is intended to be a practical handbook for persons designing and operating equipment using external cavity power klystrons. For a more theoretical approach the reader should consult one of the many excellent textbooks available on the subject.

The information in this bulletin is based on data believed to be accurate, but no responsibility is accepted for the successful application of the systems or principles discussed. Likewise, no responsibility is accepted for patent infringement, if any, resulting from the application of this information.

The Care and Feeding of EIMAC External Cavity POWER KLYSTRONS

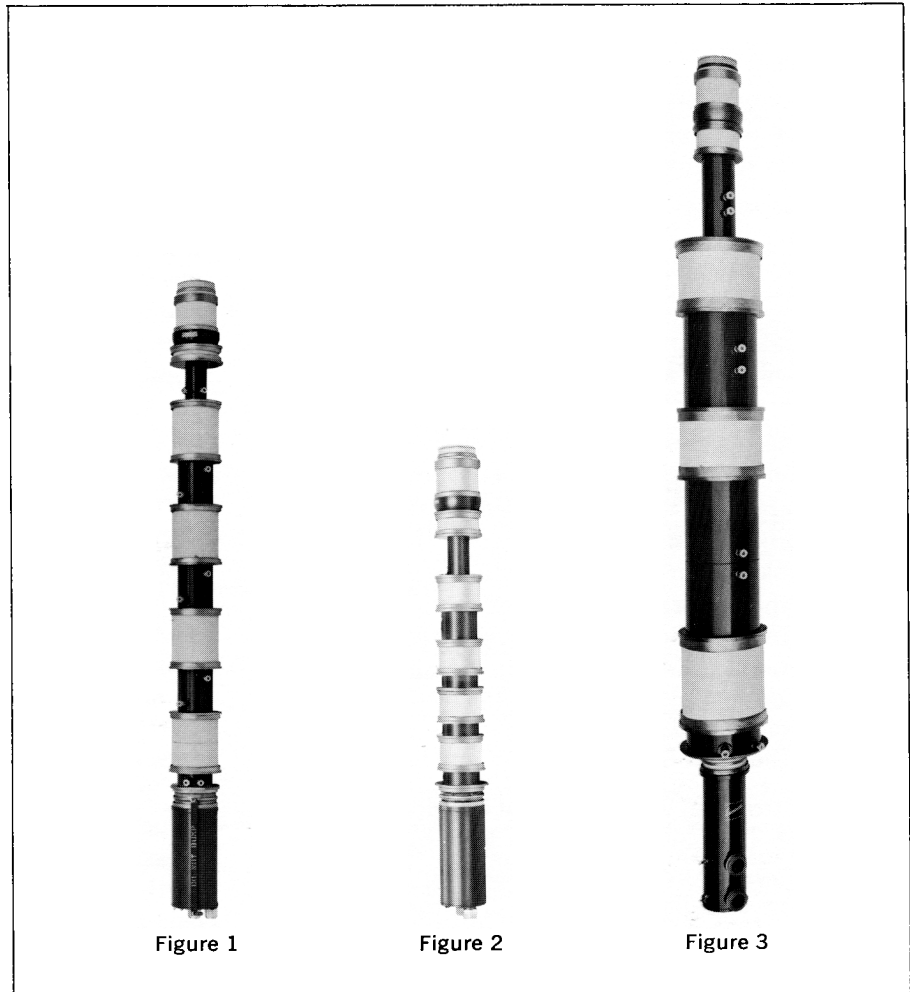


Figure 1

Figure 2

Figure 3

Section 1.0

INTRODUCTION TO THE KLYSTRON

The klystron is not as mysterious as it may seem to persons accustomed to using conventional tubes, even though it has no grid and no plate, and no lumped tuned circuits are connected to it by means of wires leading out of the tube. Actually the klystron is a simple device which exists for the same reason that conventional negative-grid tubes exist—it controls the behavior of electron streams flowing in a vacuum. The great difference between the klystron and the conventional tube lies not in *what* it does, but in *how* it does it.

Conventional triode or multigrid tubes, in which the electron flow is controlled by potential fields surrounding the grids, have upper usable frequency limits beyond which the electrons can not respond efficiently to the alternating control voltages applied to the grids. This occurs when the time required by the electrons for the transit of their paths becomes a substantial part of the period of one cycle at the operat-

ing frequency.

As a result of transit time effects, efforts to obtain satisfactory operation of conventional tubes at the higher frequencies have resulted in the development of extremely small tubes in which the lengths of the electron paths are reduced to the practical minimum. Such tubes are extensively used in low-power applications, but they are simply too small to control great amounts of power.

On the other hand, klystrons must be made relatively large in order to take advantage of transit time effects, which are essential to their operation. As a result, a klystron for operation near 500 megacycles, such as the 4KM50,000LA3 (Fig. 1), can be nearly 5½ feet long and produce more than ten kilowatts of useful CW output power. The 4KM50,000LR (Fig. 2), is a smaller klystron for operation at higher frequencies, and can deliver ten kilowatts output power at frequencies from 755-985 megacycles. The Eimac 3KM50,000PA (Fig. 3), for operation from

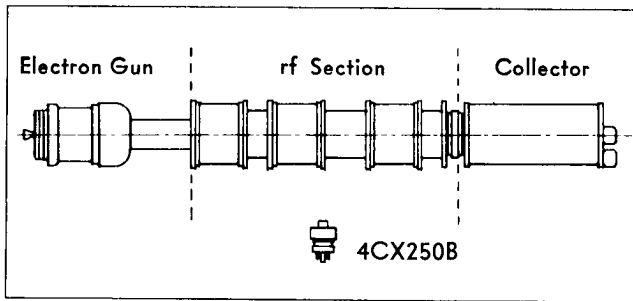


Figure 4—Typical Eimac Externally Tuned Klystron, Compared to a 250-Watt UHF Tetrode Tube.

225-400 megacycles, is nearly seven feet long and can develop over 20 kilowatts of CW power output.

A typical Eimac externally-tuned klystron is illustrated in Figure 4. It is apparent from the form of a klystron that it can be divided into three functional sections: the electron gun, the rf section, and the collector. In the following paragraphs, these parts of the klystron will be described in detail and their operation explained in simple terms.

1.1 The Electron Gun

The electron gun is the source of the electron beam upon which the operation of the klystron depends. The electron beam is simply a fast-moving stream of electrons expelled from the electron gun into the drift space of a klystron in somewhat the same manner that a jet of water is expelled in a solid stream from a nozzle.

A sectional schematic drawing of an electron gun of the kind used in Eimac klystrons is presented in Figure 5. The electrons destined to form the beam are emitted from a heated cathode and they flow

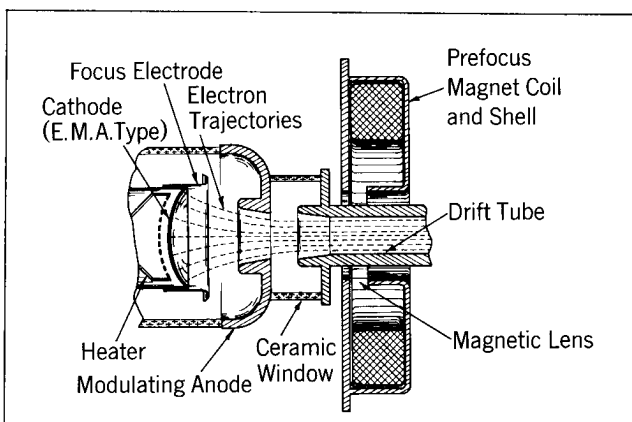


Figure 5—Simplified View of Electron Gun, Prefocus Magnet Coil and Entrance to Drift Tube.

away from the cathode along converging paths because of the specially shaped electric field set up by the electrodes.

The cathode is a concave section of an ellipsoid located inside one end of a cylindrical metal piece called the "focus electrode." Just beyond the opposite end of the focus electrode the modulating anode and first drift tube section are located. The focus electrode is maintained at cathode potential or at some negative potential with respect to the cathode. The modulating anode potential is positive with respect to the cathode. The positive charge applied to the modulating anode causes the electrons to flow away from the cathode toward the anode, and the negative or zero charge applied to the focus electrode tends to force them toward the axis. As a result of the two forces acting on the electrons, they form a converging beam, which focuses inside the first drift tube section. In klystrons which have no modulating anode, the end of the drift tube is formed into a cup which partially surrounds the cathode and serves as an anode.

Modern Eimac klystrons use oxide-coated cathodes at power levels up to and including 2 kilowatts. At higher power levels the Eimac Matrix Cathode Type A (EMA) is used. This cathode is made by pressing a mixture of powdered nickel and various earth carbonates under great pressure onto a nickel backing. Oxide-coated and EMA cathodes are easily heated by radiation from a filament or heater since they operate at relatively low temperatures.

Some of the older Eimac power klystrons use solid metal cathodes operating at relatively high temperatures. Radiation heating cannot be used in this case and the metallic cathodes must be heated by electron bombardment. This is accomplished by placing a filament behind the cathode and applying approximately 2000 volts dc between the filament and the cathode structure. Electrons emitted from the filament will travel at high velocities to the rear of the cathode, where they will release all their kinetic energy in the form of heat when they strike the cathode. By this means, the cathode can be heated to the operating temperature.

1.2 The rf Section

The rf section of a klystron is made up of the drift tube and the several resonant cavities which surround it at intervals along its length. The drift tube is an axial, interrupted tube with a length about twenty times its diameter. There may be from two to six interruptions, called "gaps," along the length of the drift tube.

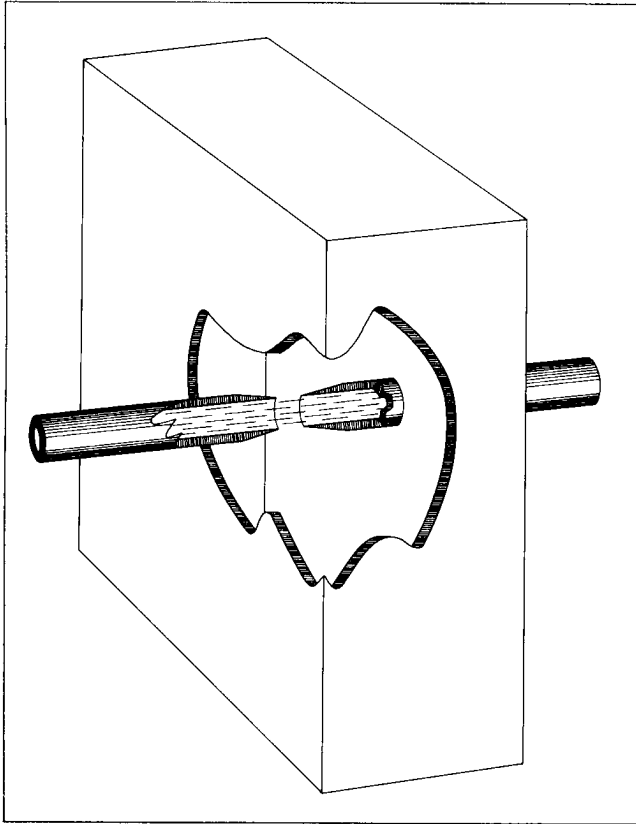


Figure 6—Simplified View of Resonant Cavity.
Note Drift Tube Tips. Electron Trajectories
Represented by Broken Lines.

A resonant cavity is constructed around each drift tube gap, as shown in Figure 6, and arranged so that the ends of the drift tube sections protrude into the cavity at opposing high-voltage points on the cavity wall. Thus, the drift tube tips become the capacitive loading elements in the cavity, and large rf voltages will be induced across them when the cavity is excited at resonance.

In Eimac external cavity klystrons, the drift tube gaps are surrounded by cylindrical ceramic envelope sections, and external demountable tuning cavities are assembled around the ceramic sections to form the complete cavities. The construction of the ceramic envelope and gap assembly, and the method of assembling a typical tuned cavity on the klystron body can be seen in Figure 7. In this type of resonator, only the drift tube gap is in the evacuated space, and the tuning mechanism remains entirely outside the vacuum. This permits a few klystron types of simple design to cover a relatively large frequency range.

1.3 The Collector

The electron beam transfers some of its energy to the rf circuits as it flows through the rf section of the klystron, and it carries the balance of its energy out of the rf section into an electrode called the "collector." The collector gathers the electrons and passes them out of the klystron into the external circuits leading to the positive terminal of the beam power supply.

The large energy content of the partially spent beam must be dissipated by the collector. When the electrons collide with the collector surface all their kinetic energy is transformed into thermal energy which heats the collector. The thermal energy is then transferred to the surroundings by cooling the collector with air or a liquid coolant such as water, or water in combination with antifreeze fluids like ethylene glycol.

1.4 The Axial Magnetic Field

The klystron requires a strong axial magnetic field to maintain and direct the electron beam throughout the length of the drift tube. The electron beam is a concentration of negative charges which tend to disperse because of the mutual repulsion existing between like charges. The axial magnetic field overcomes this tendency of the beam to disperse by exerting restoring forces on any electrons which try to move in directions not parallel to the axis. Thus, electrons attempting to move away from the axis of the beam are constrained to remain within the confines of the beam by the magnetic field.

The magnetic field is usually established by several individual electromagnet coils forming part of the magnetic assembly in which the klystron is mounted. The direct currents used to energize the electromagnet coils are sometimes made individually adjustable, to permit variation of the field strength along the length of the klystron if necessary. In many cases, however, the focus coils are so designed that they can be operated in series from a single power supply.

The proper use of the magnetic field is imperative to the long life and satisfactory performance of a klystron, and this matter will be discussed in detail in Section 4.

1.5 The Electron Beam

At the beginning of its passage through the drift tube the electron beam is a continuous stream of electrons moving at constant velocity. Although it is not confined to a wire, it is nevertheless a direct



Figure 7—Typical Eimac Klystron and One of Its External Cavities Before and After Assembly.

current of electricity, flowing through the free space enclosed by the drift tube. Ideally the beam would never touch the drift tube, but in practice there are always some electrons which stray far enough from the center of the beam to be caught by the drift tube walls.

Just as a direct current produces no sound as it flows through a headphone, so a direct current electron beam can produce no rf power as it flows through a klystron. It must be *modulated* in some manner before it can be useful and in the klystron this is accomplished at the drift tube gaps, which modulate the velocity of the electrons in the moving beam.

In Section 1.2 it was explained how a drift tube gap is formed by the ends of drift tube sections, which enter the cavity axially, from opposite ends. The cavity is designed so that the drift tube tips then become its highest voltage points, in order to build up strong radio frequency fields in the gap. This construction is clearly illustrated in Figure 6.

Velocity modulation occurs when the dc beam passes through the radio frequency alternating field established in the first drift tube gap by the rf driver. Following is how velocity modulation is accomplished, and how it transforms itself into density

modulation as the beam passes down the drift tube.

Those electrons in the parts of the beam passing the first gap when it is “positively polarized” experience an increase of velocity because they will flow from a region of negative charge toward a region of positive charge. The negative region repels the electrons and the positive region attracts them, with the result that the velocity and the energy content of that part of the beam are increased. The energy gained by the faster parts of the beam is provided by the driving power furnished to the input cavity.

Conversely, the electrons in that part of the beam passing through the first drift tube gap during the half cycles of “negative polarity” will be forced to travel from a positive to a negative region. As a result they will lose velocity and surrender some of their energy to the input cavity.

The beam leaving the first gap is continuous and of uniform density, but alternate parts along its length will contain electrons having higher or lower velocities than they had before entering the gap. The faster electrons begin to overtake the slower electrons as the beam travels freely down the axis of the drift tube, until at some point a few inches from the gap, the fastest electrons will be traveling in company with the slowest electrons for a brief period. At that point, optimum “bunching” has occurred, and the density of the beam will vary periodically at signal frequency, when seen from a fixed point. In other words, the beam will have become a density-modulated beam. If a gap is located at the point of optimum bunching or “density modulation” the beam can be made to surrender many times as much energy as was originally required for velocity modulation. In other words, the klystron will have acted as a radio frequency amplifier.

Energy is extracted from the bunched beam by the same mechanism used to velocity-modulate it in the first gap. As the beam travels through the output gap, the gap polarity will vary in such a way that the denser portions of the beam will be decelerated while the less dense parts of the beam will be accelerated. As a result, there are many more electrons being made to give up energy to the circuit than there are electrons which take energy, and the net effect is to transfer power from the electron beam into the external circuits of the klystron.

The preceding paragraphs have described the action of a two-cavity klystron, in which rf power is used to velocity-modulate an electron beam, so that it can be made to surrender energy to another cavity after traveling a short distance down the drift tube. Experience has shown that klystrons having more

than two cavities offer advantages in higher gain and higher efficiency; as a result, three-cavity and four-cavity klystrons are in common use and klystrons with as many as six cavities have been used for special applications.

There is little or no reverse flow of electrons in the drift tube. The fields in the drift tube which are not due to the presence of the beam are so small that great isolation between the output cavity and the input cavity can be obtained. As a result it is possible to obtain stable operation with power gains of up to 50 db, in the case of four-cavity klystrons.

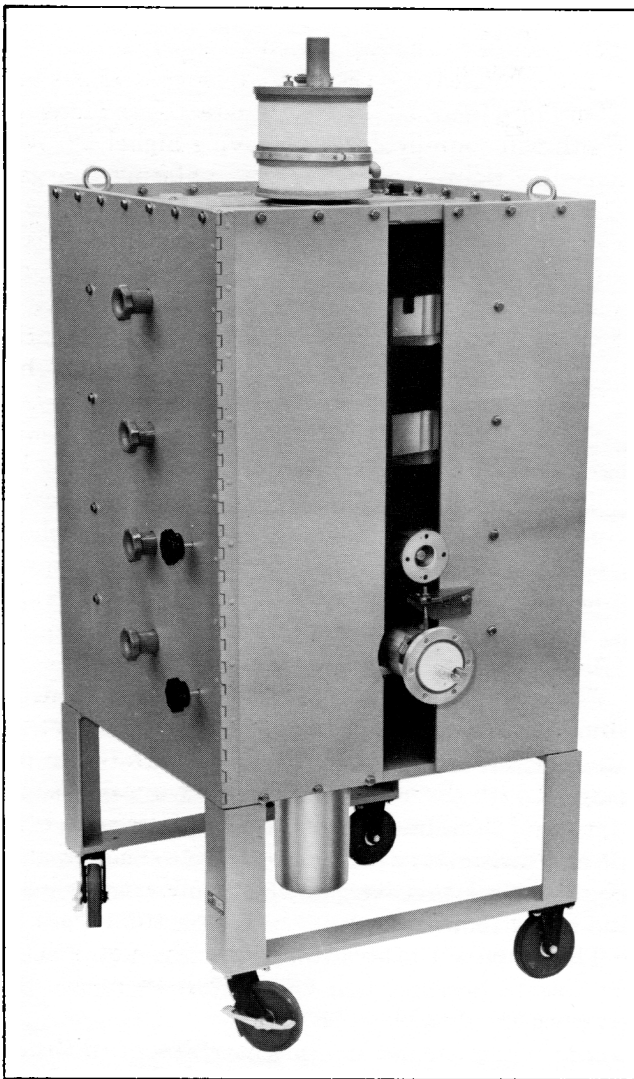


Figure 8—4KM100LA Klystron and H-163 Circuit Assembly. Designed for UHF Television, This Tube Develops 25 Kilowatts of Peak Synchronizing Power at Frequencies from 470 to 610 Megacycles.

1.6 Modulating Anode Klystrons

The klystron is a velocity-modulated device, and the velocity of the electron beam entering the drift tube must be maintained within certain limits if the klystron is to function well. Therefore, attempts to amplitude-modulate the klystron beam voltage with modulation factors larger than 0.3 have been unsatisfactory because the velocity depends entirely upon the beam voltage. Some means must be provided to modulate the beam intensity without varying the beam velocity if satisfactory amplitude modulation is to be obtained.

Certain Eimac klystrons, as shown in Figure 9, are designated by the letters "KM" in their type numbers, and are equipped with "modulating anodes." The electrode configuration of these klystrons is identical to that of standard klystrons, except that the anode of the electron gun is insulated from the rest of the klystron. As a result, the total accelerating potential difference between the klystron body and the cathode can remain constant, while the anode of the electron gun can assume any voltage between zero and the body voltage, with the result that the intensity of the electron beam can be varied at will while the total acceleration and the velocity remain constant.

The modulating anode makes possible amplitude modulation of the klystron with low distortion and high modulation factors. It also provides an excellent means for pulse modulating the klystron with minimum modulating power. In CW applications the modulating anode may be connected to the beam supply through a resistor to provide protection against internal arcs.

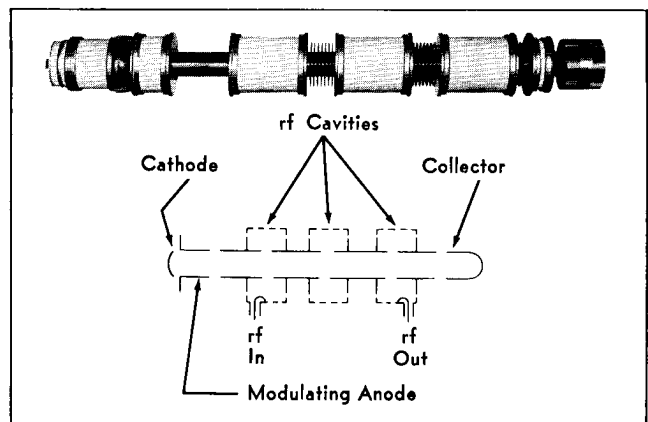


Figure 9—Eimac's Modulating Anode Klystrons Employ an Insulated Anode Placed Between the Cathode and Drift Tube Section.

1.7 Titanium Getter

Most Eimac external cavity power klystrons, rated at or above 10 kilowatts, employ a titanium getter which is designed to be energized simultaneously with the heater. The getter, which consists of a tungsten or molybdenum heater around which is wound a smaller titanium wire, is generally located near the upper end of the collector. One end of the getter is connected to the collector, the other to an insulated terminal.

Getter power supply requirements for Eimac external cavity klystrons range from 2 to 9 volts ac, at 20 to 33 amperes. Provision must be made to limit starting current to twice operating value. The purpose of the getter is to adsorb the small amounts of gas which may be released during operation from the normally hot or accidentally overheated surfaces of the klystron. The getter functions in two ways. The hot titanium adsorbs the common gases directly, and in addition a slow evaporation of titanium takes place which condenses on the walls of the collector to form a cooler layer of titanium to adsorb hydrogen and the inert molecules. In addition to its use during normal operation, the getter can be valuable in conditioning tubes which are unused for long periods of time. For example, site or warehouse spares can be maintained in good condition through periodic energizing of the getter.

Section 2.0

MECHANICAL CONSIDERATIONS

2.1 Shipping Klystrons

Eimac power amplifier klystrons are shipped in strong wooden boxes designed to protect the tube against damage during shipment. Special rubberized hair packs molded to completely fill the space between the tube and the shipping crate, or shock-mounted aluminum cradles, are used to protect and support the klystrons during shipment. These packs support the entire length of the klystron, and prevent accidental bending of the long body section.

Klystrons should be unpacked immediately upon receipt and inspected carefully. If possible they should be installed and operated in a klystron amplifier for a sufficient time to insure that they have arrived in usable condition.

2.2 Storing Klystrons

Klystrons may be stored vertically or horizontally until they are to be used. If vertical storage is pre-

ferred, they should be kept in racks, with the weight of the tubes supported by the mounting flanges. Horizontal storage requires the use of the shipping crates and their rubberized hair packing or cradle which provide support for the entire length of the tube body (Fig. 10).

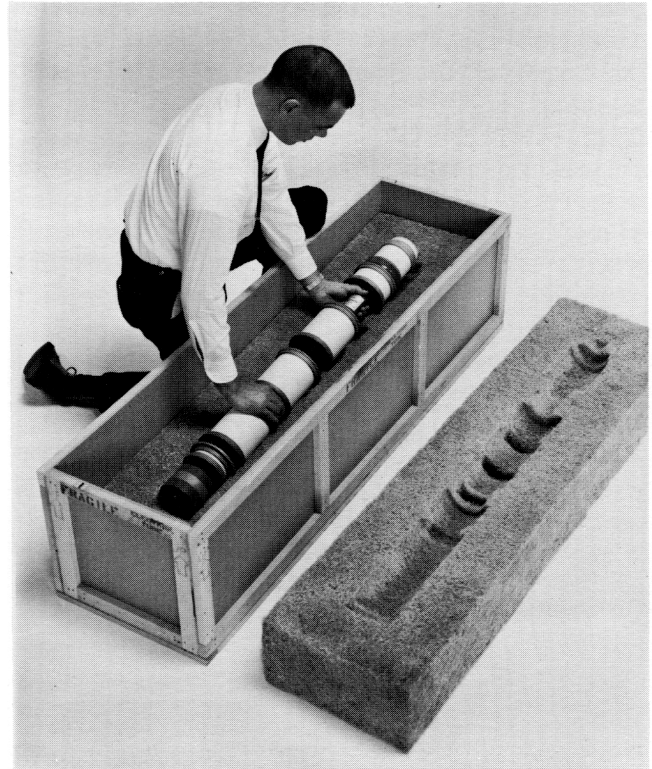


Figure 10—Storage of Klystron in Shipping Crate.

2.3 Handling Klystrons

Eimac power amplifier klystrons of the externally tuned cavity type are among the sturdiest electron tubes being built today. However, they must be handled with the same care accorded to other types of tubes of the same weight and size if maximum tube life and satisfactory performance are to be obtained. The handling precautions which follow are simple and easily remembered.

The shape of the klystron makes it especially susceptible to bending near the center; therefore, the klystron should always be supported at two or more points when picked up in a horizontal position. (Fig. 11).

Water-cooled klystrons are equipped with heavy water-jacketed collectors in order to dissipate large amounts of power when necessary. The collectors of Eimac klystrons are insulated from the rf sections



Figure 11—Recommended Method of Hand Carrying Eimac Klystrons.

by ceramic envelope rings, and the ceramic-to-metal seals can be broken by rough handling, or lack of proper support. Therefore, when a klystron is picked up in a horizontal position the collector should be supported about one-third of its length from the inner end of the water jacket to balance the forces acting on the collector.

The larger Eimac klystrons are shipped in aluminum cradles which facilitate handling. These cradles are so designed that the klystron may be lifted to a vertical position while still strapped in its cradle, the collector end of the cradle may be removed, and the tube mounted in operating position prior to removal of the main cradle.

2.4 Acceleration Forces

Forces exerted on the tube structure as the result of sudden accelerations, such as occur when the klystron is dropped or set down roughly, can be destructively great. In the larger tubes, the structure is such that acceleration, such as could occur when the tube is picked up roughly by the center section, can bend the klystron body.

Some of the larger klystrons can be handled safely only when two persons move them, or when a hoisting device is used.

2.5 At the Bench

Occasionally it becomes necessary to place a klystron in a horizontal position for inspection and cleaning. Experience has shown that the safest and most convenient way is to use wooden V-blocks as supports. For short tubes, two blocks are usually sufficient, but long klystrons require three. When three blocks are used, they should offer uniform support to the tube, and one block should always support the full weight of the collector directly. (Fig. 12).

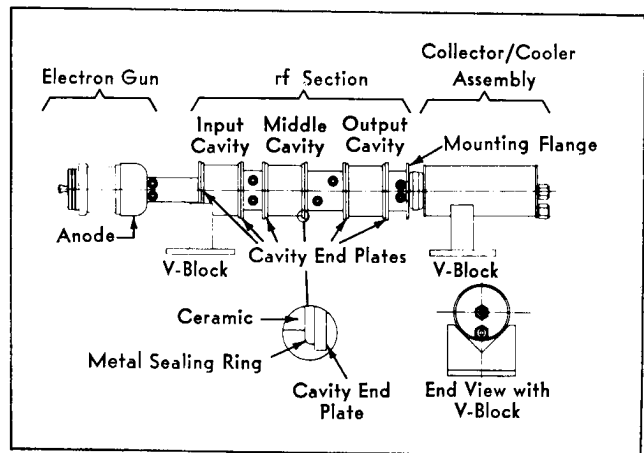


Figure 12—View of Klystron Mounted Correctly on V-Blocks.

V-blocks should be placed so that they touch the rims of the metal ends of the ceramic envelope sections. These metal surfaces are the contact surfaces which connect to the tuning cavities through spring finger contacts. Great care should be exercised to avoid marring or scratching these contacts, because the rf losses which can result are capable of destroying the contact fingers in the tuning cavities.

The massive metal end plates connected to the ceramic envelope sections of the klystron are not sufficiently flexible to be attached directly to the ceramic envelope cylinders. The vacuum-tight attachment between these parts is made by soft metal sealing rings, shown circled in Figure 12, which are intentionally made thin and flexible. In any handling or cleaning operation, care should be taken to protect these thin metal sealing rings against accidental damage.

2.6 Cleaning the Ceramic

Klystron ceramics are best cleaned with an abrasive household cleanser. A cleanser which does not contain bleaches or dyes is preferred. Scrubbing with a small stiff brush will help to remove baked-on deposits. The cleanser must be completely removed by rinsing with clean water before the klystron is restored to service or placed in storage.

2.7 Care of the External Tuning Cavities

The adjustable tuning cavities, which are assembled around the body of the klystron to form resonant circuits in conjunction with the drift tube gaps and their metallic end plates, must be maintained with care. The contact fingers should be protected against accidental deformation, because every individual finger must make effective contact with its opposing metal surface. The walls or metal parts against which the fingers bear must be kept clean and free of oxidation for the same reason. The tuning cavities may be cleaned by wiping them with a dust rag, but should not be left oily. A few drops of mineral lubricating oil or light application of grease should be applied to the adjusting screws if necessary, and all the excess lubricant wiped off.

2.8 Air and Liquid Coolant Supplies

All Eimac klystrons require air cooling, and some of them require water cooling of the collectors and drift tubes. Air circulated for cooling should be thoroughly filtered to avoid undue collection of dirt on the klystron. Accumulation of air-borne dirt on the ceramic envelope sections can cause local heating or voltage flash-over on the surface of the ceramic, and must be avoided.

The air filters should be inspected at suitable intervals to insure the free passage of air through them.

Water or other liquid used for cooling collectors and drift tubes of the larger klystrons must be free of minerals capable of encrusting the water passages and the metal surfaces being cooled. The use of a closed water-cooling system employing heat exchangers is the most satisfactory way to cool the large klystron. Aeration of coolant liquids containing water should be avoided in closed systems to keep oxidation effects to a minimum and derive the greatest benefit from closed-system operation.

In cold climates, where the coolant will be subjected to temperatures below 32°F, mixtures of water and ethylene glycol can be used in closed systems. The heat capacity of such mixtures is lower than the

heat capacity of water, and the use of such mixtures will require some readjustment of the flow rates if equivalent cooling is to be obtained with them.

Aqueous solutions of ethylene glycol will freeze at temperatures which depend on the concentration of the ethylene glycol as follows: 25% ethylene glycol, 75% water, freezing point = 10° F (−12.2° C); 52.5% ethylene glycol, 47.5% water, freezing point = −40° F (−40° C).

Water mixed with ethylene glycol has greatly increased viscosities depending upon the temperature of the solution. This may change the indicated pressure drops in various parts of the cooling system as compared to the pressure drops observed when pure water is circulated.

2.9 Coolant Connections

The insulated envelope section interposed between the klystron body and the collector should be protected against unnecessary lateral forces tending to break the ceramic or its seals. The collector should be supported while the nuts on the water hose fittings are tightened, and the hoses should be sufficiently flexible to avoid exerting lateral forces against the end of the collector during operation. For the same reason, air ducts leading to air-cooled collectors should be flexible enough to avoid stresses resulting from poorly fitting duct work. The air connections to the air system socket and to the air-cooled cavities must also be made through flexible hose to avoid deforming the contact fingers in these devices.

Section 3.0

ELECTRICAL CONSIDERATIONS

3.1 High Voltage Protection

It is convenient to operate klystrons with their rf sections and collectors at or near ground potential. When this is done, the electron gun end of the tube, the focus electrode voltage supply, the cathode-heating supply, and the instruments associated with these must all be operated at high potentials with respect to ground.

Adequate interlocking devices must be provided to protect operating personnel against accidental contact with these high-voltage circuits, and any effort to defeat the purpose of these safety devices should not be tolerated.

Measuring instruments connected to the cathode end of the tube must be adequately insulated from ground and located behind glass or plastic windows to protect operating personnel.

The filament transformers and cathode-heating power supply transformers must be adequately insulated to withstand the total beam voltage (plus the bombarding voltage in certain klystron types).

3.2 Equipment Protection

Protective devices should be installed to avoid damage to the klystron as a result of malfunctioning of the associated equipment. A minimum complement of such devices would include:

(1) Air-flow and water-flow interlocks arranged to remove all electrical power supplied to the klystron in the event of failure in either or both of the cooling systems.

(2) Current overload relays to remove the beam power and the cathode heating power in the event that excessive current should flow in either of those circuits.

(3) Body current overload relay, arranged to remove the beam power upon the rise of body current beyond the maximum permissible value.

(4) Water-temperature or air-temperature interlock switches to remove the beam power in the event of collector overheating.

(5) Low power output interlock, or VSWR interlock to remove the beam power in case the output cavity becomes unloaded due to output line or antenna defects.

(6) Focus coil current failure interlocks to remove the beam power in the event of focus coil power supply failure.

3.3 Focus Coils

Klystron equipment must incorporate means for producing a controllable magnetic field, arranged so the flux is parallel to the axis of the klystron. The field is usually produced by two or more large electromagnet coils carrying direct current.

Each individual klystron may require slightly different magnetic field strengths to control and direct the electron beam, and these may change slightly each time the tuning is changed. Unless designed for series operation each individual coil should be furnished with an independent control for the current supplied to it, and each control must be capable of smooth, continuous adjustment. In addition, it is recommended that each coil be provided with an individual ammeter, permanently connected to its supply circuit. With series-connected coils, of course, only one ammeter is used.

All the electromagnet coils must establish their fields in the same direction. In equipment where all

the terminals and the tops of the coils are marked, careful observance of polarity should assure correct field polarities. The polarity can be tested by means of a fluxmeter or by use of the galvanometer-and-loop method, in case doubt exists that the coils are correctly connected.

The direct current provided by the electromagnet power supplies should be filtered to 5% ripple, or less if minimum noise output is desirable. The design values should be stated so the operator can see that the filter circuits continue to function effectively.

The magnetic field will not remain parallel to the axis of the klystron if there are large steel or iron objects in or near the klystron amplifier frame. The magnetic frame of the amplifier should be located away from unsymmetrical cabinet work and in a place free of strong ac fields. Before operation is started, care should be taken that no tools or other magnetic materials are permitted to remain in the magnetic frame.

3.4 Instrumentation

The equipment associated with a power klystron should be provided with instruments to indicate the filament voltage, filament current, bombarder power (if used), beam power input, focus coil currents, body current and relative power output. The relative power indicator should be a sensitive instrument, arranged so that its coupling to the load can be varied to provide on-scale indications at any power level. The relative power indicator and the body current meter are the fundamental tuning tools available to the operator, and they must be located conveniently close to the tuning position. If this provision is not made by the equipment manufacturer, it should be done in the field before any attempt is made to tune the klystron.

It is convenient to operate a klystron with the rf section and the collector at or near ground potential. As a result, the instruments connected to the electron gun end of the klystron are necessarily at high potential with respect to ground. These instruments must be isolated from accidental contact with personnel, as outlined in Section 3.1.

It sometimes happens that instruments connected to circuits at high potentials with respect to ground may experience electrostatic forces exerted by fields set up between them and their surroundings. Errors resulting from this effect can be eliminated by the use of electrostatic shielding or guard circuits in the vicinity of the instruments.

Section 4.0

OPERATING AND TUNING

4.1 Test Data Cards

Every Eimac klystron is operated and tested individually in a standard Eimac Klystron Amplifier

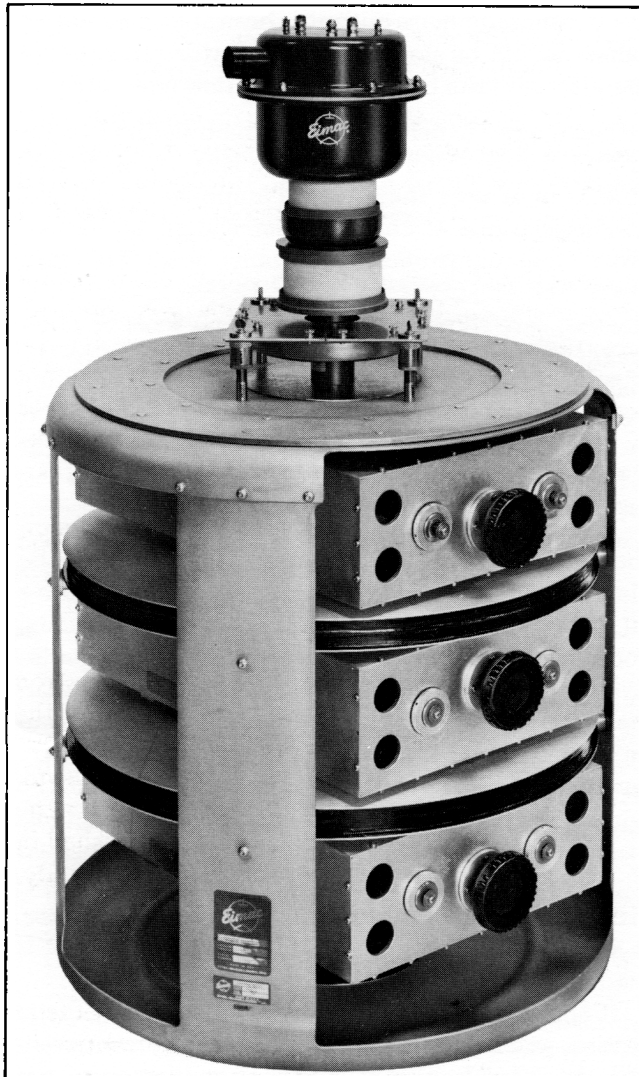



Figure 13—Typical Eimac UHF Klystron Amplifier Assembly.

Circuit Assembly (Fig. 13) before it is shipped to the customer. The complete tuning data and the conditions under which the klystron was operated are recorded in duplicate on test cards. One of these test cards is kept on permanent file at the factory, and the other is shipped in the same package with the klystron to which it belongs. This copy of the

test card is one of the most important tools required by the transmitter operator, especially when the klystron is being operated for the first time in the field. A sample is shown in Figure 14.

TEST DATA															
TYPE <u>4N650,000L</u>				POWER AMPLIFIER KLYSTRON				EITEL-McCULLOUGH, INC.							
SERIAL NO. <u>AJ-79-B</u>				E_f <u>7.5</u>		I_f <u>39.6</u>		GAS CHECK <u>/</u>			DATE <u>2-1-63</u>				
F_o	E_b	I_b	I_{by}	E_{foc}	P_o	P_d	Eff	I_{m1}	I_{m2a}	I_{m2b}	I_{m2c}	I_{m2d}	I_{m3}		
9B)	12	1.06	30	-200	4.32	.085		1.0	3.0	3.0	3.0	-	1.0		
"	14	1.36	35	"	7.12	"		1.04	"	"	"	-	"		
"	17	1.89	30	"	12.1	"		1.10	"	"	"	-	"		
755	12	1.06	30	-200	3.38	.085		1.03	3.0	3.0	3.0	-	3.0		
"	14	1.36	35	"	7.78	"		1.05	"	"	"	-	"		
"	17	1.89	30	"	12.4	"		1.08	"	"	"	-	"		

E_f - AC FILAMENT VOLTAGE	P_o - DRIVING POWER IN WATTS
I_f - AC FILAMENT CURRENT	Eff - EFFICIENCY IN PERCENT
F_o - FREQUENCY IN MEGACYCLES	I_{m1} - PREFOCUS COIL CURRENT IN AMPERES
E_b - BEAM VOLTAGE IN KILVOLTS	I_{m2a} - FIRST BODY COIL CURRENT IN AMPERES
I_b - BEAM CURRENT IN AMPERES	I_{m2b} - SECOND BODY COIL CURRENT IN AMPERES
I_{by} - BODY CURRENT IN MILLIAMPERES	I_{m2c} - THIRD BODY COIL CURRENT IN AMPERES
E_{foc} - FOCUS ELECTRODE VOLTAGE	I_{m2d} - FOURTH BODY COIL CURRENT IN AMPERES
P_d - OUTPUT POWER IN KILOWATTS	I_{m3} - COLLECTOR COIL CURRENT IN AMPERES

PLEASE USE REVERSE SIDE FOR SERVICE LIFE RECORDS

Figure 14—Test Data Card. (front)

SERVICE LIFE RECORD										SERIAL NO. _____	
DATE RECEIVED _____					CONDITION _____						
SITE _____					INITIAL GAS CHECK: ION _____, ELECTRON _____						
GAS CHECKS - RECOMMENDED EACH MONTH WHEN KLYSTRON IS NOT IN SERVICE											
DATE											
ION CURRENT											
ELECTRON CURRENT											
DATE IN SERVICE	TRANS MITTER	CARRIAGE	FILAMENT HOUR METER	BEAM HOUR METER	DATE OUT OF SERVICE	FILAMENT HOUR METER	BEAM HOUR METER	REASON FOR REMOVAL	TOTAL FILAMENT HOURS		

Test Data Card. (back)

When a klystron is operated in several individual transmitters of the same type, its performance can be expected to vary slightly from one installation to another. Variations up to five percent are not usually cause for concern, but variations greater than ten percent often indicate maladjustment or trouble with the equipment.

4.2 Preliminary Focus Coil Adjustment

In new equipment, or in equipment in which the focus coils or their wiring may have been disturbed for any reason, the procedure outlined here and in Section 3.3 should be followed before the electron beam is started.

The prefocus coil should be centered physically around the neck of the drift tube and lightly held by the four locknuts at its corners. This preliminary adjustment is made visually, and it will be of aid in final centering later when the klystron is energized.

Before the beam is energized, the currents specified for operation at the lowest recorded beam voltage on the test data card must be established in the focus coils. These preliminary current values will change slightly during tuning, according to the requirements of the individual circuit, after the klystron is placed in dynamic operation.

4.3 Starting the Electron Gun

The cooling system must be placed in operation and its functioning checked before power is applied to the klystron. Large klystrons have electron guns which must dissipate considerable amounts of power, and they can be seriously damaged by operation without adequate cooling.

The magnetic field must be established in the klystron before any attempt is made to energize the beam. Although very low beam voltages will not usually damage a klystron operating without its magnetic field, damage can occur and it is not good practice to start the beam without first establishing the magnetic field. The electromagnet currents should be adjusted to the values corresponding to the lowest beam voltage shown on the test data card, and initial operation should not exceed that beam voltage.

Attention should be paid to the recommended focus electrode bias voltage. The correct value for normal operation of the klystron is recorded on the test card and should be used during all preliminary tuning operations. Small adjustments in the beam current obtained at any fixed beam voltage can be obtained by variation of the focus electrode voltage around the recommended value, which is not critical.

Two distinct methods of heating cathodes in Eimac klystrons are in general use: direct radiation heating, and electron bombardment heating. The starting instructions for electron guns using each of these methods are given in the following sections:

4.3.1 Starting the Electron Gun, Radiation-heated Cathode Type:

1. Start cooling system, check its operation.
2. Establish recommended currents in focus coils.
3. Increase heater voltage gradually to the rated value, holding the heater current to the specified value.

4. Apply the focus electrode voltage if this is obtained from a power supply. If the focus electrode voltage is obtained from a cathode series resistor, this should be set to approximately its operating resistance.
5. Permit the cathode to heat as specified.
6. Beam voltage may now be applied to the klystron in accordance with Section 4.4.

4.3.2 Starting the Electron Gun, Bombarded Cathode Type:

1. Start cooling system, check its operation.
2. Establish recommended currents in focus coils.
3. Increase filament voltage gradually to the rated value, keeping filament current to the specified value.
4. Apply bombarder voltage, increasing it gradually until rated bombarding power is obtained.
5. Apply focus electrode voltage specified for the type klystron in use if this is obtained from a power supply. If the focus electrode voltage is obtained from a voltage divider across the bombarder supply, it should be pre-set to approximately the correct value.
6. Beam voltage may now be applied to the klystron in accordance with Section 4.4.

4.4 Applying Beam Voltage

Initial adjustment and operation of the klystron must be done at the lowest voltage specified on the test card provided with each tube. Failure to observe this rule can result in the destruction of the klystron.

The beam voltage may be applied only after the recommended magnetic field has been established in the equipment, the prefocus coil centered visually, and the electron gun started.

4.5 Magnetic Field Coils

The magnetic field which guides the electron beam in an Eimac klystron is created by controlled amounts of direct current flowing in electromagnet coils surrounding the klystron (Fig. 15).

The number of coils required is not the same for all types of klystrons, but operators will find four or five coils in most transmitters. These are the prefocus coil, several body coils and the collector coil.

The purpose of the magnetic field is to control the diameter and direction of the electron beam as it flows through the klystron, so that as little beam current as possible will strike the drift tube walls and be wasted. It follows that the best adjustment of the focus coil currents is the setting for minimum

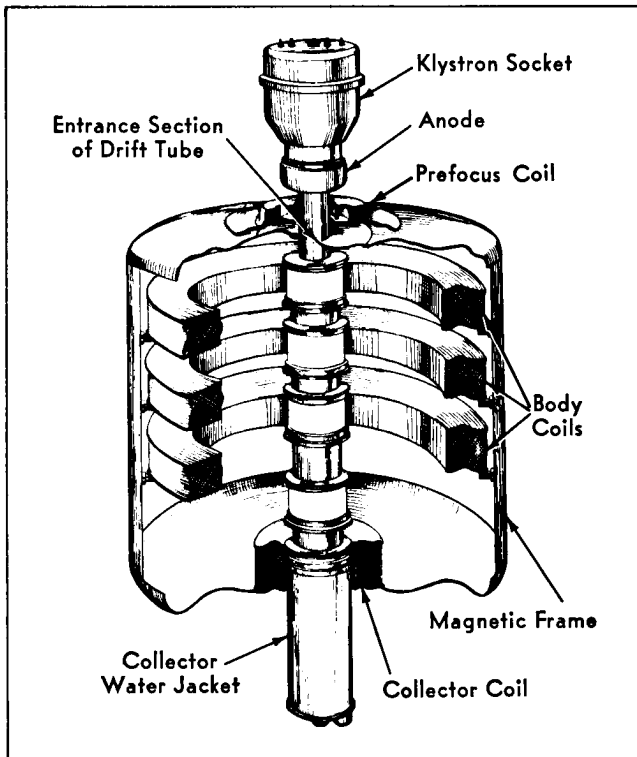


Figure 15—Simplified View of a Klystron and Its Magnetic Circuit with the Tuning Cavities Removed.

body current, consistent with good output. Sometimes slight changes in the coil current settings will produce large changes in power output without correspondingly great body current changes. In such cases, if the body current is not too near the permissible maximum, it is wise to adjust for a compromise body current setting which permits the larger power output to be obtained.

Each time the rf circuits are tuned, some changes will take place in the velocity and bunch density of the beam, which may increase the body current. As a result, each readjustment of the rf tuning will usually make it necessary to trim the focus coil currents slightly to obtain minimum body current again. This behavior is normal, and the adjustment is not critical despite its importance.

Focus coil resistances undergo considerable variation as the coils heat up after being turned on. The effects of this resistance variation on the coil current must be corrected by some means, and in transmitters where the currents are controlled manually, the operator should make frequent checks on the coil currents and over-all klystron operation during the warm-up period.

4.5.1 Prefocus Coil (Not Required for Some Klystrons)

The prefocus coil is much smaller than the body

coils used with the klystron, and it is enclosed in a special magnetic shell containing an annular air gap. The flux outside of the air gap forms a magnetic lens located on the axis of the klystron at the approximate point where the convergent paths of the electrons would focus. This magnetic lens overcomes the tendency of the electron paths in the beam to diverge and strike the drift tube wall before the beam enters the main magnetic field, and it directs the beam down the center line of the drift tube. To accomplish these two ends, the prefocus coil requires two separate adjustments: the current must be correctly set, and the correct position of the coil around the axis of the drift tube must be found.

The initial current settings should be those shown on the test data card, for the lowest operating beam voltage specified. After the magnetic field has been established and the beam energized, the locknuts on the prefocus coil mounting pillars can be loosened and the coil carefully positioned to obtain the lowest possible body current (Fig. 16). When the optimum

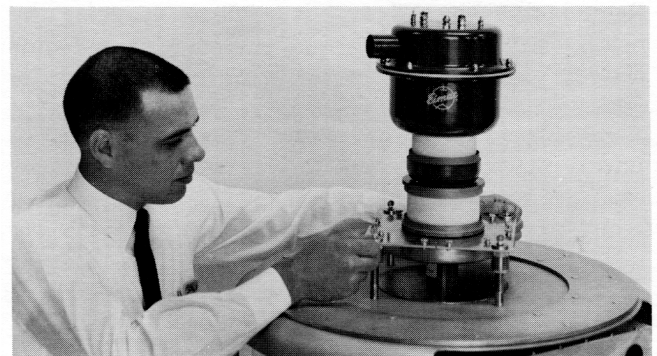


Figure 16—Adjustment of Prefocus Coil.

position has been located, the coil may be locked in place again.

The prefocus coil mount should *never* be unlocked at beam voltages higher than the low beam voltage used during the position adjustment just described. To move the prefocus coil at higher beam voltages is to invite destruction of the klystron and, although it can be done in some instances by experienced personnel, moving the prefocus coil during high-voltage operation is NOT recommended.

Some of the newer Eimac external cavity klystrons do not require prefocus coils. This is because they use confined flow electron gun designs which make prefocus coils unnecessary. In the confined flow principle the main magnetic field is permitted to extend through the cathode and is so shaped that the electrons are confined by the field from the instant they leave the cathode. This minimizes focusing adjustments and provides a more stable beam.

4.5.2 Body Coils

Many body coils are supported in the klystron amplifier frame by small mounting pillars, which are secured to the side bars by single machine bolts running in tapped eccentric holes in the support pillar base. By this means, the support pillars can be rotated to provide four-point suspension of the coil, and the body coils can be levelled within small limits. The coils are positioned on the axis by small shoulders turned on the bodies of the mounting pillars.

Once the coils have been correctly set on the mounting pillars, it only remains to adjust the currents during the process of tuning the klystron amplifier. The original current values required are given by the test data card for each beam voltage. The test values should be used as starting points, and the final currents should not deviate greatly from them. In most cases, deviation from the test values of more than ten percent will result only when an error has been made in setting up the adjustments, or in assembly of the equipment.

4.5.3 Collector Coil

The collector coil is located around the soft steel sleeve in the bottom of the magnetic frame which supports the mounting flange of the klystron. The mounting flange is also made of magnetic material, and it serves to establish the magnetic field needed near the collector end of the drift tube whenever the collector coil is energized. The collector coil current adjustments are made in the same manner as the body coil current adjustments, and with the object of reducing the body current as much as is consistent with good power output.

4.5.4 Results of Improper Adjustment of Focus Coils

If the focus coils are improperly adjusted so that the electron beam is not centered in the drift tubes or if the beam is too large in diameter, it will graze the drift tube tips and evaporate copper which will raise the gas pressure in the tube and possibly poison the cathode. In extreme cases the drift tube tips may be partially melted by the beam. On the other hand, if the beam is over-focused by using an excessively strong magnetic field, the beam size is too small as it leaves the field and therefore it will not spread properly before it strikes the collector, with resulting damage. It is quite possible to burn a hole in the collector if the beam is overfocused.

Correct focusing of the electron beam is accomplished by keeping the body current well below the maximum limit at all times using focus coil currents that do not deviate more than 10% from those

shown on the Eimac test data card. Adjustment of the focus coil currents should be made carefully so that the body current overload relay is seldom, if ever, called upon to operate. If the beam is thrown considerably out of focus it is quite possible for the tube to be damaged before the body current overload relay can operate.

4.6 Beam Transmission and Beam Loss

Some of the electrons in the klystron beam will inevitably strike the drift tube walls, instead of passing on through the klystron to the collector. Captured by the wall of the drift tube and returned to the external electrical circuits (through the body current milliammeter), these electrons are totally wasted as far as the production of rf power is concerned. The electrons lost in this manner are called the "body current," and the rest of the electron beam, which reaches the collector, is called the "collector current." The sum of the collector current and the body current is equal to the total beam current emitted from the cathode.

The collector current, expressed as a percentage of the total cathode current, is called "beam transmission."

The body current, expressed as a percentage of the total cathode current, is called "beam loss."

4.7 Tuning the Klystron

It has been noted that klystrons may have any number of cavities, but those most common in the field have either three or four. The nomenclature for klystron cavities has arisen from the functions they perform, and it is natural that the first cavity be called the "input cavity," no matter how many cavities may follow it.

Similarly, the last cavity transfers power from the electron beam to the output transmission line, and it is logically referred to as the "output cavity."

The cavity preceding the output cavity is tuned by the same rules regardless of whether the klystron has three, four, or more cavities. Therefore, it is convenient to refer to this next-to-the-last cavity by some descriptive word independent of the number of cavities which precede it, so it will be referred to as the "penultimate cavity."

The remaining cavities, not given descriptive names according to the scheme outlined above, are referred to by their position on the drift tube as the "second cavity," "third cavity," and so on. Most Eimac external cavity klystrons use either three or four cavities and the following tuning instructions will therefore be chiefly concerned with these tubes.

Before driving power is applied to the input cavity

of a klystron, the tuning cavities should all be adjusted to the highest possible frequency. This is done by moving the tuning doors as far as possible toward the centers of the cavities. The output load coupler should also be adjusted for maximum coupling (loop vertical). After this is done, beam power and rf drive can be applied to the klystron and tuning may begin.

The tuning procedures which follow will apply particularly to narrow-band, maximum-gain amplifier operation. The procedures for broad-band klystron operation are ordinarily evolved for each individual application, and therefore cannot be treated as generally as can the narrow-band case. (See Section 5.3 for broad-band application information.)

The operator should not permit his familiarity with conventional electron tube behavior to confuse him when he tunes a klystron amplifier. In some respects a klystron behaves like a linear amplifier using conventional electron tubes, because the "plate current" does not change during tuning and the best indicator of correct tuning is the power output. Furthermore, when the driving power level is increased to a point above "saturation" the power output will start to fall with increasing driving power, which is similar in some respects to "overloading" a conventional amplifier circuit (Fig. 17).

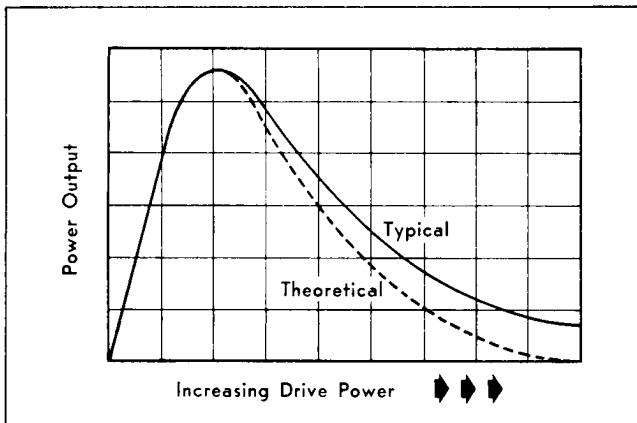


Figure 17—Overdriving a Klystron Reduces Output.

The klystron offers the operator the advantage that he can be guided in his actions by the variations in body current resulting from changes in the rf tuning adjustments. As each cavity is tuned, the body current may vary, and it is often necessary to trim the focus currents after each readjustment of the rf tuning, especially when the klystron is operating near its highest efficiency at any given power level.

Many Eimac klystrons carry dual body current ratings. One of these is intended for use during long

periods of continuous operation and is usually half the absolute maximum rating. The absolute maximum rated body current is established for observance during tuning operations, to free the operator from the necessity of stopping frequently to trim the focus currents and to avoid tripping overload current relays frequently during tuning.

4.7.1 Input Cavity Tuning

The input cavity is tuned to resonance at the driving frequency. A beam voltage equal to 50% of that required for full rated power is applied to the klystron during this adjustment. Resonance is usually indicated by tuning for minimum VSWR at the input cavity. A directional coupler is ordinarily inserted in the driving line for this purpose. The two tuning doors of the cavity should always be equally spaced from the ceramic cylinder. The input cavity coupling loop should be adjusted to the position giving lowest reflected power as indicated by the directional coupler in the drive line. This is the condition of best match for the drive line. The input cavity must be resonated after each coupling adjustment. After the coupling is adjusted for best match, the driving power should be set at the value specified for the particular klystron. This power can be measured with a bolometer at the incident power terminals of the input directional coupler. After the input cavity is tuned, the second cavity (if applicable) and output cavity tuning doors should be adjusted to approximately the same positions as those of the input cavity. Since the cavities are similar, this will approximate resonance. The penultimate cavity tuning doors should next be set at positions midway between those of the input cavity and the maximum high frequency setting (tuning doors nearest to klystron).

4.7.2 Second Cavity Tuning

(Ignore for 3 cavity klystrons)

The second cavity is also tuned to resonance at the driving frequency (unless stagger tuning is employed for broad-band operation). This is accomplished by tuning for maximum output power. It will probably be necessary to adjust the output cavity to resonance at this time in order to obtain adequate output power for tuning purposes. The relative power output indicator must be sufficiently sensitive to detect the low power output during this tuning procedure.

4.7.3 Penultimate Cavity Tuning

After the input and second cavities are resonated, the beam voltage can be increased to the lowest value shown on the Eimac test data card. (Adjust

focus coil currents for minimum body current). The input and second cavities should then be rechecked for resonance because their tuning may change as the beam current changes. The penultimate cavity can then be slowly tuned toward a lower frequency as the output power is carefully observed. As the cavity is tuned, the output power will increase to a maximum and then start to decrease. Return the tuning to the point which gave maximum power output and then detune on the high frequency side until the output power drops 10%. This is the correct tuning point for the penultimate cavity. See Fig. 18.

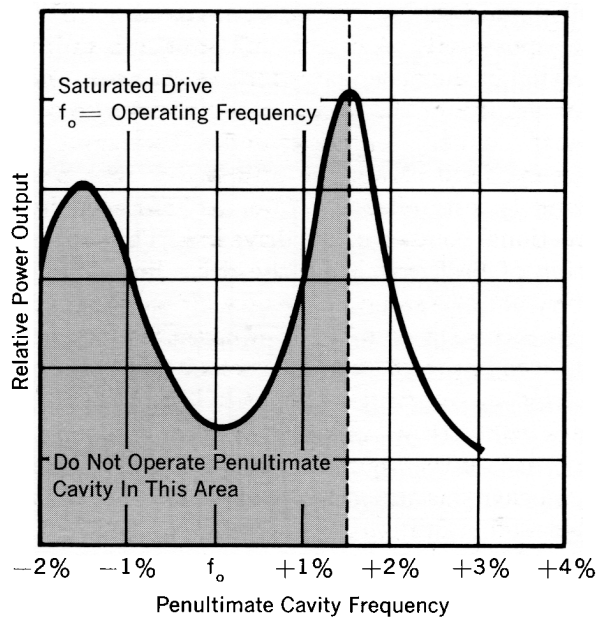


Figure 18—Penultimate Cavity Tuning

4.7.4 Output Cavity Tuning

After the penultimate cavity is tuned, the output cavity is retuned for maximum output power. Next the output coupling is adjusted. Starting in a vertical position the coupling loop is moved in 5° steps toward a horizontal position. The output cavity must be retuned at each step because its resonant frequency will change as the coupling is adjusted. As the output coupling is reduced the output power will increase. Eventually optimum coupling (maximum power) will be reached and if the coupling is further reduced the output power will start to decrease. *Do not reduce the coupling past the point of optimum coupling.* Instead, increase the coupling until the output power drops to 95% of its value at optimum coupling (see Fig. 19). The klystron is now correctly tuned at the lowest beam voltage shown on the Eimac test data card and the output power should be near the value shown on the test

data card. If it is not, the tuning procedure should be repeated until the reason for the discrepancy is discovered.

At the lowest beam voltage shown on the Eimac test data card mistakes in tuning will not ordinarily injure the klystron and it is suggested that the operator take this opportunity to practice tuning the klystron and familiarize himself with its behavior before increasing power.

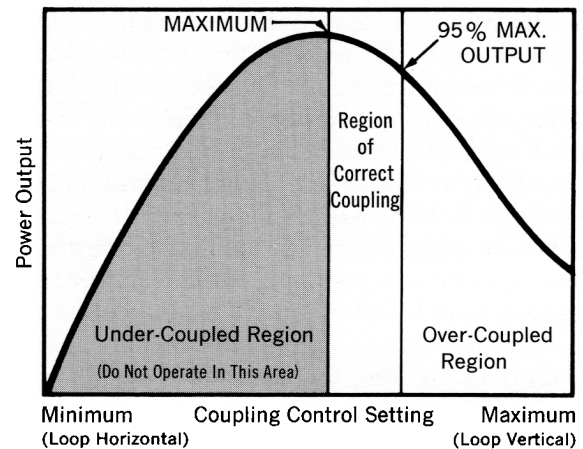


Figure 19—Adjustment of Output Coupling Control.

4.7.5 Load VSWR Check

After the klystron has been tuned at the lowest beam voltage shown on the Eimac test data card, the load VSWR should be determined by comparing the incident and reflected power measured at the directional coupler in the output transmission line. Most Eimac external cavity power klystrons will deliver rated output power with any load VSWR up to 1.5:1. This is equivalent to 4.2% reflected power with respect to forward power. If the reflected power exceeds this value the load must be adjusted to reduce the VSWR to 1.5:1 or less before the beam voltage is increased.

4.7.6 Trimming

When the tuning procedure has been completed and the operation appears reasonably satisfactory, each adjustment in turn should be trimmed to assure the operator that optimum performance has been obtained. When satisfactory operation at any given power level has been obtained, operation at the next higher power level may be started.

4.8 Increasing Power

Before increasing power the following precautions must always be taken.

1. Increase the frequency of the penultimate cavity until the output power decreases by 50%. (Move tuning doors toward the center of the cavity.)

2. Increase the output coupling to maximum. (Coupling loop vertical.)

The beam voltage may then be increased in steps to the desired value. Observe the body current during each voltage increase and adjust the focus coil currents as required to keep the body current at minimum. After the desired beam voltage is reached, the input cavity and second cavity (where applicable) are again checked for resonance. Next the penultimate cavity is tuned exactly as described in Section 4.7.3 and finally the output coupling and output cavity tuning are adjusted exactly as described in Section 4.7.4. If the output power obtained in this way is greater than required, the output coupling should be increased until the desired output is obtained.

Section 5.0

APPLICATION OF THE POWER KLYSTRON

Figure 20 shows the filament and beam supplies, protective circuitry and instrumentation for a klystron amplifier. Focus coils and their power supplies have been omitted for simplicity. Commonly used abbreviations for klystron electrical characteristics are shown in Figure 21. Heater voltage and current (E_f , I_f) are typically supplied from a transformer, insulated for high voltage, and a variable autotransformer. The heater transformer is often designed to be short circuit limited to twice the normal heater current rating. The heater voltmeter should be connected directly to the klystron socket to minimize measurement errors due to voltage drop in the connecting cable.

Resistor R_{surg} is the current limiting resistor for the beam supply. Its value should be chosen to limit short circuit current to 25 to 100 times nominal beam current. A value of 100 ohms is typical for 10 kW power amplifiers.

Focus electrode voltage is most conveniently and reliably obtained from a cathode resistor (R_c). Focus electrode voltage is developed across this resistor by the beam current. R_c should have ample power dissipating capability. A voltmeter should be provided to monitor the focus electrode voltage (E_{foc}) and this meter should be protected by a thyrite element.

At least two overload circuits are required, one for the beam current and one for body current. These overloads are set to trip at the values of maximum beam current and body current specified for

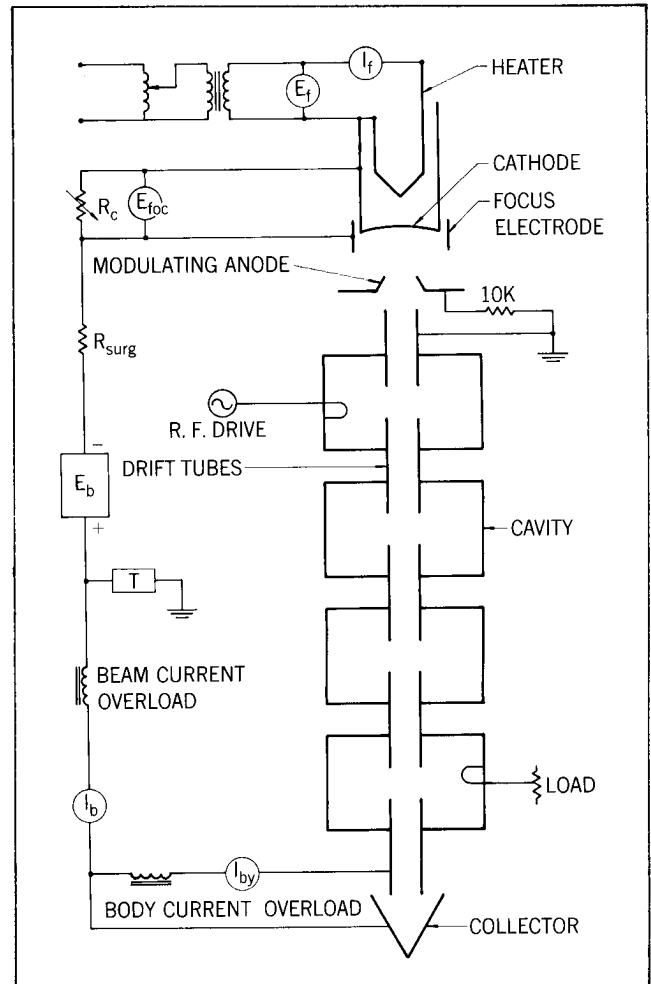


Figure 20—Klystron Power Supply Connections

the klystron. Meter relays are often used in these circuits and have been found to be satisfactory. The thyrite at T is desirable to protect the metering circuits and the klystron collector insulator in the event of power supply shorts. Every effort should be made to keep the total impedance between the klystron body (ground) and the positive terminal of the high voltage supply at a minimum. This resistance should be less than 5 ohms and one ohm is desirable.

Beam current and heater current should never be carried in the same conductor. Amplitude modulated random noise can be reduced several decibels if this rule is observed.

Beam supply ripple should be less than 1% for systems requiring incidental FM and AM noise down 40 db or more from the carrier. For noise down 60 db, 0.1% or less ripple is required. The supply should be variable or adjustable to at least four equally spaced voltage levels between 50% and 100% E_b .

Focus coil power supplies (not shown in Fig. 20) should be filtered to 5% ripple. In most cases three phase full wave supplies may be used unfiltered. The focus coils have enough inductance to reduce the ripple adequately. Means must be provided to adjust the focus coil power supply voltages over wide limits. In many cases a variable autotransformer is used with each supply to provide continuous voltage variation from zero to the maximum specified on the klystron data sheet. An ammeter must be supplied to measure the current in each focus coil. An under-current relay is often provided in each power supply, interlocked so that the beam power supply cannot be energized unless the focus coils are energized. The body and collector coils of many modern klystrons are operated in series from a single power supply but the prefocus coil always has a separate supply.

5.1 Modulating Anode—CW Applications

Most modern klystrons are equipped with modulating anodes. For CW applications the modulating anode is connected as shown in Fig. 20. The 10,000 ohm resistor is usually wire-wound and rated for 200 W. If the power supply and its filter capacitors stored with energy were connected directly from cathode to anode and should the slightest surface arc, gas burst or interelectrode arc take place, the full energy of the power supply would be dissipated in the tube. This energy would pass through the cathode with disastrous results. The tube would have to withstand the energy supplied and stored by the power supply until the mechanical inertia of the primary breaker and the filter capacitor shorting

switch could be overcome. This situation can be somewhat improved by the use of current limiting resistors but the power loss is prohibitive if the resistance is high enough to be fully effective.

The problem is solved by connecting the modulating anode as shown in Figure 20. It is clear that the normal condition of negligible current to the anode does not exist at the time of the arc. When the arc occurs, a large current tends to flow to the anode. With the modulating anode connected as shown, this current is limited to a small value and has the further advantage of removing the off-cathode gradient. This extinguishes the arc and cuts off the beam current automatically in an extremely short period of time. Application of this technique at power output levels of 10 kW and above may well make the difference between a successful system and an unreliable system plagued by occasional arcs costing valuable down time.

5.2 Modulating Anode—Pulse Applications

The use of the modulating anode is very advantageous in many pulse applications. By use of this additional element it is possible to switch the tube directly across the beam power supply without the use of conventional storage networks which impose severe restrictions on the switching tubes. However, in order to take full advantage of this desirable modulation property, it is necessary to build a modulator which can efficiently drive this high impedance electrode with high voltage pulses. A new type of circuit has been developed to meet this need.

The pulse voltage can be applied to the modulating anode with a pulse transformer. However, for high voltage long pulse applications, variations of the circuit shown in Figure 22 are used. These circuits use two hard switching tubes. One tube is used to switch the anode up to operating potential, and the other to pull the anode back to cathode potential thus cutting off the beam. Rise and fall times of less than 1 microsecond through 60 kv have been achieved with jitter down in excess of 40 db.

The circuit shown in Figure 22 consists essentially of two switch tubes in series. The lower switch tube drives the modulating anode positive with respect to the klystron cathode, causing beam current to flow. The current supplied by the switch tube is only the charging current to the anode and associated circuit capacitance. This tube usually conducts during the full length of the pulse, but the dissipation is negligible because the voltage drop across the switch tube is small and the conduction current consists of only the leakage current and the intercepted beam current both of which are small. The upper

COMMONLY USED ABBREVIATIONS FOR POWER KLYSTRON CHARACTERISTICS:

E_f	—Heater Voltage
I_f	—Heater Current
f_o	—Carrier Frequency
E_b	—Beam Voltage
I_b	—Beam Current
I_{by}	—Body Current
E_{foc}	—Focus Electrode Voltage
P_o	—Output Power
P_{in}	—Beam Input Power (dc)
P_d	—Driving Power
I_{m_1}	—Prefocus Coil Current
$I_{m_{2a}}$	—First Body Coil Current
$I_{m_{2b}}$	—Second Body Coil Current
$I_{m_{2c}}$	—Third Body Coil Current
$I_{m_{2d}}$	—Fourth Body Coil Current
I_{m_3}	—Collector Coil Current

Figure 21

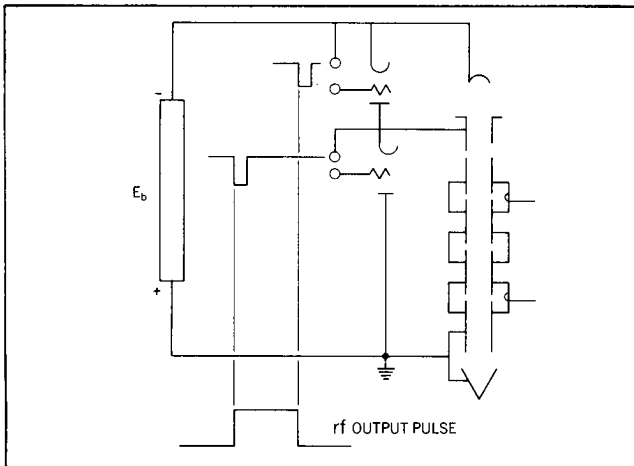


Figure 22

tube is triggered at the end of the pulse, shorting the modulating anode back to the cathode and cutting off the beam. This arrangement is known as the floating deck circuit because the circuitry which drives the lower tube must float with the modulating anode.

This circuit arrangement is particularly useful in long pulse applications because the switching tubes must work only during the rise and fall time of the pulse.

In addition, this circuit is desirable where adjustable pulse length is required. Pulsers have been made which generate a continuously variable pulse length from a few microseconds to several milliseconds.

5.3 Broad-Band Applications

External cavity klystrons are well suited to broad-band applications because the cavities can be loaded with external resistive loads to increase the bandwidth of the klystron. The circuit assemblies for many Eimac external cavity klystrons include provisions for coupling external loads to the cavities and, in other cases, coupling loops or load couplers for this purpose can be supplied on special order. The input cavity, second cavity and penultimate cavity are ordinarily loaded for broad-band operation. For extreme bandwidth, stagger tuning in addition to cavity loading is sometimes employed. The klystron is best adjusted for broad-band operation by using a sweep frequency source for the drive signal and adjusting the tuning and loading of the cavities while observing the output response curve on an oscilloscope. Such adjustments can also be made by the point-by-point method but this becomes very time consuming.

Driving power requirements for the klystron under broad-band conditions are greatly increased

with respect to narrow-band operation. The gain of a three-cavity klystron under maximum broad-band conditions will be in the order of 20 decibels. The gain of a four-cavity klystron under these conditions will be from 30 to 35 decibels. The beam power efficiency of the klystron is also reduced in broad-band operation. Efficiencies of 30% to 40% can be expected.

The 3 db bandwidth of a properly loaded and adjusted three-cavity klystron is approximately 0.4% of the operating frequency. A four-cavity klystron under these conditions can provide bandwidths up to 1% of the operating frequency.

Section 6.0 MISCELLANEOUS

6.1 Eimac Power Klystron Catalog Numbering System

The catalog numbers for Eimac power klystrons have been designed to convey maximum information regarding the klystron. Here is an example:

4KMP10,000LF

The first number indicates number of cavities (4). The first letter is always K, indicating klystron.

The second letter, M, indicates that the tube has a modulating anode. If no modulating anode is used, the M is omitted.

The third letter, P, indicates that this is a pulse klystron. In the case of CW klystrons the P is omitted.

The second number, 10,000, indicates the maximum collector dissipation of the klystron. In catalog numbers assigned prior to May 1, 1961, this was expressed in watts, but in those assigned after that date it is expressed in kilowatts in the interest of brevity.

The next to last letter, L, indicates the general frequency band in which the klystron operates.

The last letter, F, indicates the frequency sub-band in which the klystron operates. Since no standard system of sub-band assignments exists, Eimac uses its own.

Eimac klystrons described by the letter X followed by three or four numerals are usually newly developed tubes which have not yet been assigned catalog numbers. In a few cases klystrons become so well known by their developmental designations that these are used permanently.

6.2 Klystron Gas Check

The power amplifier klystron can be used as an

ion gauge to check relative gas pressure and thus indicate the condition of its own vacuum. This technique is used in the Eimac factory and can be used to advantage in the field. The gas check is performed by applying +150 volts dc to the electrode nearest the cathode (usually the focus electrode) and -45 volts dc to the electrode next closest to the cathode (usually the modulating anode or anode). These voltages are with respect to the cathode. The heater voltage is then applied. As the cathode heats, electrons are attracted from it to the positively charged electrode and some of the electrons collide with gas molecules, dislodging electrons from these molecules and forming positive ions. These ions are attracted to the negatively charged electrode causing a current to flow in this circuit which is proportional to the density of the gas molecules in the klystron and hence to its gas pressure. With most external cavity klystrons the ion current in the -45 volt circuit is read when the electron current in the +150 volt circuit increases through 20 milliamperes. The heater voltage is usually maintained at approximately 75% of rated value so that the electron current rises slowly enough to permit accurate readings. The heater voltage should be removed immediately after measurement. If a klystron is found to have an ion current reading greater than five microamperes it should be aged in the transmitter at the lowest available beam voltage or with other aging equipment as described in Section 6.3.

The gas check circuit is shown in Figure 23. Because ion currents in the order of one microampere or less are involved, it is convenient to measure them by inserting resistors in the ion current circuit and measuring the voltage across these resistors with a sensitive vacuum tube voltmeter. With the voltmeter and resistor combination shown in Figure 23, equivalent full scale readings of 0.1, 1, 10 and 100 microamperes are available.

Because of the small currents involved, the leakage resistance across the tube elements involved in the gas check must be very high. This can be checked by watching for current indication in the ion circuit before heater power is applied.

Specific information on gas checking any particular Eimac klystron is available by writing to Eitel-McCullough, Inc., San Carlos, California.

6.3 Klystron Reconditioning or "Aging"

It is often inconvenient to recondition a klystron which exhibits excessive gas current by operating it in a transmitter. Equally satisfactory results can be obtained with the following procedure.

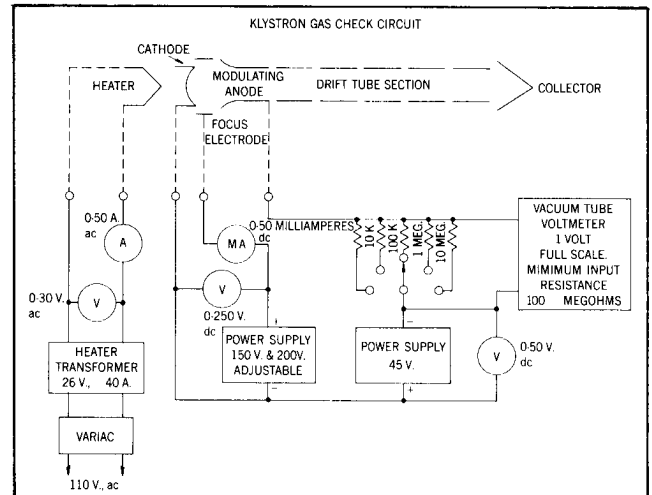


Figure 23

1. Support the klystron in a position permitting free circulation of air around the gun structure. Klystrons which are shipped in a metal frame may be aged in this frame, but those shipped in hair pack must be removed from the shipping container.
2. Apply forced air cooling to the gun structure in the amount specified in the data sheet.
3. Apply rated heater voltage to the klystron, limiting starting current to the specified value. Allow five minutes to warm up.
4. Short the focus electrode to the cathode.
5. Short the anode, drift tubes and collector together and ground.
6. Apply 500 volts ac or dc from the anode to the cathode. If dc is used the positive terminal must be connected to the anode. Cathode current will be approximately 15 to 30 milliamperes.
7. Energize the klystron in this manner for 12 hours or until the ion current, as indicated by the gas check, decreases to one microampere or less.

If the klystron has a titanium getter, it will be advantageous to energize the getter during the aging process.

6.4 Technical Assistance

Eitel-McCullough, Inc. will gladly assist users in the choice of klystrons best suited to their particular applications. This cooperation is especially important when a prototype design, which will later be manufactured in quantity, is being contemplated. Such assistance makes use of accumulated, detailed experience with the Eimac klystron types involved, and is handled confidentially and without charge.



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