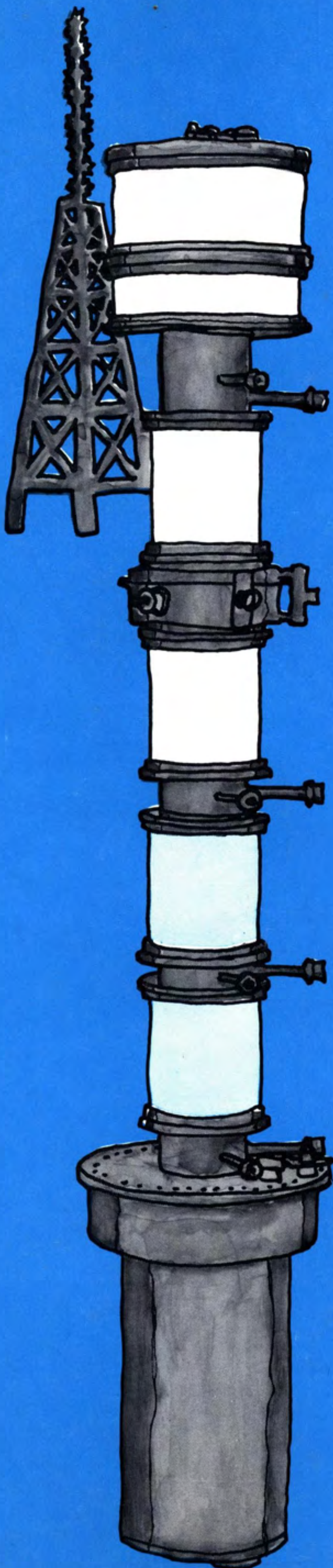

external cavity klystrons for UHF TV transmitters

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CONTENTS

EXTERNAL CAVITY KLYSTRONS
FOR
UHF TV TRANSMITTERS

Technical Services Department

PURPOSE

The purpose of this booklet is to familiarize the operator with basic principles of klystron operation, the need for care during tube installation, proper operating methods, and some troubleshooting suggestions for correcting difficulties which may occur with a klystron in a system.

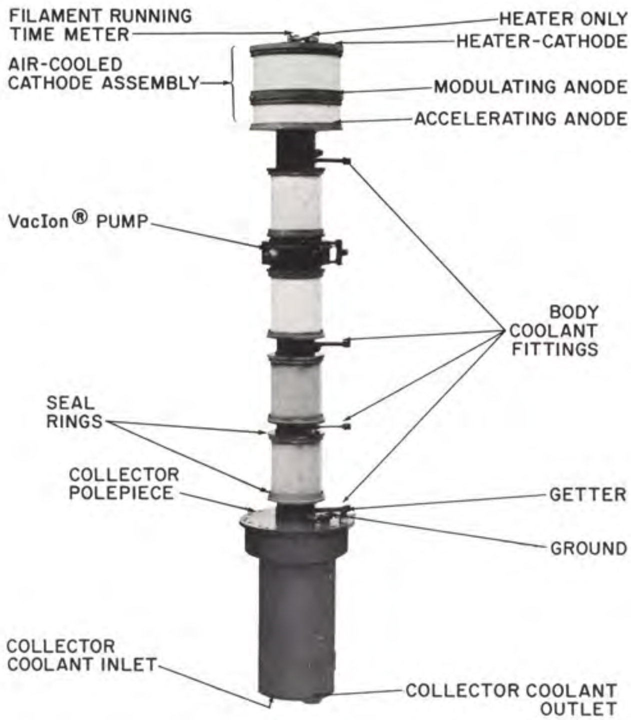
INTRODUCTION

At UHF-TV frequencies, suitable modulation of an electron stream in a conventional vacuum tube is very difficult to achieve. In a triode, for example, as an electron stream travels from the cathode to the plate, it is modified by the voltage on the grid. At microwave frequencies, the voltage on the grid oscillates so rapidly that it may complete several oscillations during the time an electron travels across the tube. This decreases efficiency and output power and causes excessive back-heating of the cathode by electrons from the grid region. Although this effect can be partially overcome by using closer interelectrode spacings and operating the triode at reduced heater voltage and increased plate voltage, it is difficult for any grid operating at microwave frequencies to have enough control over the electron stream to modulate it efficiently.

To solve this problem, engineers for many years have been evaluating various methods of modulation at microwave frequencies. One method commonly used today is modulation of the VELOCITY of an electron stream. It eliminates the problem of electron transit time as well as the need for close electrode spacings. Some of the microwave devices which use velocity modulation include klystrons, traveling-wave tubes, backward-wave oscillators, and magnetrons.

This booklet only discusses external-cavity UHF-TV klystron amplifiers, which represent only a small portion of all of the total klystrons now in use. However, much of the theory presented is general and can be applied to other linear-beam devices.

Terminology used in the klystron photos on the following page will be helpful in the discussion of klystron operation which follows.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HEATER ONLY
HEATER-CATHODE
AIR-COOLED
CATHODE ASSEMBLY
MODULATING ANODE
ACCELERATING ANODE
VacIon® PUMP
BODY
COOLANT
FITTINGS
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RINGS
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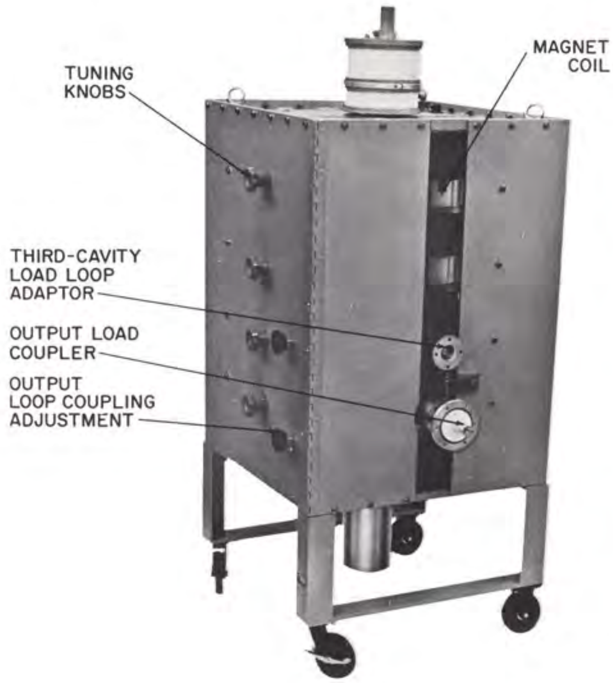
OUTLET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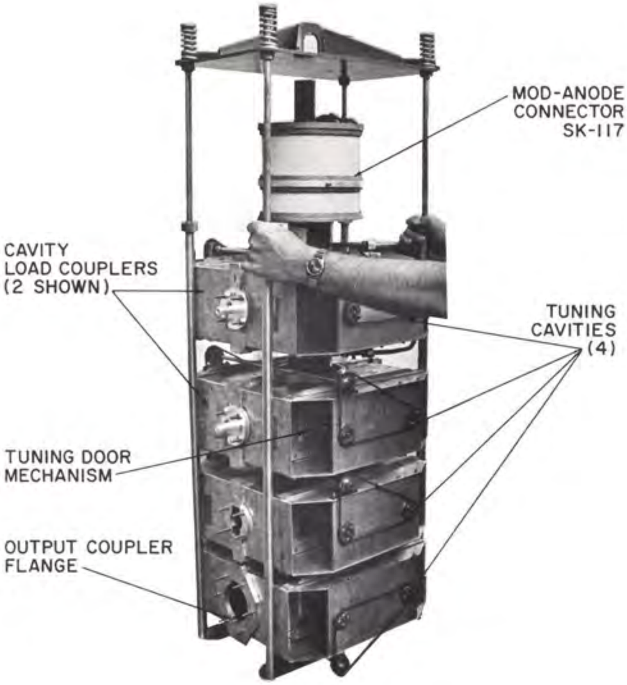
MOD-ANODE
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MECHANISM
OUTPUT COUPLER
FLANGE

THEORY OF OPERATION

The klystron is a device for amplifying signals at microwave radio frequencies. The high-velocity electron beam emitted from the cathode passes through the anode and into the rf interaction region, as shown in Figure 1. An external magnetic field is employed to prevent the beam from spreading as it passes through the tube. At the other end of the tube, the electron beam impinges on the collector electrode, which dissipates the beam energy and returns the electron current to the beam power supply.

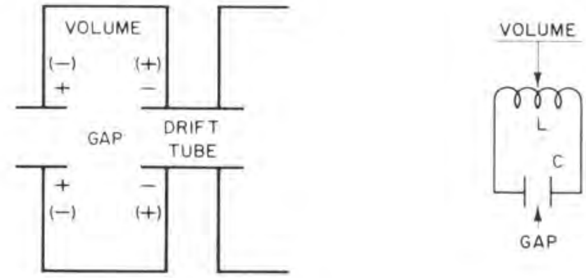

Figure 2

Typical cavity and equivalent circuit.

The rf interaction region, where the amplification occurs, contains resonant cavities and field-free drift spaces. The first resonant cavity encountered by an electron in the beam (the input cavity) is excited by the microwave signal to be amplified, and an alternating voltage of signal frequency is developed across the gap.

To see how this happens, an analogy can be made between a resonant cavity and a conventional parallel resonant LC circuit (Figure 2). The cavity gap corresponds to the capacitor, and the volume of the cavity to the inductor. If the cavity is just the right size, it will resonate at the desired microwave frequency. At resonance, opposite sides of the gap become alternately positive and negative at a frequency equal to the microwave input signal frequency.

An electron passing through the gap when the voltage across the gap is zero continues with unchanged velocity along the drift tube toward the next cavity gap; this electron can be called the reference electron. An electron passing through the same gap slightly later in time is accelerated by the positive field at the gap. This electron speeds up and tends to overtake the reference electron ahead of it in the drift tube. However, an electron which passes through the gap slightly before the reference

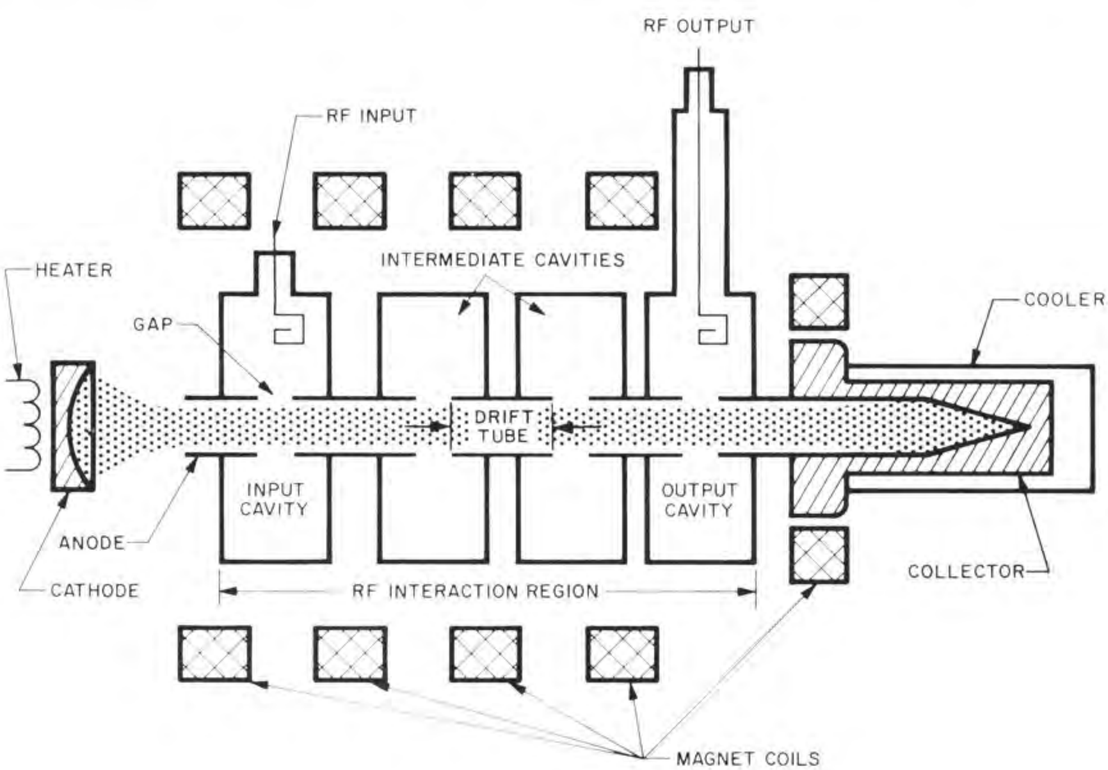

Figure 1

Principal elements of a klystron.

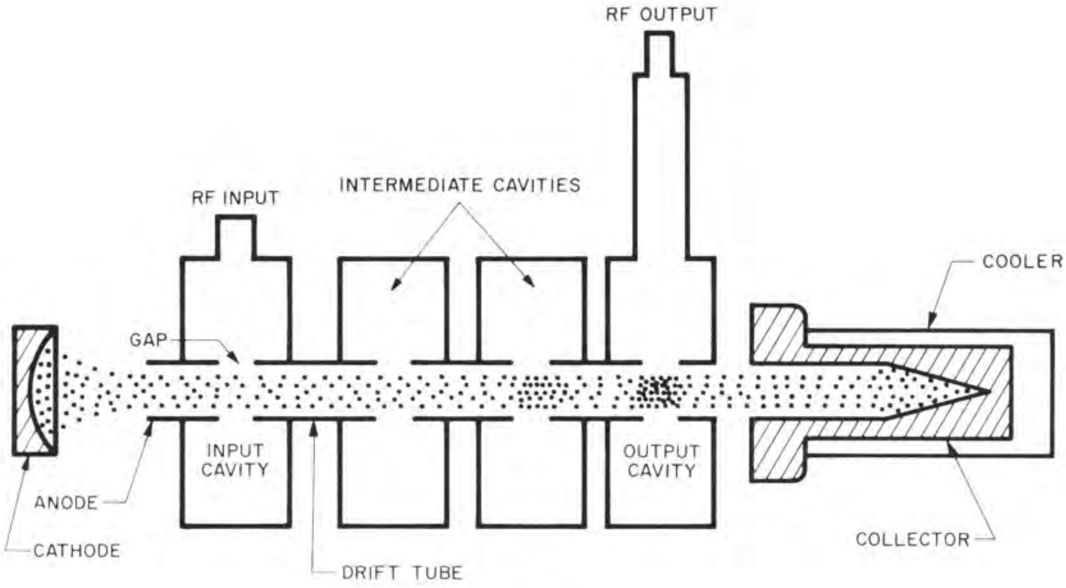

Figure 3

Schematic of a klystron.

electron encounters a negative field and is slowed down. This electron tends to fall back toward the following reference electron. Thus, as a result of passing the alternating field of the input-cavity gap, the electrons gradually bunch together as they travel down the drift tube (Figure 3).

Since electrons approach the input-cavity gap with equal velocities and emerge with different velocities, which are a function of the microwave signal, the electron beam is said to be velocity modulated. As the electrons travel down the drift tube, bunching develops, and thus the density of electrons passing a given point varies cyclically with time.

In all of the following cavities, the modulation component of the beam current induces current in each cavity. Since each cavity is tuned near resonance, the resulting increase in field at each gap produces successively more well-defined electron bunches and thus amplification of the input signal.

The rf energy produced by this interaction with the beam is extracted from the beam and fed into a coaxial or waveguide transmission line by means of a coupling loop in the output cavity. The d-c beam input power not converted to rf energy is dissipated in the collector.

EMISSION

The electron gun section of a klystron, shown in Figure 4, consists of a heater, an emitter, a beam-forming focusing electrode, and a modulating anode. When the emitter temperature is raised to the proper value by the heater, electrons are released from the emitter surface. The electrons are accelerated toward the modulating anode, which is at a positive potential with respect to the emitter. As the electrons travel between the emitter and the modulating anode, they are formed into a beam by the lens action of the focusing electrode and modulating anode. Figure 5 shows how this lens is formed.

Cathode Operating Temperature

All cathodes have preferred ranges of operating temperature. The operating temperature of the cathode must be high enough to prevent variations in the heater power from affecting the electron emission current (beam current) in the klystron. However, the temperature of the emitting surface must not be higher than necessary, since excessive temperature can shorten emission life.

Figure 6 shows beam current (emission current) as a function of the emitter temperature, which varies directly with heater power.

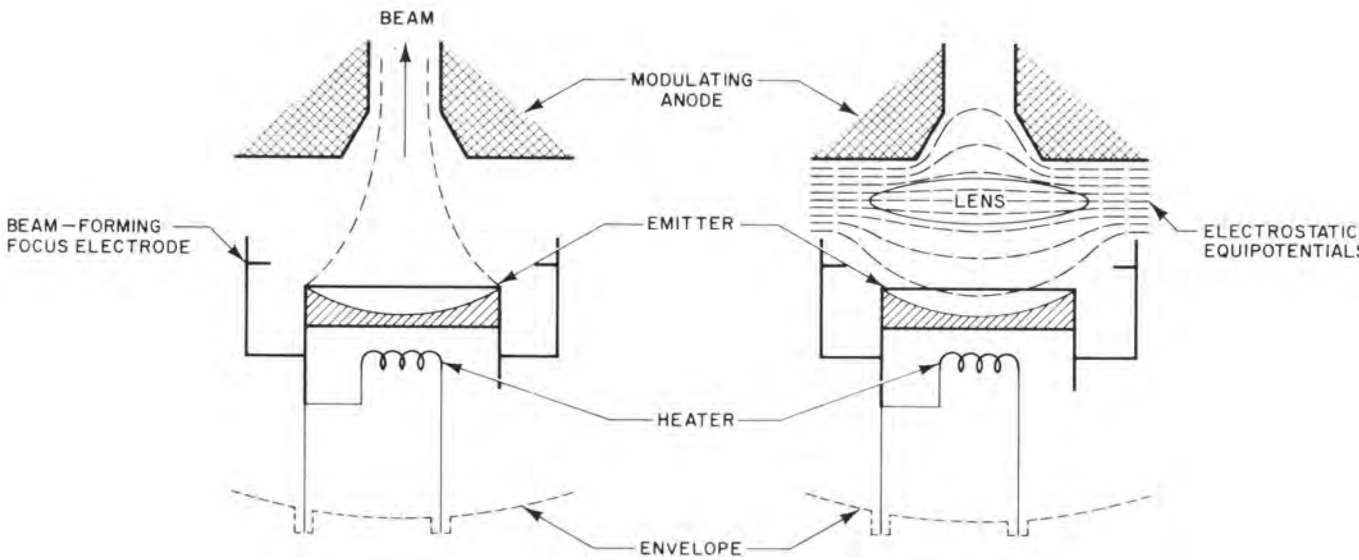

Figure 4

Diode section of a klystron electron gun.

Figure 5

Beam forming in the diode section.

When the heater voltage (Ef_1) is too low, the emitter will not be hot enough to produce the desired beam current. In addition, small variations in heater voltage will change the beam current significantly. With the proper heater voltage (Ef_2), constant beam current will be maintained even with minor variations in heater voltage. The same is true for a higher heater voltage value (Ef_3), but in this case, the emitter temperature is greater than that needed for the desired beam current and will reduce tube life. The correct value of heater voltage and/or heater current is included in the data shipped with each klystron.

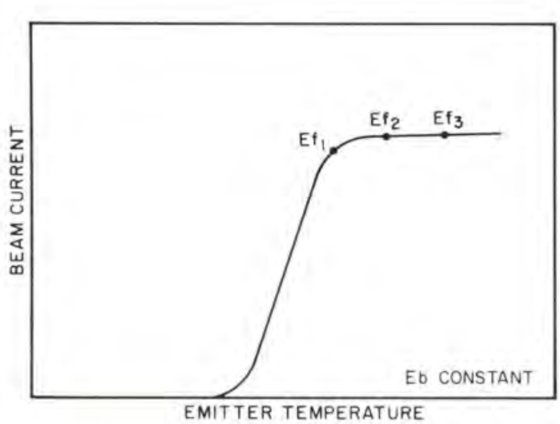

Figure 6

Beam current variation with emitter temperature.

Modulating Anode

Since the modulating anode is electrically isolated from both the cathode and klystron body (the rf structure, between polepieces) the voltage applied to it provides a convenient means for controlling beam current independently of the beam voltage applied between cathode and body, see Figure 8. When the cathode is operated in the space-charge-limited region, Ef_2 and Ef_3 of Figure 6, the emission current will be a specific function of the applied voltage.

$$Ib = kE^{3/2}$$

where

Ib = beam current, amperes

E = beam potential, volts

The constant, k, is a function of the geometry of the cathode-anode structure, and is termed <u>perveance</u>. Since the modulating anode is physically positioned between the rf structure (body) and the cathode, even if the full beam voltage is maintained between cathode and body, the actual beam current into the tube may be reduced at will by "biasing" the modulating anode to any voltage between cathode and body. Bias voltage is readily provided from a resistive voltage divider on the beam supply.

Figure 7 shows the relationship between beam current and voltage described in the above equation. Two examples for using the graph

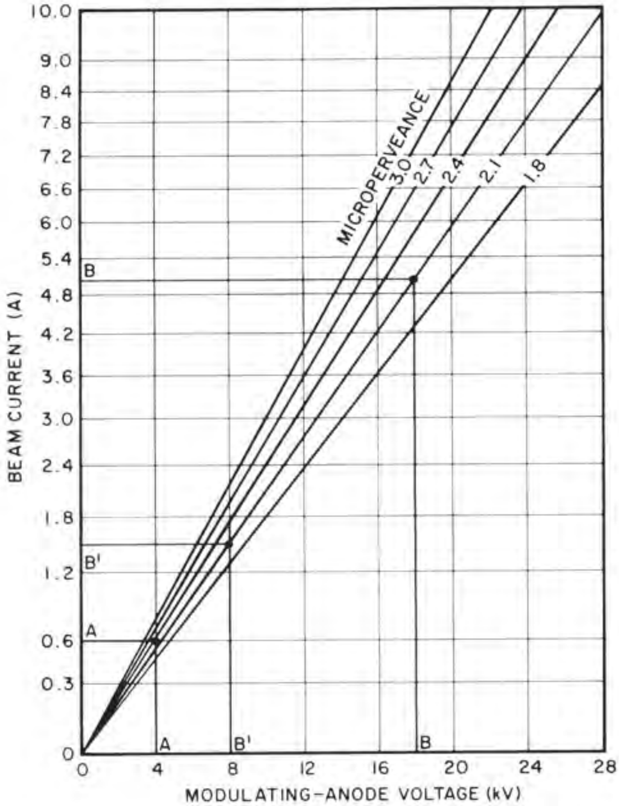

Figure 7

Beam current variation with modulating-anode voltage.

are given. In example A, if a modulating anode of 4000 volts produces a beam current of 0.6 amperes, the intersection point lies on the 2.4 microperveance line, and the perveance is expressed as $2.4 \times 10^{-6} A/V^{3/2}$, or 2.4 micropervs. Operating condition B illustrates a rather practical television transmitter situation in which a common beam supply of 18 kilovolts is used to power both the visual and aural klystrons. At 18 kV, the visual tube operates at a beam current of approximately 5.0 amperes if the modulating anode is connected (through an isolating resistance) to the body of the tube, and the perveance is $2.1 \times 10^{-6} A/V^{3/2}$, or 2.1 micropervs. Since the aural output power required is much less, the d-c input power can be reduced from that required to operate the visual tube. Points B' indicate that if the modulating anode is supplied with only 8 kV (through a voltage divider) then the intersection with the 2.1 microperv line yields a beam current of only 1.5 amperes, thus accomplishing the necessary reduction of input power for aural service.

MAGNETIC FIELD

Electromagnet coils are placed around the klystron to develop a magnetic field along the axis of the rf circuit which controls the size of the electron beam and keeps it aligned with the drift tubes.

Figure 8 illustrates the beam-forming portion at the cathode end of the klystron and rf section, where the magnetic field is developed between two cylindrical disks called polepieces. The electron beam in this illustration is shown travelling two paths. One path shows the beam spreading out to Points AA; the other path shows the beam confined by the magnetic field to a constant size throughout the distance be-

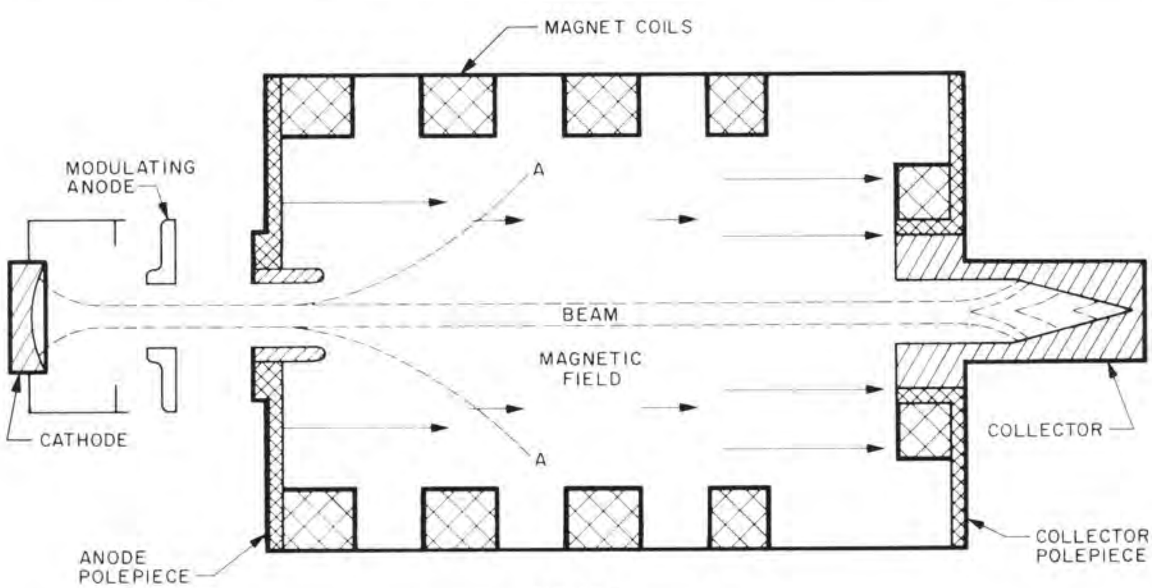

Figure 8

Effect of the magnetic field on the electron beam.

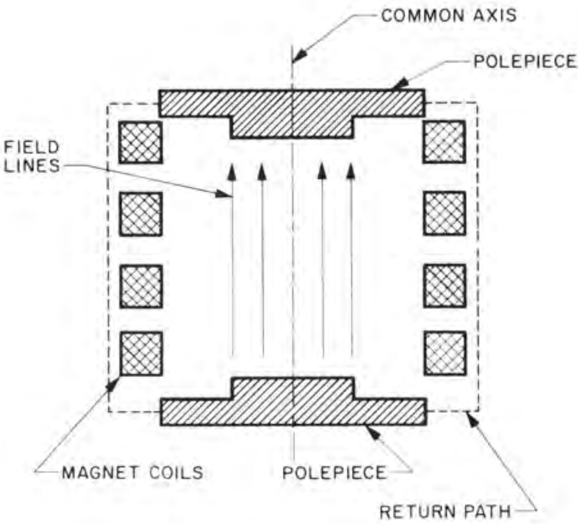

Figure 9

Field pattern of a klystron electromagnet.

tween polepieces. The beam spreads toward Points AA when the magnetic field is inadequate.

Figure 9 illustrates the magnetic field pattern of a typical solenoid used for klystrons. When d-c current passes through the magnet coils, a magnetic field is generated along the axis of the tube. The strength of this magnetic field can be controlled by changing the current flow through the magnet coils. The shape of the field, however, is determined by polepiece geometry and winding distribution inside the solenoid.

Figure 10 illustrates the field pattern and the shape of the beam for a properly adjusted field.

Figure 11 illustrates how the beam of a klystron is distorted when a piece of magnetic material is placed near the rf circuit of the

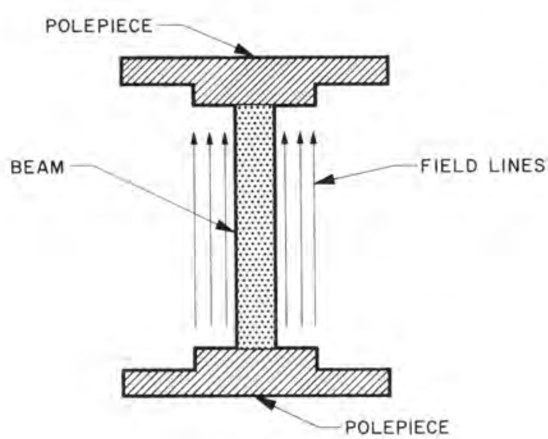

Figure 10

Field pattern and beam shape in a properly adjusted magnetic field.

tube. The beam will bend in this fashion if a nut or bolt, even as small as a 1/4-20 size, is in the magnetic field of the magnet. In this case, electrons in the beam will follow the bent magnetic field lines and may strike the walls of the drift tubes and klystron damage can occur. Remember, magnetic materials such as screw drivers, wrenches, bolts, or nuts must not be left near the magnetic circuit nor near the cathode or collector.

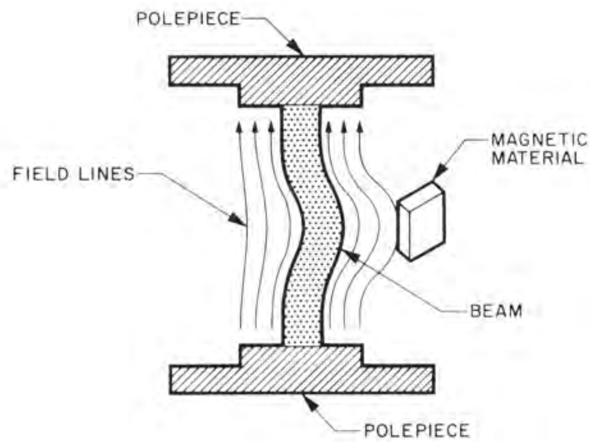

Figure 11

Distortion of field pattern and beam shape due to magnetic material in the magnetic field.

RF STRUCTURE

The rf structure of a klystron amplifier is comprised of several tunable resonant circuits (cavities) positioned along the axis of the electron beam. An rf signal is fed into the input cavity, at the cathode end of the tube, and an amplified signal is removed from the output cavity. The electron beam traveling through the cavities provides the coupling between each of the rf circuits. Velocity modulation occurs along the beam forming electron bunches.

Cavities

The cavities of a klystron are high-frequency parallel resonant circuits constructed so that they provide an rf voltage across the capacitive component (gap) which interacts with the d-c beam. Figure 12(a) illustrates the polarity near the drift tube tips within a cavity excited by an alternating voltage of microwave signal frequency. Figure 12(b) is the equivalent circuit of a simple cavity. To achieve circuit resonance, the inductive and capacitive reactances of each of the components must be equal.

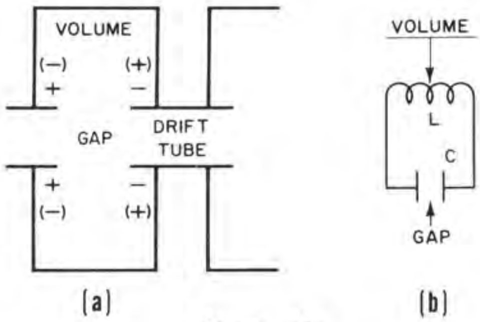

Figure 12

Typical cavity and equivalent circuit.

The reactance of each of the components shown in Figure 12(b) can be determined, since each component can be measured as a separate unit. However, the reactances of the components within a klystron cavity are more difficult to determine, because they cannot be measured individually. Therefore, the regions of voltage maxima or minima can be used to define each component of a klystron cavity in the following way:

1. The capacitance of a cavity is developed across the gap at the drift tubes where the voltage is maximum.
2. The inductance of a cavity is located in the outer volume of the cavity where the voltage is at a minimum.

By defining each component of a cavity in the above terms, it becomes easy to visualize changes in the volume as changes in inductance, and changes affecting the gap as changes in capacitance.

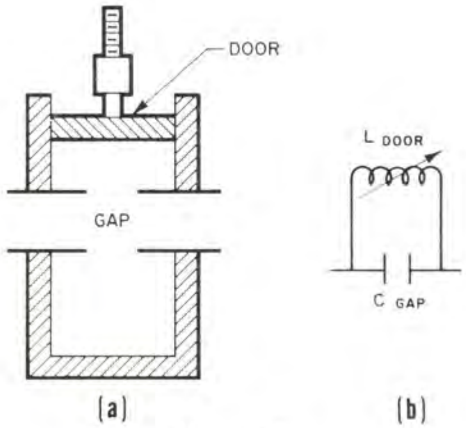

Figure 13

Typical capacitance-tuned cavity and equivalent circuit.

Cavity Tuning

The resonant frequency of each of the cavities of a klystron can be adjusted to the operating frequency of the transmitter. This can be done in two ways:

1. The inductance can be changed by changing the volume of the cavity, or
2. The capacitance of the drift-tube gaps can be changed.

External-cavity klystrons manufactured for UHF-TV stations are tuned by adjusting movable doors in each cavity to change the inductance (volume) of the cavity.

Figure 13 illustrates how the inductance of a cavity can be changed by varying the position of movable doors within the cavity. Figure 13(a) shows the mechanical configuration of a cavity with this type of tuning. For simplicity, only one door is shown; actually each cavity has two movable doors opposite each other. Moving the door toward the gap decreases the cavity volume and increases the resonant frequency of the cavity. Figure 13(b) shows the equivalent circuit.

Figure 14 shows a schematic diagram of the equivalent circuits of a four-cavity klystron. Circuit No. 1 is the input and Circuit No. 4 is the output. An rf signal is injected through the input coupling causing an a-c voltage across the capacitance (gap) of the input cavity. Depending on the polarity of this voltage, electrons passing through the gap are either accelerated or slowed down.

As the beam continues to travel toward the output cavity, electrons with increased velocity overtake the electrons that have slowed down, causing bunches of electrons to form in the beam. These bunches excite the cavities between the input and the output, which in turn affect the beam passing through. This creates a beam that is density modulated at the output gap, where the signal is removed from the klystron through the output coupling.

Cavity/Transmission Line Coupling

Figure 15 (a) illustrates magnetic-loop coupling, where the rf energy is fed through a coaxial line with its center conductor inserted into the klystron cavity. The end of the center conductor is formed into a loop. This forms a simple one-turn transformer which couples rf energy into or out of the cavity through a coaxial transmission line.

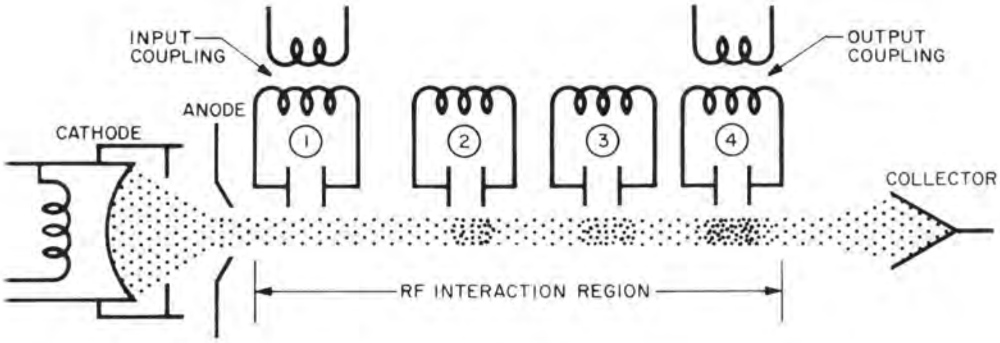

Figure 14

Schematic equivalent circuit of a four-cavity klystron.

Figure 15(b) shows the equivalent circuit. The transformer formed by the loop and cavity is an impedance-matching transformer between the transmission line and the cavity. For optimum klystron performance, components following the klystron in the system must be designed to present an impedance match (VSWR) as close to unity as possible.

Cavity Loading

Klystron cavities may be externally loaded to improve their instantaneous electronic-bandwidth characteristics. These loads lower the Q of the cavities slightly and thereby increase the bandwidth of the klystron.

RF PERFORMANCE

Output power stability of a klystron is sensitive to changes in beam input power, rf drive power, rf drive frequency and tuning as well as magnetic fields, output VSWR's, etc. Varying any of these parameters will affect rf output power response.

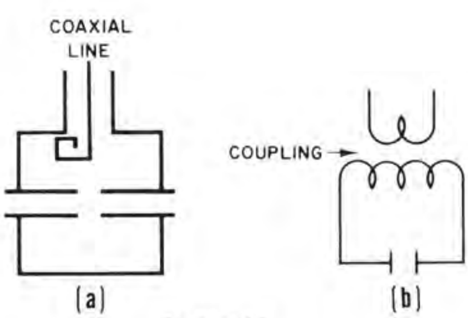

Figure 15

Loop coupling and equivalent circuit.

DC Input Power vs. RF Output Power

Figure 16 shows how changes in d-c beam input power affect the rf output power of a klystron under constant rf drive conditions. Small changes in d-c input power produce marked changes in rf output power. Hence, poor line-voltage regulation may cause the output power to vary excessively.

Effect of RF Drive Power on RF Output Power

Figure 17 shows rf output power as a function of rf drive power applied to the tube. From this curve, we see that when the rf drive power level is low, the rf output power is low. As the level of rf drive power increases, rf output power increases until an optimum point is reached. Beyond this point, further increases in rf drive power result in less rf output power. Because of these effects, two zones and one point have been labeled on the curve. In the zone labeled "Underdriven", rf output power in-

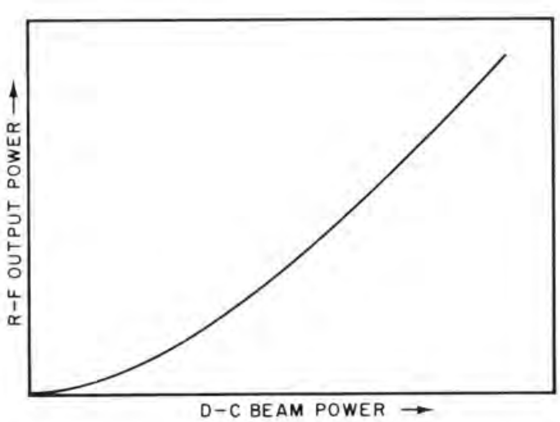

Figure 16

Rf output power variation with dc beam input power.

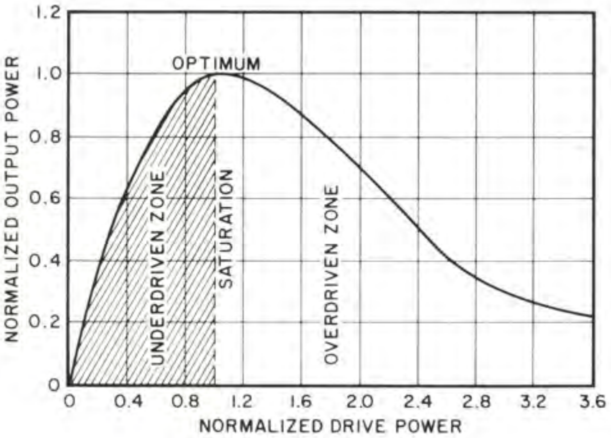

Figure 17

Rf output power as a function of rf drive power.

creases when the rf input power is increased. The point labeled "Optimum" represents the maximum rf output power obtainable. Klystrons are said to be saturated at this point, since any further increase in rf drive only decreases the rf output power. The zone formed at the right side of saturation is labeled "Overdriven". To obtain maximum rf output power from a klystron, sufficient rf drive power must be applied to the tube to reach the point of saturation on the curve. Operating at rf drive levels beyond the saturation point will only overdrive the klystron, decrease rf output power, and increase the amount of beam interception (body current) at the drift tubes. In TV service, klystrons are always operated within the underdriven zone of Figure 17.

Tuning and Bandwidth

In the section on klystron cavities, the analogy of a parallel resonant circuit was used

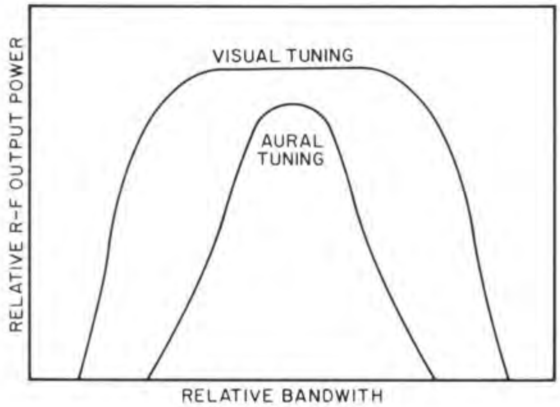

Figure 18

Bandwidth and output power variation with tuning.

to illustrate the equivalent circuit of a single cavity. Figure 18 represents the response of all of the cavities of a klystron combined. Tuning of any cavity will affect the size and shape of these curves.

There are three common methods of tuning klystrons. They are:

1. Synchronous tuning for maximum gain.
2. High-efficiency tuning for aural service.
3. Broadband tuning for visual service.

Figure 19 shows how rf output power changes with various levels of rf drive power applied to a klystron under different tuning conditions.

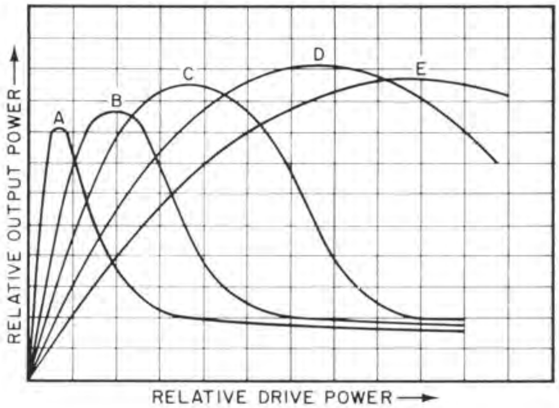

Figure 19

Output power variation with drive power under different tuning conditions.

The rf power at Point A represents the drive saturation point for a synchronously-tuned tube. Point B shows a new point of saturation that is reached by tuning the penultimate (next to the last) cavity to a somewhat higher frequency. By tuning the penultimate cavity still further, Point C is reached. There is a point, Point D, where increasing the penultimate cavity freqeuncy no longer increases rf output power; instead, it reduces the output power, Curve E. Curve D is a typical gain curve for a klystron correctly tuned for visual operation.

This concept is important because improper tuning of the klystron (Curves B and E) will cause excessive sync-compression and low rf output power. Figures 20 and 21 indicate the effect of tuning on sync response at a constant blanking power level. Figure 20 shows the output obtained when the klystron is tuned correctly for visual service. It can be seen that the klystron is operating well within the linear

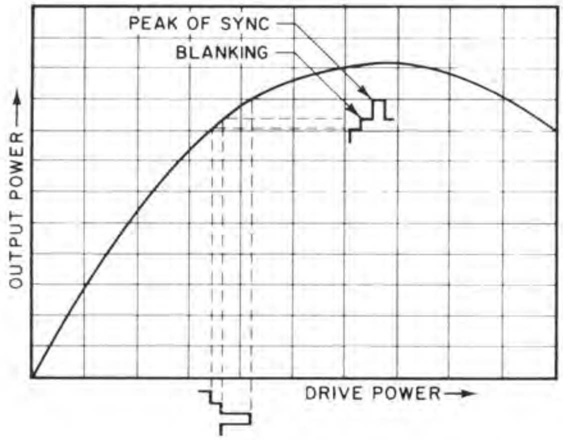

Figure 20

Output power and sync response of a klystron properly tuned for visual service.

portion of the gain curve D. In Figure 21, gain curve B is used to show the effect of improper visual tuning, leading to sync compression. Note that the klystron in this case is being operated too close to the point of saturation, the very non-linear portion of the gain curve. Tuning procedures are described in detail starting on Page 14.

PROTECTIVE MEASURES

A klystron amplifier must be protected by control devices in the system. These devices offer either visual indications, aural alarm warnings, or actuate interlocks within the system. Under "Troubleshooting", methods of determining causes of faults are discussed. This discussion covers many types of monitoring and protective devices that can be used in a UHF-TV system. The explanation will

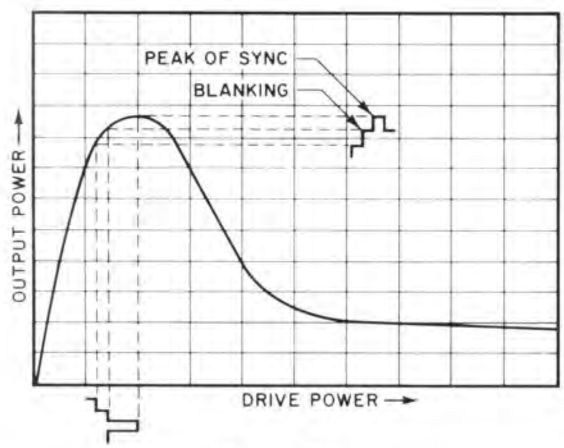

Figure 21

Gain curve of an improperly tuned klystron showing undesirable sync compression.

cover the reasons for protection and what should be monitored. Only power supplies and rf system will be discussed at this time. Monitoring of the cooling system will be discussed in the section on cooling systems.

Figure 22 is a pictorial diagram of a klystron amplifier and the basic components associated with its operation as well as the metering for each of the power supplies. Sections of coaxial transmission line, representing essential components, are shown attached to the rf input and rf output of the tube. A single magnet coil is shown to represent any coil configuration that may exist; its position in the drawing is for convenience only and does not represent the true position in the system.

Heater Supply

The heater supply can be either ac or dc. If it is dc, the positive terminal must be connected to the common heater-cathode terminal and the negative terminal to the heater terminal.

The amount of power supplied to the heater is important since this establishes the cathode operating temperature. The temperature must be high enough to provide ample electron emission but not so high that emission life will be jeopardized.

The Test Performance Sheet accompanying each tube provides the proper operating values of heater voltage and current for that tube. To verify meter calibration, heater voltage should be measured at the heater terminals of the tube. In this way, heater voltage and current can be correlated with the values on the Test Performance Sheet.

Since the cathode and heater are connected to the negative side of the beam supply, they must be insulated to withstand full beam potential.

Beam Supply

The high-voltage beam supply furnishes the d-c input power to the klystron. The positive side of the beam supply is connected to the body and collector of the klystron. The negative terminal is connected to the common heater-cathode terminal. Never connect the negative terminal of beam supply to the heater-only terminal because the beam current will then flow through the heater to the cathode and cause premature heater failure.

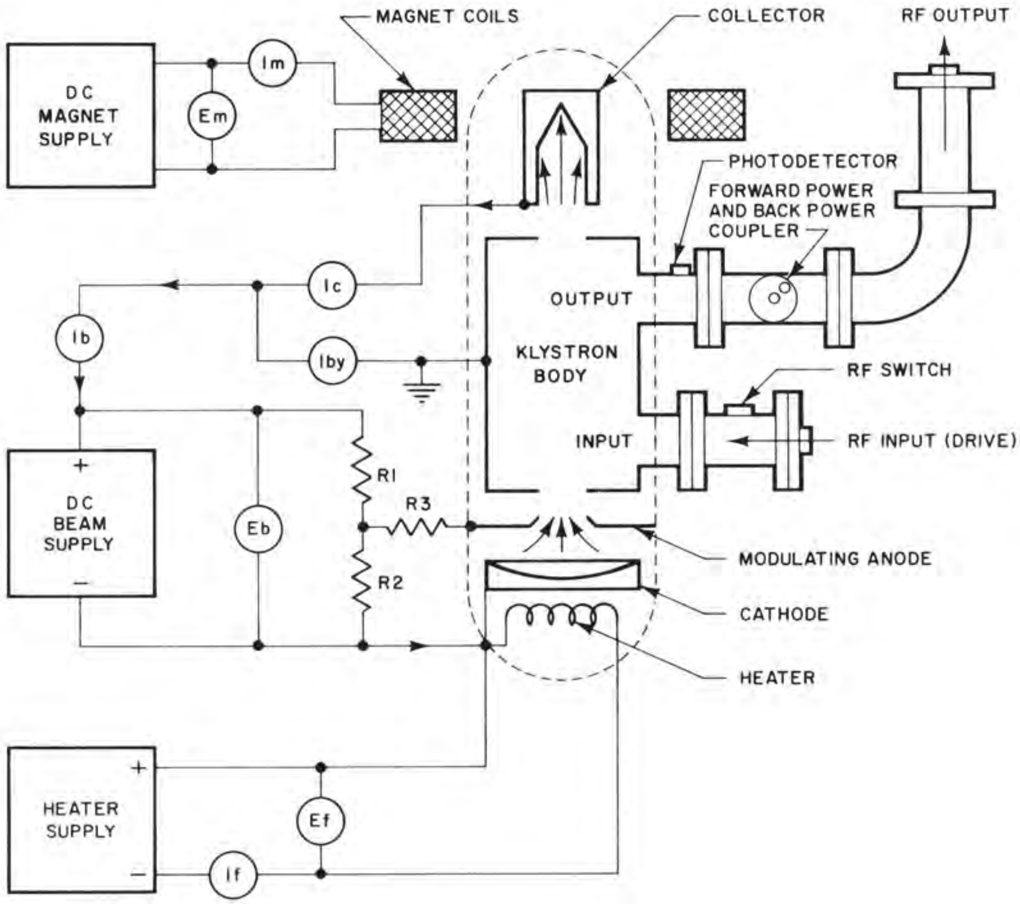

Figure 22

Power supplies, protective components, and metering.

The voltmeter (E_b) measures the beam voltage applied between the cathode and the body of the klystron.

Resistors R_1 and R_2 form a resistive divider which provides the necessary modulating anode bias voltage for aural service. Resistor R_3 is connected in series with the modulating anode. If an arc occurs between the cathode and the modulating anode, this series resistance limits the amount of surge current between the cathode and modulating anode.

Current meter (I_c) measures collector current. This is about 95%, or more, of the total current. Current meter (I_{by}) measures body current. This current should be less than 150 mA. An interlock set to interrupt the beam supply if the body current (I_{by}) exceeds its maximum rating can protect the klystron against magnet failures, overdriven conditions, arcing, etc. Check the individual Tube Data Sheet for the maximum allowable value of body current.

The sum of the body current (I_{by}) and collector current (I_c) equals the beam current (I_b), which should stay constant as long as the beam voltage and modulating anode voltage are held constant.

Magnet Supply

Electrical connections to the d-c magnet supply should be made in accordance with the applicable operating instructions. Two meters are shown, one for measuring current through the circuit (I_m), and one for measuring voltage (E_m). When a klystron is installed in the magnet, both parameters should be measured and recorded for future reference. If excessive body current or other unusual symptom should occur, as outlined under "Troubleshooting", these data will be valuable for system analysis.

Undercurrent protection should be provided to remove beam voltage if the magnetic circuit current falls below a preset value. This undercurrent interlock should prevent the beam voltage from being applied if the magnetic circuit is not energized. However, it will not provide protection if the coils are shorted. Shorted conditions can be determined by measuring the normal values of voltage and current and recording them for future reference.

The body-current overload protection should actuate if the magnetic field is reduced for any reason.

RF Circuits

Monitoring devices are shown on the rf input and output of the klystron. These monitors protect the klystron, should failures occur in the rf output circuit of the system. Two directional couplers and a photodetector are shown attached to the output of the klystron. These components and an rf switching device on the input form a protective network against output transmission-line mismatch.

The rf switch is activated by the photodetector or the backpower monitor and must be capable of removing the rf drive power from the klystron in less than 10 milliseconds.

In the rf output circuit, the forward power coupler is used to measure the relative power output of the klystron. The backpower coupler is used to measure the rf power reflected by the output circuit components, or antenna. Damaged components or foreign material in the rf line will increase the rf backpower. The amount of reflected power should be no more than 5% of the actual forward rf output power of the klystron. A properly located interlock can monitor the backpower so it will remove the rf drive to the klystron if the backpower reaches an unsafe level.

However, arcs occurring between the monitor and the klystron output window will be undetected by the backpower monitor. By placing a photodetector between this monitor and the window, light from an arc will trigger the photodetector which will actuate the interlock system and remove the rf drive before the window is damaged.

This network of couplers and light detectors has been used successfully with Varian tubes at CW power levels up to 500 kilowatts.

Ion Pumps

Some klystrons have VacIon® pumps which may also be used to monitor tube performance.

The pump continuously removes gas molecules and atoms from the vacuum envelope by forming chemically-stable compounds and by ion burial in the titanium structure illustrated in Figure 23.

Pumping is initiated by a positive high voltage between the gridded pump anode and the titanium cathode plates. Electrons flowing from the cathode, within the magnetic field provided by an external permanent magnet, are forced into a spiral path on their way to the pump anode. The greatly increased electron path length results in a high probability of collision between the electrons and gas molecules in the system. These collisions produce ions and more free electrons, forming a self-sustaining discharge. Positively charged ions are attracted to the cathode plates and titanium atoms are dislodged (sputtered). The free titanium atoms are deposited on the pump anode and form chemically-stable compounds with active gases such as oxygen and nitrogen. Inert gases are also removed by ion burial in the cathode and entrapment on the pump anode.

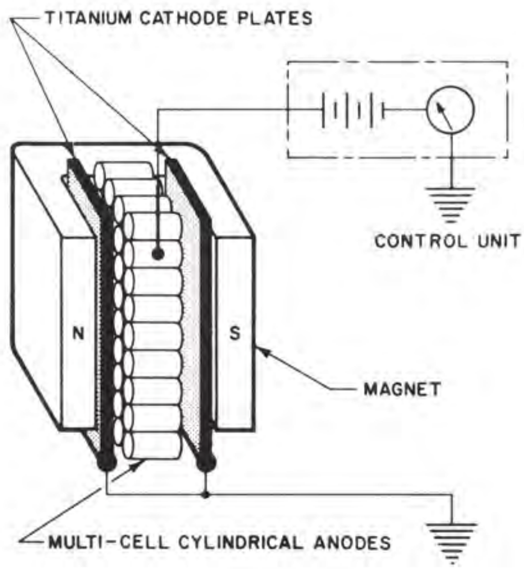

Figure 23

Schematic of an ion pump.

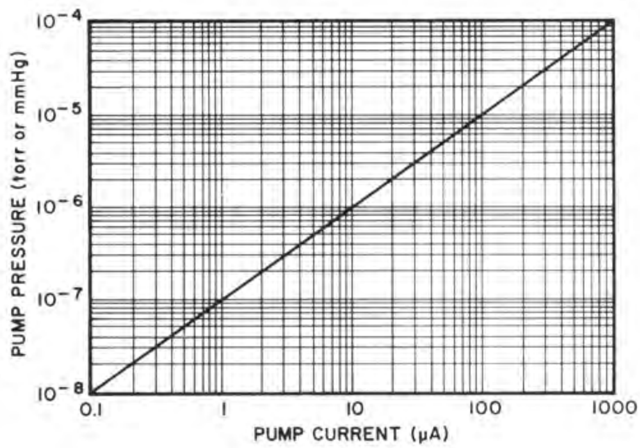

Figure 24

Relationship between pump pressure and pump current.

Ion pump current is proportional to the electron-atom collision rate and, hence, proportional to the pressure in the klystron. See Figure 24.

COOLING REQUIREMENTS

External-cavity klystrons for UHF-TV service require liquid cooling of the collector, body, and magnetic circuit. The cooling requirements for each tube type are specified on its individual technical data sheet.

To obtain satisfactory service from a liquid-cooling system, periodic maintenance of the system must be performed to prevent:

1. Scale and rust accumulation in the cooling lines.
2. Reduction of the coolant flow because of excessive pressure drop across the system.
3. Malfunction of flow interlocks because of corrosive and clogging action.
4. Clogging of critical heat transfer areas such as the body, magnet, and waterload.

Many of these occurrences can be prevented by using pure distilled water in a system that is clean and free of contaminants. If the liquid-cooling system is operating properly, the total foreign residue in the liquid will be less than 50 parts per million. Therefore, the cooling system should be cleaned and refilled with pure distilled water periodically in accordance with transmitter operating instructions.

Varian Application Engineering Bulletins AEB-26, AEB-31, and AEB-32 are available as guides for maintaining liquid cooling systems.

TUNING PROCEDURE

The procedure for tuning a UHF-TV klystron depends on whether it is to be used in aural or visual service. A synchronously-tuned klystron (all cavities tuned to the same frequency) has maximum gain and narrow bandpass. An efficiency-tuned klystron (next to the last cavity tuned above the carrier frequency for aural service) has a higher efficiency, i.e., more output power for a given beam voltage, but requires more drive power (8 - 10 dB) to achieve saturation. Bandwidth is somewhat greater than it is for synchronously-tuned klystrons. Broadband-tuned klystrons (cavities staggered in frequency for visual service) have about the same efficiency as efficiency-tuned klystrons, but the gain is lower still (4 - 8 dB).

First, we will discuss tuning the tube synchronously, then tuning for high efficiency (aural), and finally tuning the klystron for maximum bandwidth (visual service).

Whenever it is necessary to change the frequency of a klystron, such as shifting from visual to aural service, the tube should first be synchronously tuned at low drive power, then the drive frequency should be shifted while maintaining an indication of output power. At the new drive frequency, the tube should again be synchronously tuned before being adjusted for aural service. Synchronous tuning at the new frequency establishes the optimum setting for each cavity. From these cavity positions, the klystron can be properly tuned to the new type of service.

CAUTION
KEEP DRIVE LEVEL LOW
WHEN SYNCHRONOUSLY TUNING
ANY KLYSTRON AMPLIFIER OR
WHEN CHANGING ITS FREQUENCY

The drive level must be kept low so that the response of each cavity is sharp and the cavity can be tuned to the exact frequency desired. If the drive level is too high, the cavity response will be broad and it will be impossible to accurately tune the klystron cavities.

Synchronous Tuning

1. Physically center the split centering plate around the klystron.
2. Set the tuning cavities to the desired channel settings using the appropriate curves of Figures 25, 26, or 27.
3. Adjust the cavity loading loops to the coupling positions recorded on the Test Performance Sheet.
4. After the required warm-up time, apply up to 70% of the normal operating beam voltage.
5. Alternately adjust the split centering plate and magnet current until a minimum body current is obtained.

   Note: The magnet current should be within ± 10% of the operating value shown on the Test Performance Sheet.

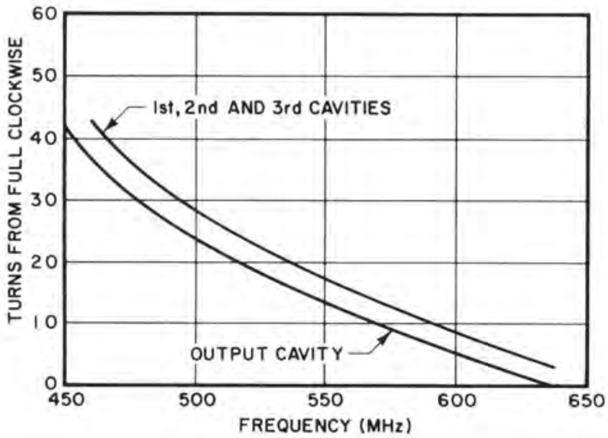

Figure 25

Cavity tuning curves for LA klystrons covering UHF-TV Channels 14 through 34.

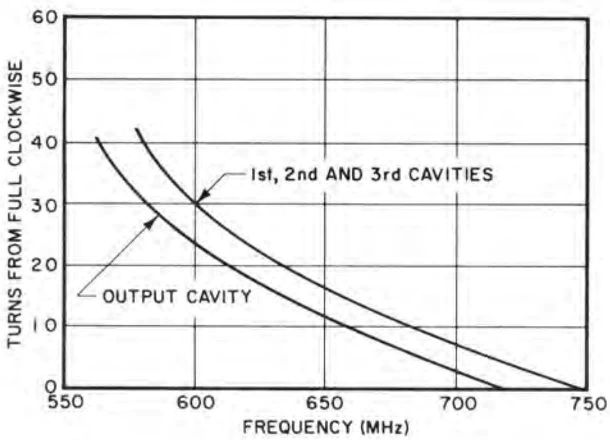

Figure 26

Cavity tuning curves for LF klystrons covering UHF-TV Channels 35 through 53.

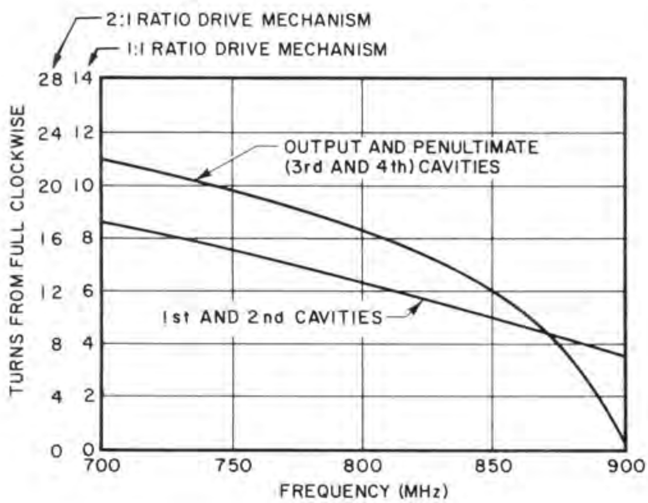

Figure 27

Cavity tuning curves for LH klystrons covering UHF-TV Channels 54 through 70.

6. Apply only enough rf drive power (about 1 watt CW) to obtain an output power indication on the power monitor or oscilloscope.
7. Match the input cavity impedance to that of the rf drive power by adjusting the input coupling loop and input cavity tuning. This match is achieved when the reflected power from the input cavity is minimum.
8. Tune the cavities in order, cavity one, cavity two, three, etc., for maximum indicated output power.

As each cavity is tuned, the output power increases very rapidly as you progress from cavity to cavity. Because of this increase in gain, the drive level must be lowered to keep the cavity response sharp. A rough rule-of-thumb is keep the drive low enough so that the output power is at least 6 dB below the normal operating rf output power.

Synchronous Tuning to Shift Frequency

1. Reduce the beam voltage to about 70% of the normal operating value.
2. Apply enough rf drive to the klystron to get a power reading on the power monitor or oscilloscope.
3. Change the driver frequency in the desired direction until the output power indication just disappears then return the rf drive frequency until there is a small indication of output power.
4. Tune the cavities, in order, for maximum power response.
5. Repeat these steps of changing rf drive frequency and retuning the cavities until the desired operating frequency is reached.

CAUTION
NEVER TUNE THE CAVITIES
WITHOUT A POWER INDICATION
ON A METER OR SCOPE.

Having reached the desired operating frequency, the klystron may now be tuned for either aural or visual service by the following methods.

High Efficiency Tuning for Aural Service

1. Synchronously tune the klystron to the desired carrier frequency, as described above.

2. Carefully increase the rf drive until maximum output power is reached (tube saturation). Do not increase the drive further at this time, as the body current will increase to values which can cause ion current or damage to the internal structure of the klystron and could poison the cathode, shortening the klystron's useful life.

3. If necessary, adjust the magnet current to keep the body current below the maximum value specified on the Test Performance Sheet.

4. Tune the penultimate cavity (next to the output cavity) five or more turns higher in frequency (clockwise) or until the output power drops 6 to 10 dB. Do not adjust the first or second cavities. If either cavity is adjusted at this point, the klystron must be synchronously retuned to regain the desired frequency.

CAUTION
NEVER TUNE THE PENULTIMATE CAVITY TO A FREQUENCY LOWER THAN THAT WHICH PRODUCES MAXIMUM OUTPUT. EXCESSIVE VOLTAGE IN THE PENULTIMATE CAVITY AND ARCING CAN RESULT.

5. Adjust the output cavity tuning until maximum output power is obtained.

6. Raise the beam voltage to the desired operating level.

7. Increase the drive level again until maximum output is obtained (tube saturation).

8. If necessary, adjust the magnet current again to make sure the body current stays below its maximum rating.

9. If the output power is too low, retune the penultimate cavity for maximum output power. Tune clockwise first to increase the cavity frequency. If the output power decreases, then tune counterclockwise until maximum output power is obtained.

10. Readjust the output cavity tuning and magnet current for maximum output power. The magnet current should be within ± 10% of the operating value indicated on the Test Performance Sheet.

11. Finally, adjust the output coupling for maximum output power; then increase the coupling until the output power reduces between 5 and 10%. (See Figure 28).

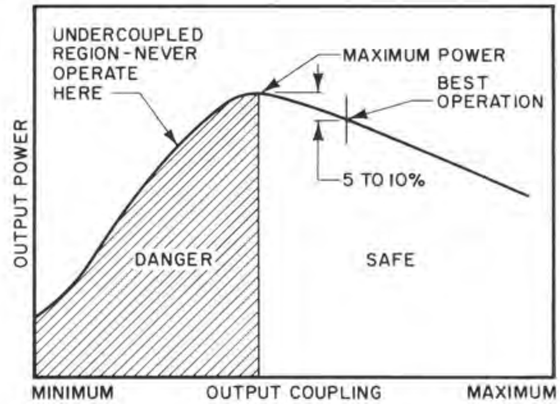

Figure 28

Adjustment of output coupling control.

Broadband Tuning for Visual Service

Before attempting to tune the klystron for visual service, refer to the transmitter manufacturer's manual.

Figures 29 through 32 illustrate the relative output power response to be expected at various stages during tuning under grey-level conditions.

A general broadband tuning procedure is to:

1. Synchronously tune the klystron to the desired visual carrier frequency, as described above. The output power response should be similar to Figure 29.

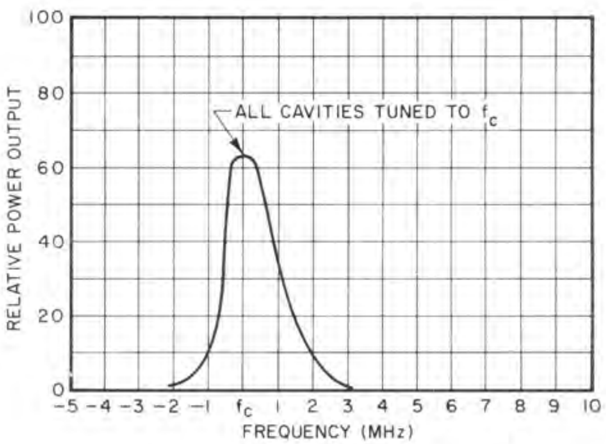

Figure 29

Response curve with synchronous tuning.

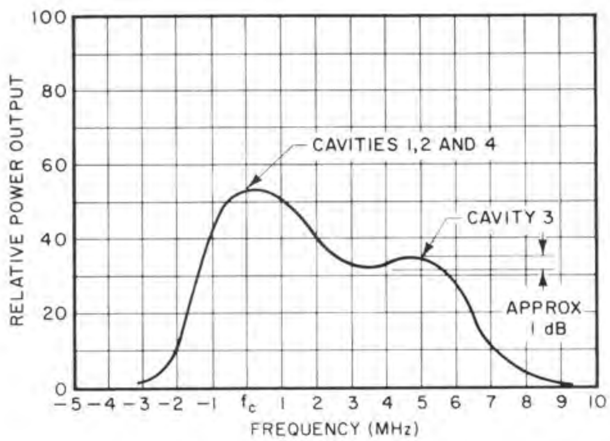

Figure 30

Output response with the penultimate cavity tuned 5 MHz above the carrier frequency.

2. Detune the penultimate cavity approximately 5 MHz above the carrier frequency. See Figure 30.

3. Detune the second cavity 1-1/2 MHz below the carrier frequency for the response shown in Figure 31.

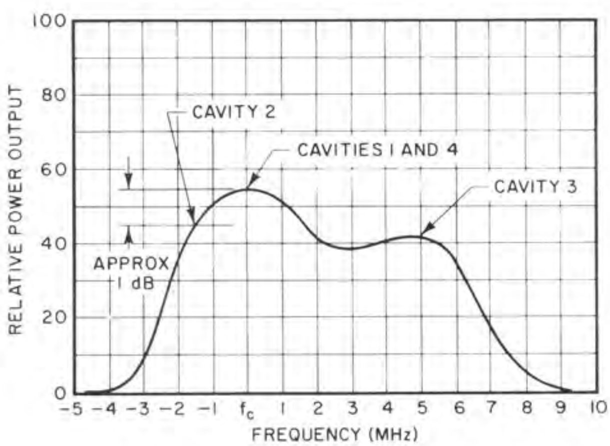

Figure 31

Response obtained when both penultimate and second cavities are detuned.

4. Detune the first cavity about 2 MHz above the carrier frequency. This should produce a response curve similar to Figure 32.

5. Raise the beam voltage to the operating level.

6. Increase the drive power until the desired output power is reached, i.e., mid-characteristic level, full peak power level, or other level suggested by the transmitter manufacturer.

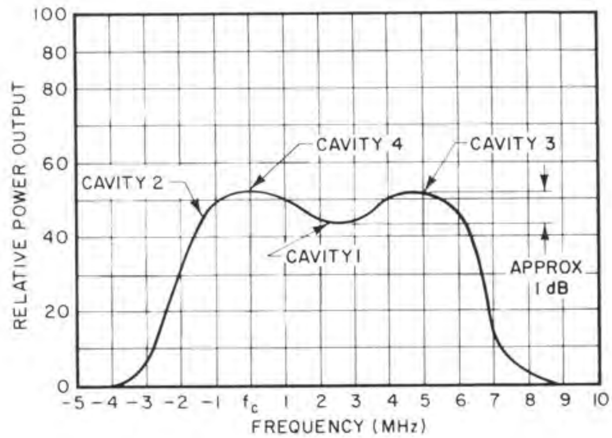

Figure 32

Response obtained when first, second, and penultimate cavities are detuned.

7. Adjust the individual cavities to make minor bandpass corrections: input or output cavities for slope, second and/or third cavities for edge effect and "holes". If this is done carefully under swept conditions, no additional cavity tuning is needed when a stairstep or multi-burst signal is applied to the carrier.

8. Adjust all load couplers until the response shown in Figure 33 is obtained. Note that the bandpass is flat and linear between white and blanking levels but peaks toward the visual carrier at peak-of-sync and saturation.

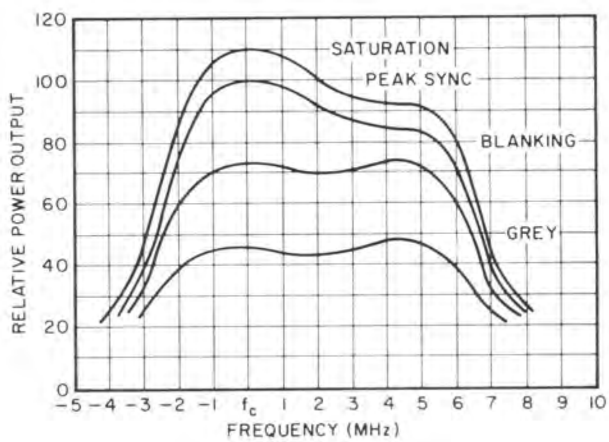

Figure 33

Output response for a klystron properly tuned for visual service.

For your guidance, Figures 34 through 37 show the various response curves which may result from improper loading. The usual cause for each curve is included under each figure.

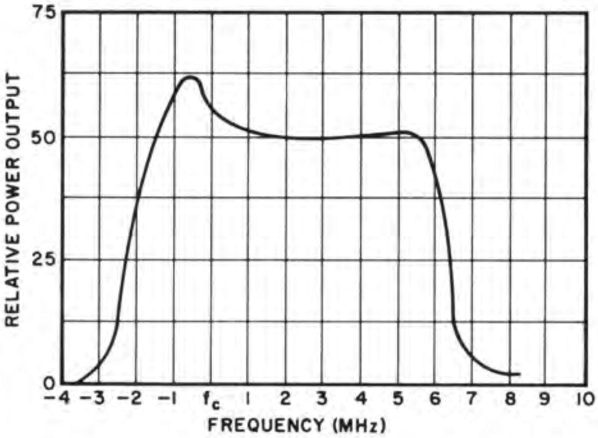

Figure 34

Second cavity is too lightly loaded or the third cavity is too heavily loaded.

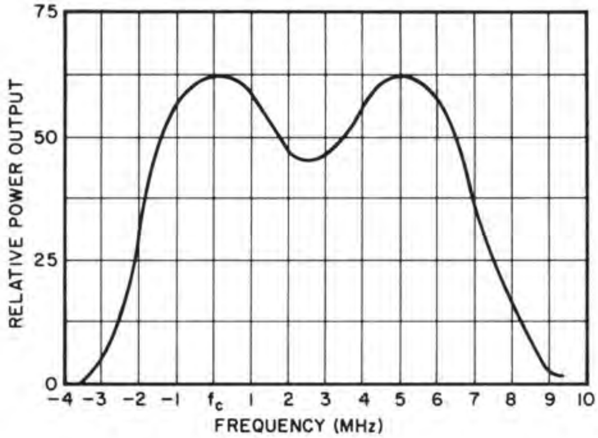

Figure 37

First cavity is too lightly loaded or the drive coupling needs adjusting.

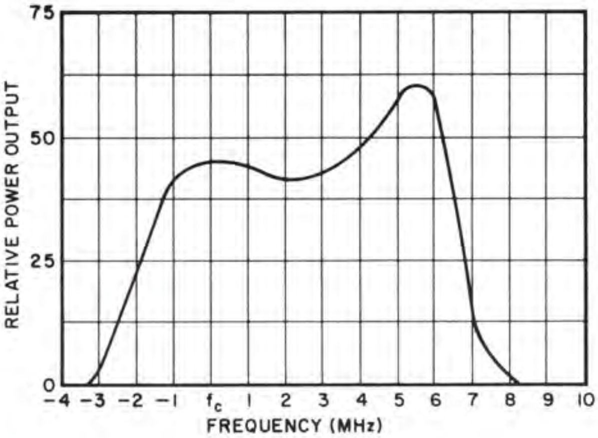

Figure 35

Third cavity is too lightly loaded or the second cavity is too heavily loaded.

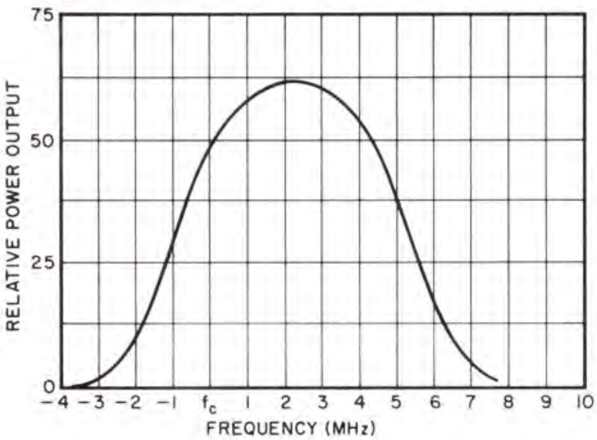

Figure 36

First and/or second cavity are too heavily loaded.

9. Adjust the output coupling until maximum output power is obtained; then increase the coupling until the output power reduces between 5 and 10%. Refer to Figure 28.

Your klystron is now tuned for use as a final visual amplifier.

Balancing Two Klystrons for Visual Service

Each klystron should be tuned and set for operation individually, as described in the previous section. Final adjustments are for combined operation and are easy to make.

The purpose of these final adjustments is to:

1. Match the gain slope of the two klystrons while they are being driven from white to blanking level.
2. Match the rf power output from the combined klystrons.
3. Match the output phase of the klystrons.
4. Minimize the power dissipated in the balance loads.

One procedure is as follows:

1. Combine the output power of the two klystrons into a dummy load.
2. Drive the klystrons simultaneously with swept signals of equal amplitude to each tube.
3. Start at a low level and slowly increase the rf drive, observe the combined swept

response as well as the balance load meter for minimum power.

4. Adjust the phase-balancing network in the drive line to one of the klystrons for minimum power in the loads.

5. If the power of the individual klystron does not increase at a uniform rate, small adjustments of the second or penultimate cavity of either klystron should be enough to balance the combined output.

Another procedure is to individually sweep each klystron, at the mid-characteristic level, into a dummy load through a combiner, filters, etc. Tuning in this manner will result in power being dissipated in the balance load. If the individual klystrons are tuned so that the power into the dummy load and balance load are the same for each klystron, the combined power and gain should be correct. At this point, minor adjustment of the second, or penultimate cavity of either klystron will balance the combined output.

In either case, the amount of adjustment to either klystron should be minimal. Again, all tuning should be done under swept conditions. Adjustment with a stairstep or multiburst is not desirable.

TROUBLESHOOTING

The following information may be of assistance when troubleshooting a system. It is a summary of common problems or failures and some of their causes.

RF Power Measuring Equipment should be accurately calibrated before attempting to measure the rf power from a UHF-TV klystron. A simple method is to compare the power value indicated on the rf power measuring device with the power absorbed in a high-power water load connected to the klystron output. The power absorbed in the water load can be calculated from:

$$P = 0.264\ (Q)\ \Delta T$$

P = Power in kilowatts
0.264 = Constant for pure water at 30°C
Q = Flow in gallons per minute
ΔT = Difference between inlet and outlet water temperature in °C

RF Backpower is an indication of the impedance match (VSWR) between the klystron rf output and its load. Increases in rf backpower should be investigated before a component failure occurs. Continued operation with high rf backpower may cause arcing and window heating, with a chance of catastrophic damage to the klystron.

Increase in Coolant Pressure Drop for a given flow rate generally indicates clogged coolant channels. Cleaning the channel is imperative. Failure to do so will cause klystron instability and overheating.

CAUTION
ALWAYS BY-PASS KLYSTRON AND MAGNET WHEN BACK-FLUSHING SYSTEM

High Heater Current for a given heater voltage indicates possible heater shorting or, coupled with an inability to apply beam voltage due to ac/dc overloads, loss of vacuum.

Low Beam Current for a given modulating-anode voltage usually indicates the approach of cathode emission end-of-life. Low emission can sometimes be temporarily overcome by increasing the heater power 5 to 10%.

Magnet Voltage for a given current through the magnet coils can be used to indicate magnet circuit malfunctions. Increases in voltage may signal coolant problems or loose connections. Decreases in voltage may result from shorts. The causes for these voltage changes must be corrected, since uniform current is not passing through all the magnet coils and the klystron can be damaged because of reduced magnetic field.

RF Output Power measured at both ends of the rf output transmission line, can be used to determine mismatches and losses in the output line. High losses in the components, usually caused by impedance mismatch, can cause dangerous heating and possible component failure.

Symptoms and Causes

SYMPTOM	CAUSE
HIGH BODY CURRENT	1. Magnet current set too low.
	2. Magnetic materials too close to tube.
	3. Rf drive power level set too high and tube is operating in overdriven region.
	4. Poor beam optics due to low heater voltage.
	5. Centering plate improperly adjusted.
LOW OUTPUT POWER	1. Low beam current.
	2. Rf drive power level set too low.
	3. Tube not properly tuned.
	4. Improper magnetic field.
	5. High VSWR between klystron and load.
	6. Output coupling loop improperly adjusted.

SYMPTOM	CAUSE
LOW BEAM CURRENT	1. Low beam voltage. 2. Modulating anode not connected. 3. Modulating-anode voltage set too low. 4. Heater voltage set too low.
NO BEAM CURRENT	1. Beam supply malfunction. 2. Modulating anode connected to cathode. 3. Heater voltage off or heater open. (If the heater is open, check output window; tube may have loss of vacuum.)
NO HEATER CURRENT	1. No heater voltage at tube. 2. Open heater.
HIGH HEATER CURRENT	1. Heater voltage too high. 2. Tube is down to air (check output window). 3. Heater may be shorted internally. 4. External short at heater connection.
THERMAL DETUNING	1. Water flow set too low. 2. Tube is detuned. 3. Rf drive level set too high. 4. Magnetic materials too close to tube.
RF LINE AND KLYSTRON CAVITY ARCING	1. Foreign material in rf output coaxial transmission line. 2. High VSWR in rf output coaxial transmission line. 3. Flange connections are poor. 4. Output coupling loop undercoupled.
FIRST CAVITY WILL NOT TUNE	1. Melted drift tubes caused from magnetic field failure. 2. Input coupling loop improperly adjusted. 3. Defective input power cable. 4. Defective input power coupler. 5. No drive power.
OUTPUT OR PENULTIMATE CAVITY WILL NOT TUNE	1. Rf drive level is set too high. 2. Cavity tuned too far from driver frequency. 3. Melted drift tubes caused from magnetic field failure.

SYMPTOM	CAUSE
TUBE OSCILLATES	1. Rf input and output connections not terminated properly. 2. High VSWR in rf output coaxial transmission line. 3. Penultimate cavity tuned too close to carrier frequency. 4. Output coupling loop undercoupled.
NARROW BANDWIDTH	1. High VSWR in rf output coaxial transmission line. 2. Improper tuning of tube. 3. Defective cavity loads.
LIQUID COOLANT BOILING — BODY, COLLECTOR, AND/OR MAGNET	1. Water flow too low or coolant channel blocked. 2. Inlet coolant temperature too high. 3. Coolant contaminated. 4. Dc input power too high.
LOW GAIN	1. Tube is improperly tuned. 2. Beam voltage set too low. 3. Improper magnet current.
ABNORMAL OR NONSYMMETRICAL BANDPASS RESPONSE	1. Rf drive level set too high. 2. Cavities improperly tuned. 3. High VSWR in output coaxial transmission line. 4. Improperly aligned driver. 5. Improper adjustment of load couplers. (See Figures 34 through 37.)
AC/DC OVERLOADS (INTERNAL ARCING)	1. Transient in power supply. 2. Heater voltage set too low. 3. Beam voltage set too high. 4. High VSWR in output coaxial transmission line. 5. Tube down to air.

System Induced Tube Failures

The reason for failure of a klystron is often written on service reports as a cracked window, open heater, burned paint on the collector, etc. Before installing a new tube in a system, check the condition of the removed tube and, if possible, determine the type of failure. If the failure is listed below, check the system as indicated.

FAILURE	CHECK FOR
OPEN HEATER	1. Broken tube ceramic. 2. Value of heater voltage at heater terminals. 3. Insulation breakdown of heater supply to ground. 4. Heater supply transients.
BROKEN OUTPUT CERAMIC	1. Foreign materials in rf output coaxial transmission line. 2. High VSWR in rf output coaxial transmission line. 3. Poor flange mating. 4. Mechanical stress at tube ceramics. 5. Damaged components in coaxial transmission line. 6. Malfunction of protective system, i.e., reflected power (VSWR) monitor or photodetector. 7. Loss of cavity cooling air.
MELTED DRIFT TUBE	1. Discoloration of the paint around the body. 2. Excessive drive power. 3. Low or no body coolant flow. 4. Body coolant inlet temperature too high. 5. Inadequate magnetic field. 6. Defective power supply circuit breakers.
BROKEN PENULTIMATE CAVITY CERAMIC	1. Penultimate cavity tuned at or through resonant frequency, to a lower frequency. 2. Excessive drive power. 3. Loss of cavity cooling air.

NOTES

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