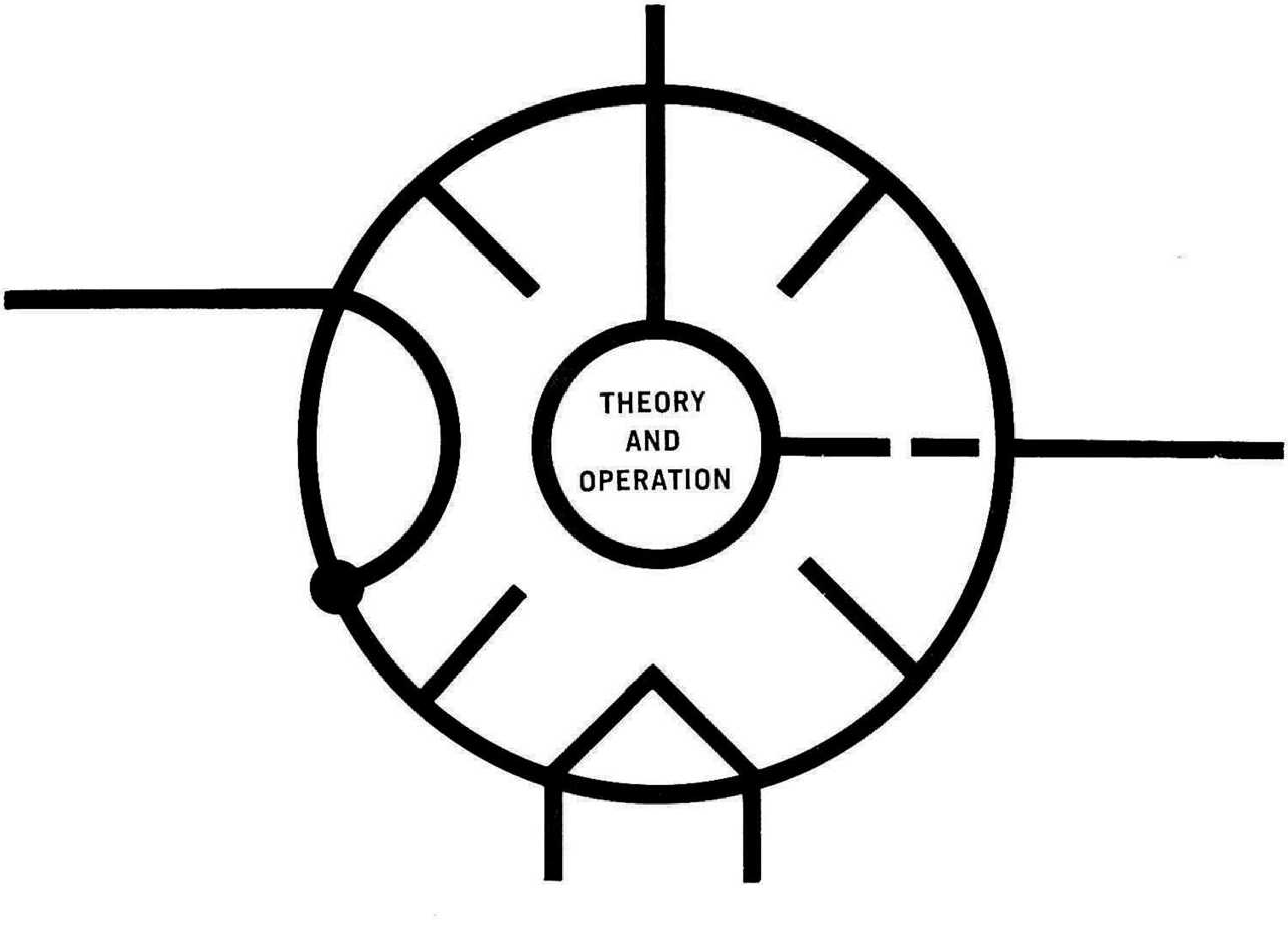
ELECTRONIC
INNOVATIONS
IN ACTION

voltage tunable magnetrons



TUBE DEPARTMENT
GENERAL ELECTRIC

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ILLUSTRATIONS:

VTM's: what are they?

Voltage Tunable Magnetrons (VTM's) are high frequency, continuous wave oscillators operating in the microwave region. General Electric VTM's cover a wide range of frequencies—from a few hundred to over 5,600 megacycles, and their capability has been demonstrated up into the X-band region.

Power output of voltage tunable magnetrons begins at tens of milliwatts and can be extended through hundreds of watts. General Electric has, in fact, attained 500 watts of power in the laboratory, and even higher levels are feasible depending on the center frequency and bandwidth being used.

A packaged voltage tunable magnetron consists of three elements:

(1) a basic vacuum tube wherein a conversion of d-c power into radio-frequency power occurs in the interaction region.

(2) an r-f circuit or cavity which presents the required impedance to the tube over the desired bandwidth.

(3) a permanent magnet which provides the required magnetic field.

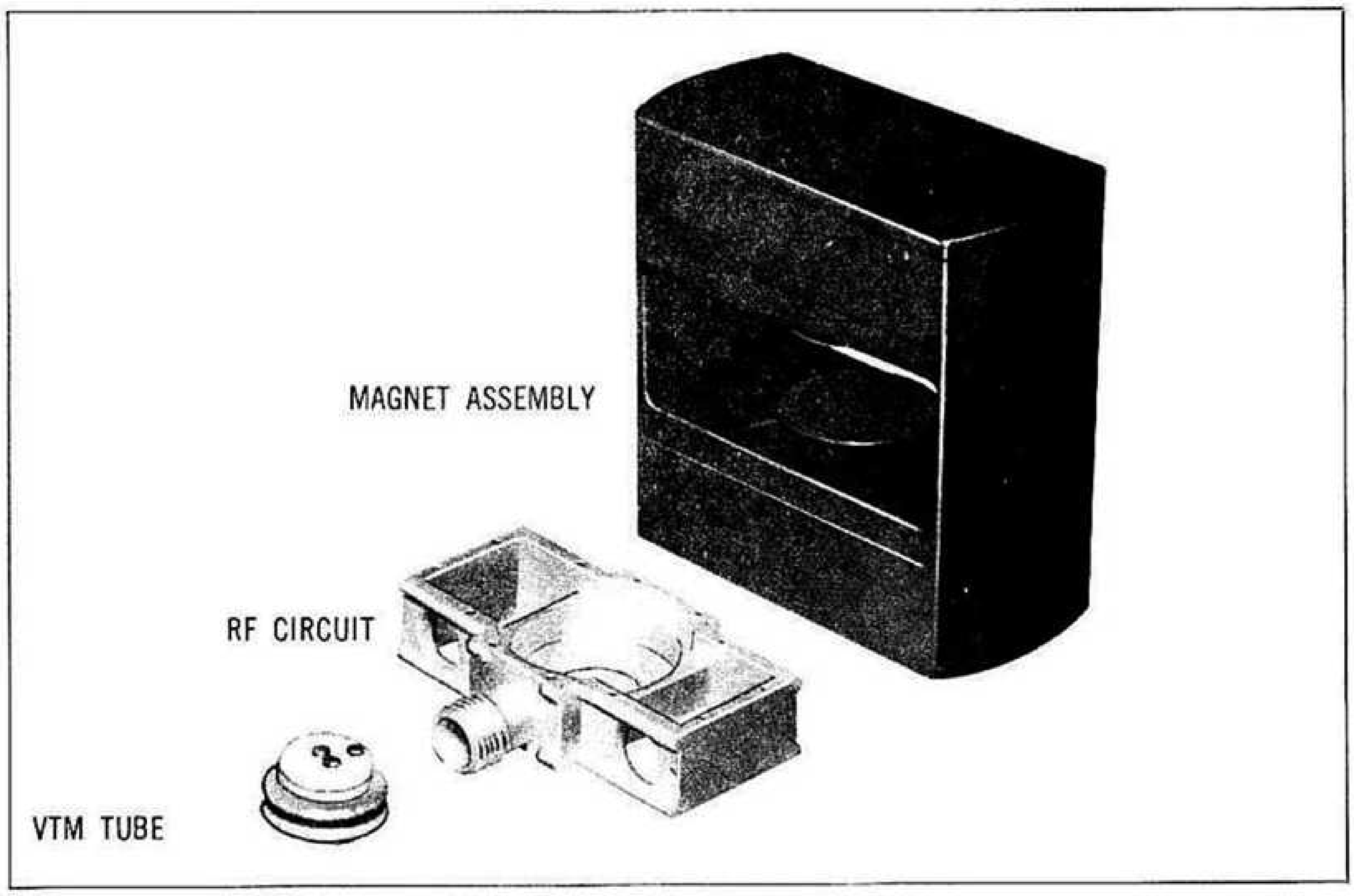


Figure 1—Elements of a Typical VTM

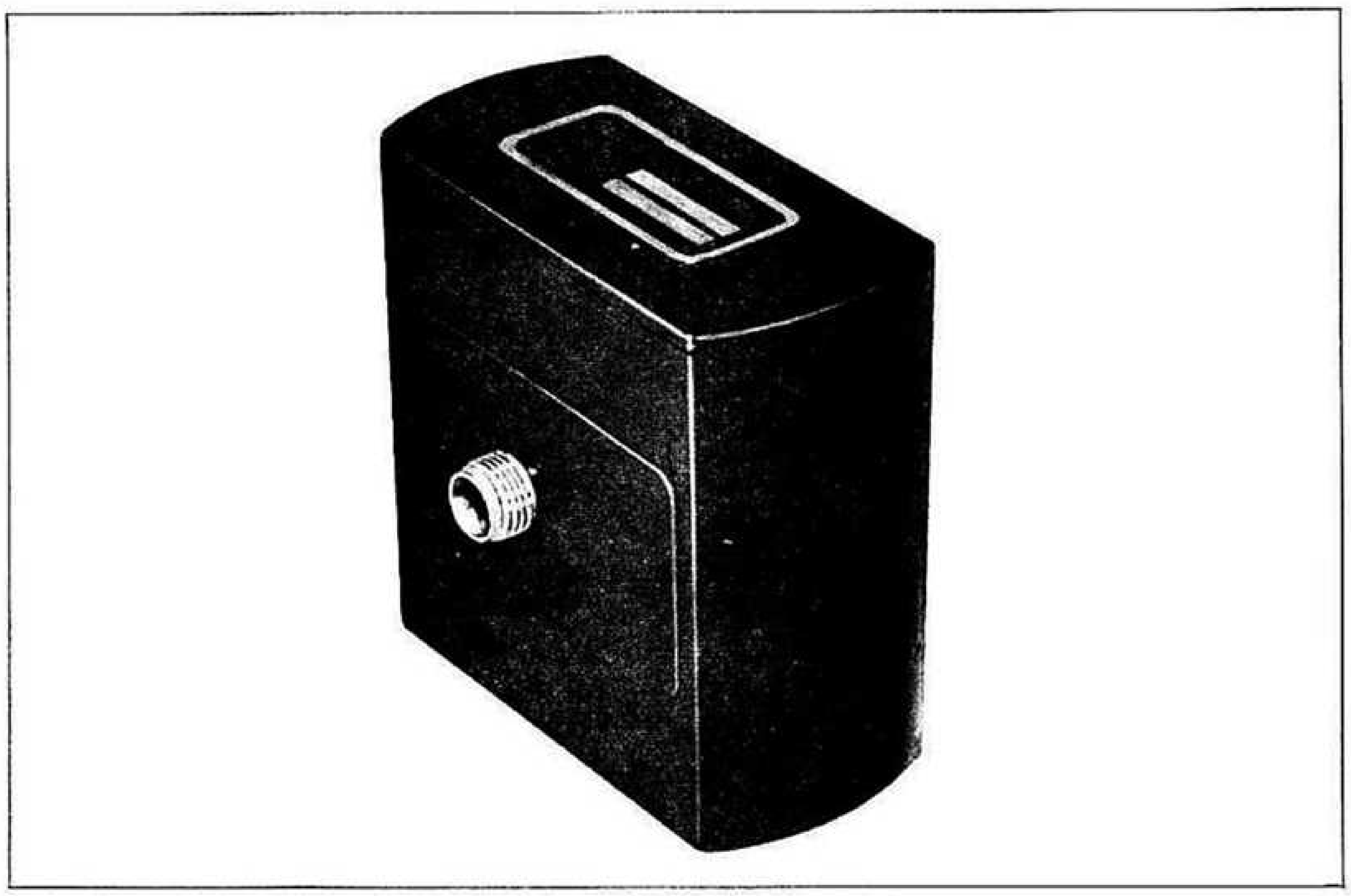


Figure 2—Typical VTM Assembly

KEY FEATURES AND ADVANTAGES

Essential features which distinguish a VTM from a conventional magnetron are:

(1) an r-f circuit loaded down to a very low Q.

(2) an electron current limited to a value less than the normal space-charge-limited (BRILLOUIN) current.

When these conditions are met, the oscillation frequency becomes a function of the anode voltage, rather than of the circuit resonant frequency.

Specific advantages of VTM's, in addition to their electronic tuning features, are:

(1) Rapid Modulation—VTM's are capable of being frequency-modulated at high rates. Sweeping rates up to 20,000 mc per microsecond have been attained.

(2) Linear Tuning—the VTM has a tuning characteristic (or frequency vs. anode voltage) which is not only linear, but also proportional. This means the tuning line passes through, or close to, the origin; hence, a good approximation to the tuning sensitivity (mc per volt) can be achieved simply by dividing the center voltage into the center frequency. Since this proportionality is an intrinsic characteristic of a VTM, one cannot specify center frequency, center voltage, and tuning sensitivity independently. For octave band tubes, the actual tuning curve is normally within ±1% (in units of center voltage) from the best straight line, and this line will pass within two or three per cent of the origin.

(3) Low Noise—the VTM can be constructed for low noise operation. IF noise, 30 mc from the carrier, may be approximately 95 db/mc below the carrier signal level.

(4) High Efficiency—high powered VTM's (75 watts and up) attain conversion efficiencies of 65 to 70 per cent.

(5) Size and Weight—VTM's operating at 10 watts over 35% bandwidths are available in one-pound packages. Size is 1⅝ inches in diameter and 1⅝ inches high in a cylindrical shape. At other levels, weight varies roughly as the square root of the power.

(6) Power Variation Across the Band—VTM power variations across an octave band can be restricted to four decibels with the use of a matched load or adequate isolation.

In addition to these features, the VTM can be made adaptable to airborne and space application environments where extremes in shock, vibration and temperature all may be encountered.

VTM TYPES AND GENERAL ADVANTAGES

The VTM family is divided into three major groups: the low power group of tubes up to one watt in power output, the intermediate group with a power output of one to ten watts and the high power VTMs ranging from tens to hundreds of watts.

The low power group is most often used in low noise applications for local oscillators, electronically tunable signal sources, test equipment such as signal generators and on wide band receivers requiring frequency agility.

The intermediate power VTM is an excellent device for fusing, altimetry, telemetry and parametric pump applications.

High power VTMs are used in ECM barrage jamming, broadband transmitters and missile and aircraft applications where their high efficiencies can be exploited.

VTMs are usually custom developed to perform one particular function in one specific application. Experience on past programs has shown that when pertinent system knowledge is obtained prior to VTM construction the result is an economic, well integrated system device.

Part of the construction procedure used to obtain optimum VTM performance for a given application lies in correctly orienting the vacuum tube-cavity combination with the magnetic field generated by the magnet. Emphasis is placed on gaining the best performance for those parameters most important to the application. This is how a VTM is customized for maximum performance at the factory. The importance of tailoring the VTM to its specific application cannot be overemphasized. Careful discussion and compiling of specifications for VTM operation is the only logical first step toward obtaining a satisfactory device; hence the potential user of a VTM is urged to follow this procedure.

general theory

CROSSED FIELD ACTION

The conventional high Q magnetron is a cylindrical diode wherein the electron current from the cathode is influenced by a magnetic field parallel to and coaxial with the cathode, and acting at right angles to the applied radial, electric field. When electrons travel in a direction perpendicular to the magnetic field, the field imposes a force at right angles to the direction in which the electrons are moving. This causes the electrons to spiral into orbit at a velocity directly proportional to the electric field applied between cathode and anode, and inversely proportional to the magnetic field. An illustration of this effect appears in Figure 3.

BUNCHING

Random noise present in the tube induces some radio-frequency voltage on the anode segments. This, in turn, tends to modulate the electron beam and build up the intensity of the radio-frequency fields on the anode structure. Figure 4 depicts three electrons rotating in the interaction space at an instant when adjacent anode segments are negatively and positively charged.

Here, electron A is moving in a reduced electrical field region caused by the radial component of the radio-frequency electric field acting in opposition to the d-c electric field. Thus, its velocity is decreased. Electron B is passing through an area of unmodified radial electric field; therefore, it maintains its initial velocity. Finally, electron C's velocity is advanced since it is moving in a higher electrical-field region where the radial radio-frequency field augments the applied d-c field. For this reason, electrons A and C tend to close in on B; furthermore, the same effect occurs at every position around the anode where the field orientations are the same as at B. Thus, the electrons form into a number of bunches equal to one-half the number of anode segments in the interaction space.

At each of these bunch positions (such as at B) there is a tangential r-f field, tending to retard the bunch. However, just as the radial field causes electrons to move tangentially in a magnetron (as in Figure 3), so a tangential field causes them to move radially. Thus the effect of the retarding force on the bunch is not to slow it down; rather it is to make the electrons move out towards the anode, lose potential energy, and contribute energy to the r-f field as they do so.

(Note that the average angular velocity of an electron around the cathode is proportionate to the d-c radial electric field on that electron.)

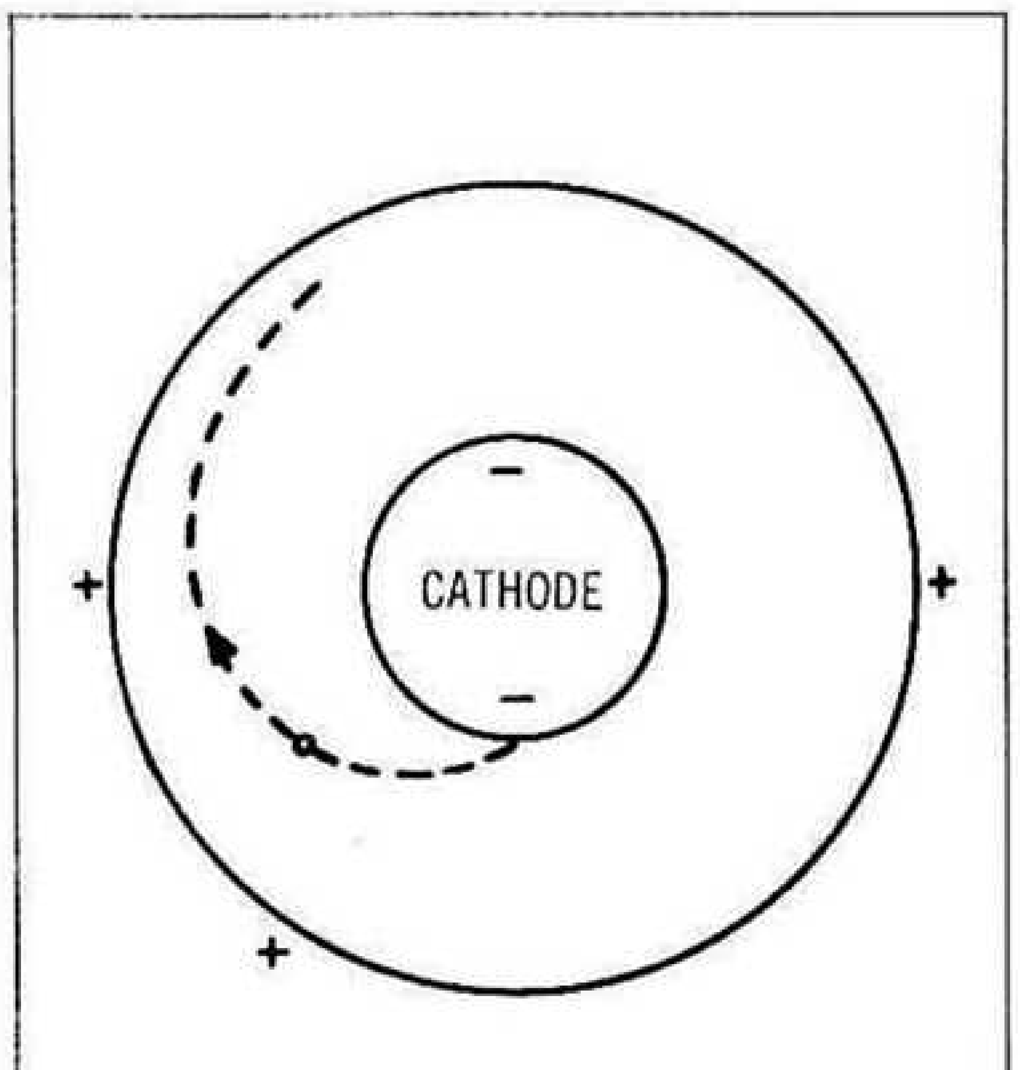


Figure 3—Electron Orbit

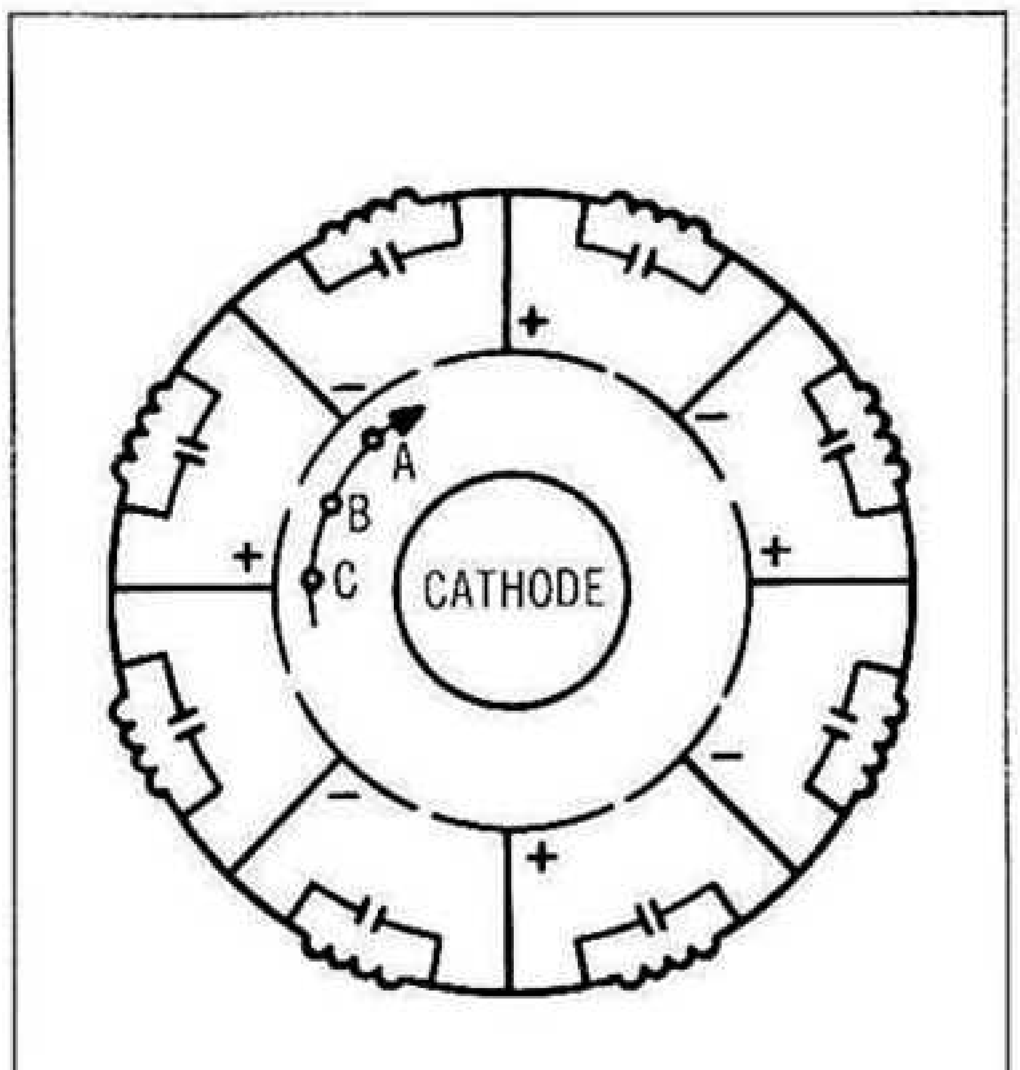


Figure 4—Electron Bunching

R-F POWER GENERATION

The continuous passage of these electron bunches past the anode induces radio-frequency fields on the anode structure. For voltage tunable magnetrons, the frequency of these fields is controlled by the average electron velocity; hence, by the anode voltage.

Interactions in a voltage tunable magnetron are similar to those in a high-Q magnetron in that an emitter produces electrons which enter into an interaction space, become bunched, and induce radio-frequency fields in an anode structure. In wide band voltage-tuned operation however, the r-f beam reactive current component is used to tune the circuit; therefore, the magnitude of the circulating beam reactive current component must be of the same order of magnitude as the circuit reactive current. This condition may be satisfied, and reasonable output powers produced, by using a heavily loaded (or low Q) radio-frequency anode circuit. Also the number of electrons injected into the interaction space is limited in order to facilitate the bunching process.

LOW Q CIRCUIT

Figure 5 shows an equivalent circuit of a magnetron. X_e is the reactive effect of the electron beam in the interaction space. C and L represent all capacitances and inductances in the magnetron and external circuit. R represents purely resistive loading and tube losses (although in many cases a reactance would be included in series with the R).

With fixed frequency magnetrons, the stored energy in the resonant circuit is very large; consequently, the effect of I_c and I_L is very large with respect to I_b, and the beam reactance, X_e, will have little effect on the change of frequency. For this reason, in a high Q magnetron, an increase in anode voltage causes considerable increase in anode current and power output, but only a slight change in frequency. As the Q of the external circuit is lowered, a corresponding decrease occurs in I_c and I_L with respect to I_b. Space-charge reactance, X_e, then has a continually greater effect on frequency determination.

One condition for oscillation is that all reactive current components must add up to zero. The reactive components in the interdigital and external portions of the circuit can accomplish this only at discrete frequencies; hence, the reactive portion of the beam current must be sufficiently large to satisfy this condition over the entire tuning range. One practical way to express the result of this phenomenon would be to say that the frequency is determined by the rate of rotation of the electron bunches around the cathode post. Their average angular velocity is controlled by the ratio of the d-c anode voltage to the magnetic field strength, V/B. By maintaining magnetic field strength at a constant value, the average angular velocity of the electron bunches past the interdigital fingers of the anode structure may be varied by changing the anode voltage. A linear relationship is then established between frequency and applied d-c voltage.

LIMITING ELECTRON INJECTION

To obtain wide-band voltage tuning, the circuit reactive current is reduced to the same order of magnitude as the circulating beam reactive current by operating at a low r-f voltage. A low Q anode circuit is then used to obtain power output over wide bandwidths. Since low r-f operating voltage increases the difficulty in bunching the electrons, the number of electrons injected into the interaction space is limited. Without this limitation, the excess space charge would saturate and prevent the low r-f electric fields in the anode interaction space from properly bunching the electrons.

INJECTION SYSTEM

The injection system for a voltage tunable magnetron is represented in cross section in Figure 6. The filamentary cathode is the original source of electrons. The injection electrode acts to accelerate and control the number of electrons entering the interaction space. The cold cathode in conjunction with the anode forms an interaction region where the d-c electron energy is converted into r-f power. In addition, the cold cathode plays an important part in the electron injection system, as illustrated in Fig. 7.

Electrons injected into the tube enter the interaction space. Those entering in the incorrect phase absorb a small amount of energy and are immediately collected on the cold-cathode to produce the relatively high current from the hot to the cold cathode. This current is collected at such low voltage, however, that it represents a negligible power loss (typically about 1% of the anode power in the 75-watt S-Band tubes). Those electrons which do enter in correct phase then constitute bunches which remain focused as they give up a large portion of their energy to the circuit; and they are then collected on the anode.

CATHODE BACK BOMBARDMENT

Not all the electrons in the interaction space contribute to the radio-frequency power output. Depending on their position and on the phase of the radio-frequency voltage on the anode segments, some electrons absorb radio-frequency energy which increases their velocity and causes them to bombard the cold-cathode post.

These electrons dissipate energy producing backheating at the cathode post. They also contribute to the cold-cathode current (referred to in the discussion of the injection system). This energy is relatively small, however, compared with the total generated radio-frequency power.

Since the emissive cathode area is removed from the interaction area, this surface is not exposed to the full back-bombardment current as in a conventional magnetron. Some electrons are directed, however, so that they do collide with the emissive cathode area. In specific instances, it may be necessary to reduce cathode power in order to compensate for added back-bombardment heating. A more detailed discussion will be found in the section on filament supply on page 6.

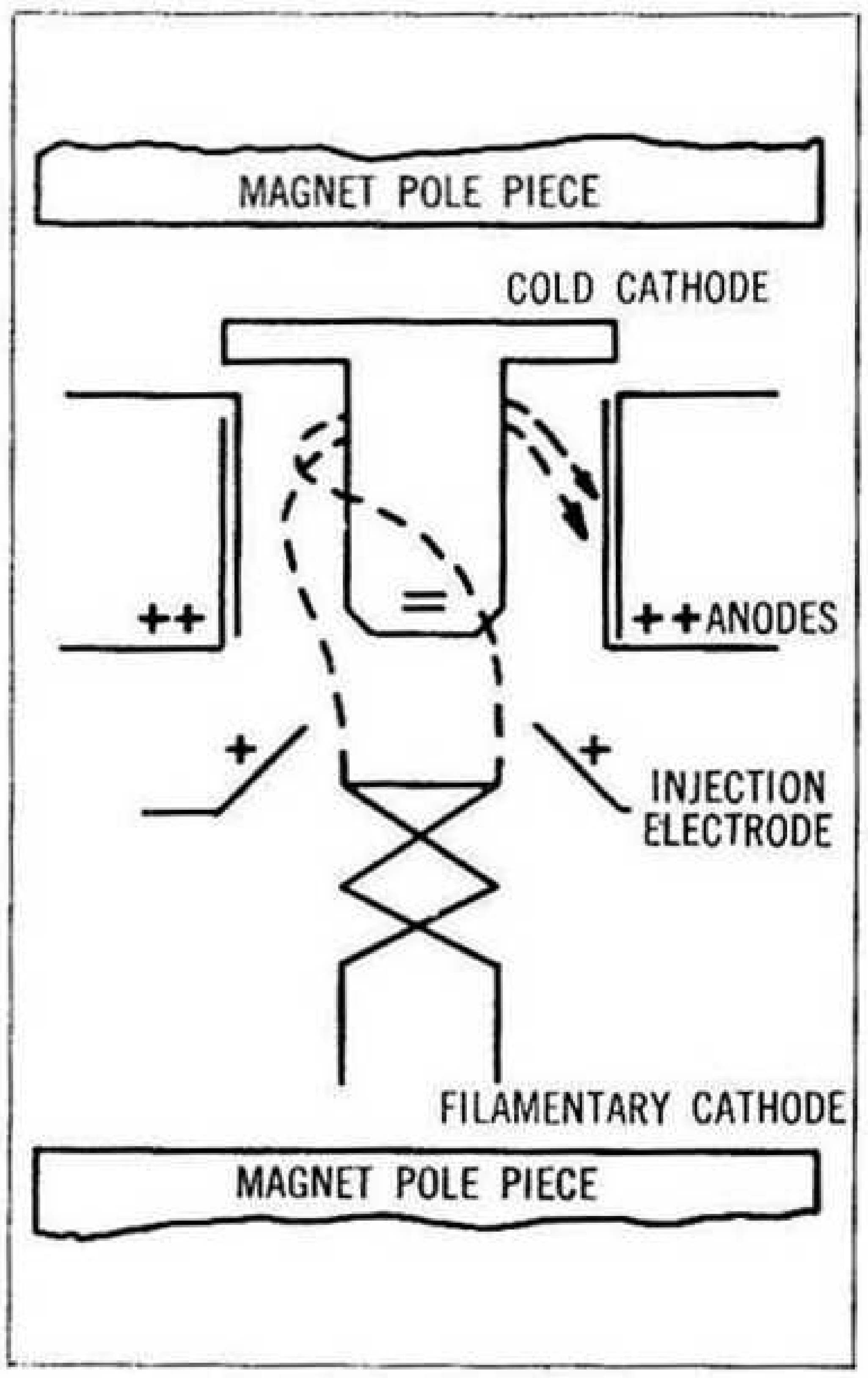


Figure 6—VTM Injection System

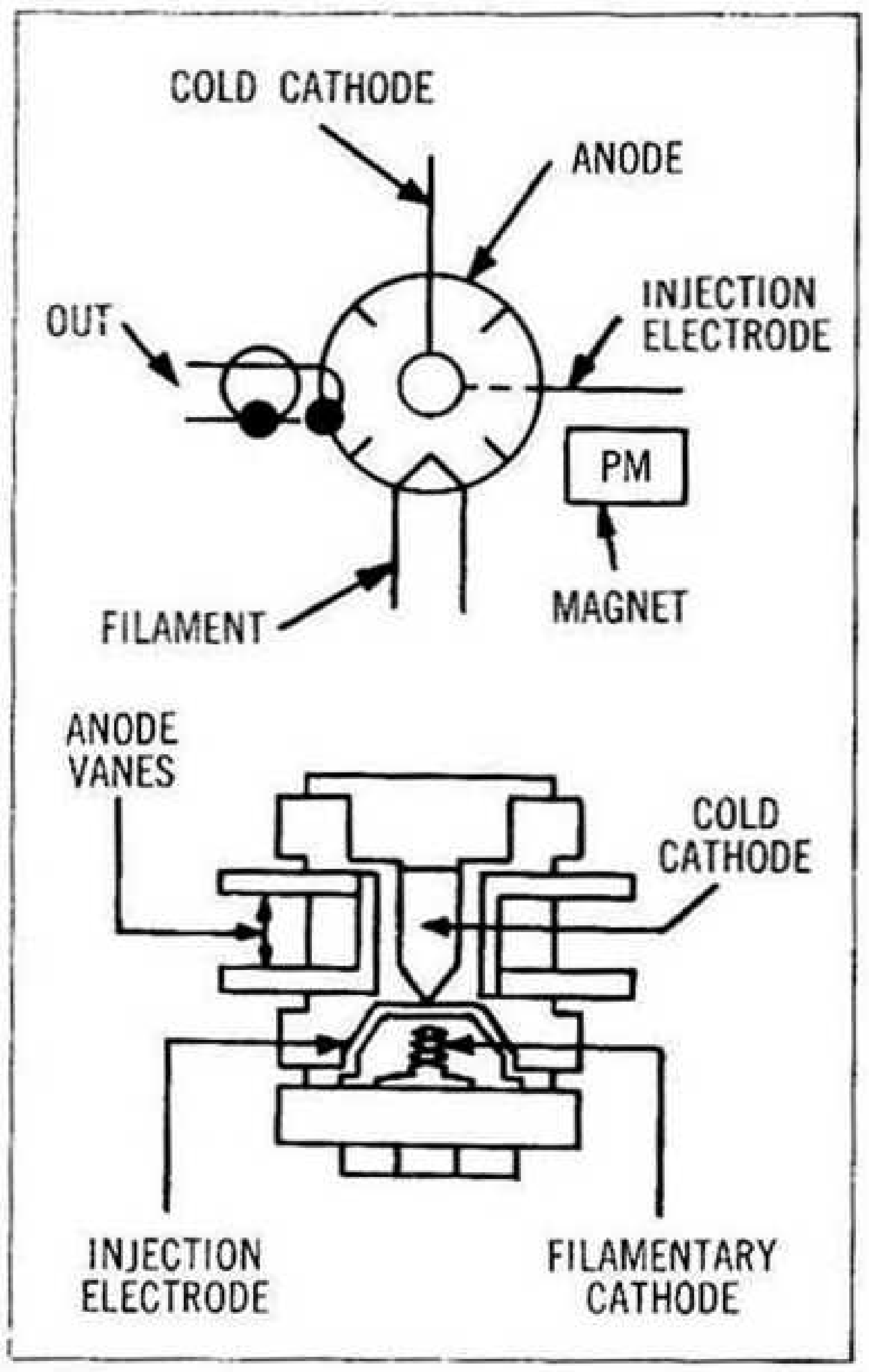


Figure 7—Tube Cutaway View

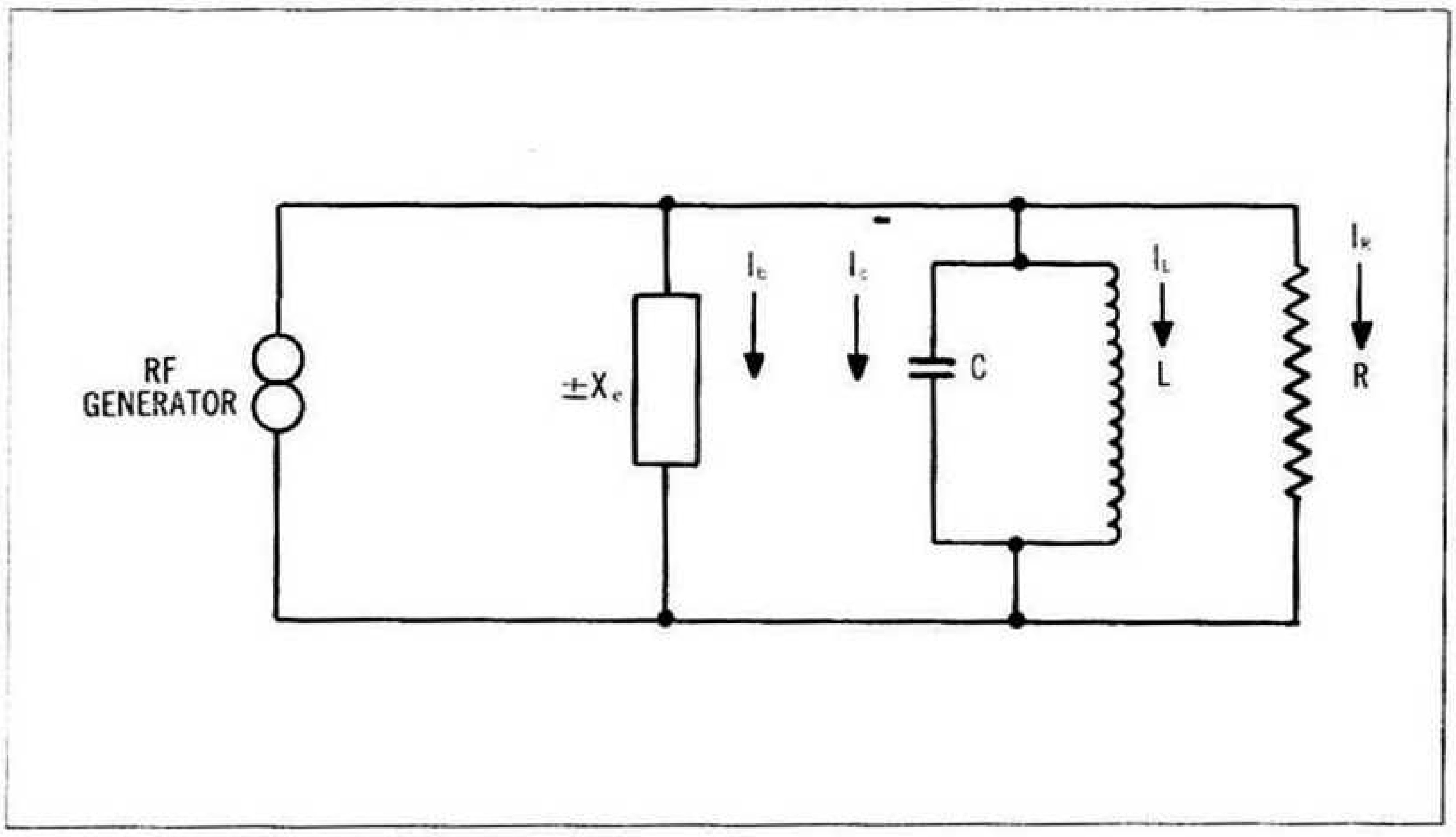


Figure 5—Equivalent Magnetron Circuit

operation and power supply

For satisfactory VTM operation, specific attention to ripple and regulation in the design of power supplies is most important. Permissible ripple can be determined, when the VTM tuning sensitivity and the amount of incidental f.m. allowed by the application both are known, by the following equation:

permissive ripple (volts)=incidental f.m. (mc)/tuning sensitivity (mc/volt)

The tuning sensitivity can be found with adequate accuracy for this purpose by dividing the center voltage into the center frequency, as explained in page 9.

The power supply requirements for the VTM include a filament (emitter) supply (low voltage a-c or d-c), an anode voltage supply (high voltage d-c with adequate current output and good regulation), an injection electrode supply (high voltage d-c very low current drain) and a modulation voltage supply (a-c) to swing the anode voltage about the d-c value and thereby modulate the output frequency.

For test purposes, the circuit of Figure 8 is normally used; the separate supplies afford good flexibility in testing, and the low modulation frequency (usually 60 c/s) allows one to disregard the capacitance of the anode supply unit.

For operation, one can economically derive the Injection Electrode supply from a bleeder across the Anode supply. When the operational modulation frequencies are high, as is usually the case, the modulation supply must follow the anode supply to avoid swinging the capacity of the latter. A coupling capacitor is then required to apply the modulation signal to the Injection Electrode also. This circuit is shown in Figure 9.

FILAMENT SUPPLY

The voltage tunable magnetron (VTM) is capable of long life when operated under proper electrical and mechanical conditions. In addition to the obvious cooling requirements and power limitations, the regulation of the VTM filament-cathode power is extremely important.

Figure 10 shows that the back heating ratio increases very rapidly with frequency so that a low power VTM operating at 4000 mc will have a d-c input to the heater approximately 10% higher than that at 2000 mc, and 6% higher than that at 3000 mc. The leveling off of the solid line is due to a decrease in power level at the higher frequencies. The dashed line indicates the theoretical back-heating ratio at power levels essentially the same as those at the bunch frequency.

Figure 11 shows that a reduction of filament current below 2.0 amperes for the tube operating at 2160 mc brings a rapid fall off in power output due to temperature limited emission from the filament-cathode. At 3160 mc this fall off in power does not occur until 1.9 amperes due to the higher back heating of the filament-cathode. This condition is even more pronounced at 4160 mc where the heating of the filament-cathode due to back heating is more severe and the fall off in power does not occur until 1.7 amperes.

If the VTM is to be operated at spot frequencies or with a very slow sweep (less than 60 cps), then a constant d-c voltage filament supply regulated to ±5% is advised for all VTM's with bandwidths of 50% or greater. This will provide temperature compensation for the filament-cathode by decreasing the d-c input power when the back heating ratio increases.

When using a constant voltage supply, the filament current should be adjusted to the specified value (usually 2.0 amperes) while the tube is operating continuous-wave at the lowest specified frequency for that particular tube. This will provide adequate cathode emission at the lowest back heating ratio. Adjustment of the filament current while the VTM is operating at other than the lowest operating frequency will cause the filament-cathode to operate at higher temperatures than are necessary for adequate emission, and thereby shorten tube life.

If the VTM is to be operated under swept conditions only, and the sweep speed is 60 cps or higher and covers the full band, then the variation of back heating is averaged so that either constant d-c voltage or constant d-c current may be used. Constant current (regulated to ±3%) is advisable in this case as it will tend to decrease the rate of emissive material depletion with tube operation, and thereby help to extend VTM life.

The filamentary cathode is the anode current source. Since the VTM is susceptible to pushing (see separate section on Pushing, Page 13) a ±3% current regulation of a constant current filament supply, or ±5% regulation of a constant voltage filament supply will control this effect. As shown in Figure 12, a change of ±3% in filament current will cause a frequency change of approximately 0.018%; however, it must be realized that the rate of change will vary from tube type to tube type and will depend on what filamentary cathode is used for the particular type.

Use of an a-c filament supply, or of a d-c supply with appreciable ripple, will cause some degree of incidental F.M. Figure 13 shows some typical curves. Information should first be sought from the manufacturer, however, for specific cases with regard to incidental F.M. as well as with susceptibility to pushing.

When specifying the filament power supply, refer to Figure 14 for the volt-ampere characteristics of several G-E VTM filaments.

INJECTION SUPPLY

VTM injection electrode voltage controls the number of electrons injected into the r-f interaction region and thereby

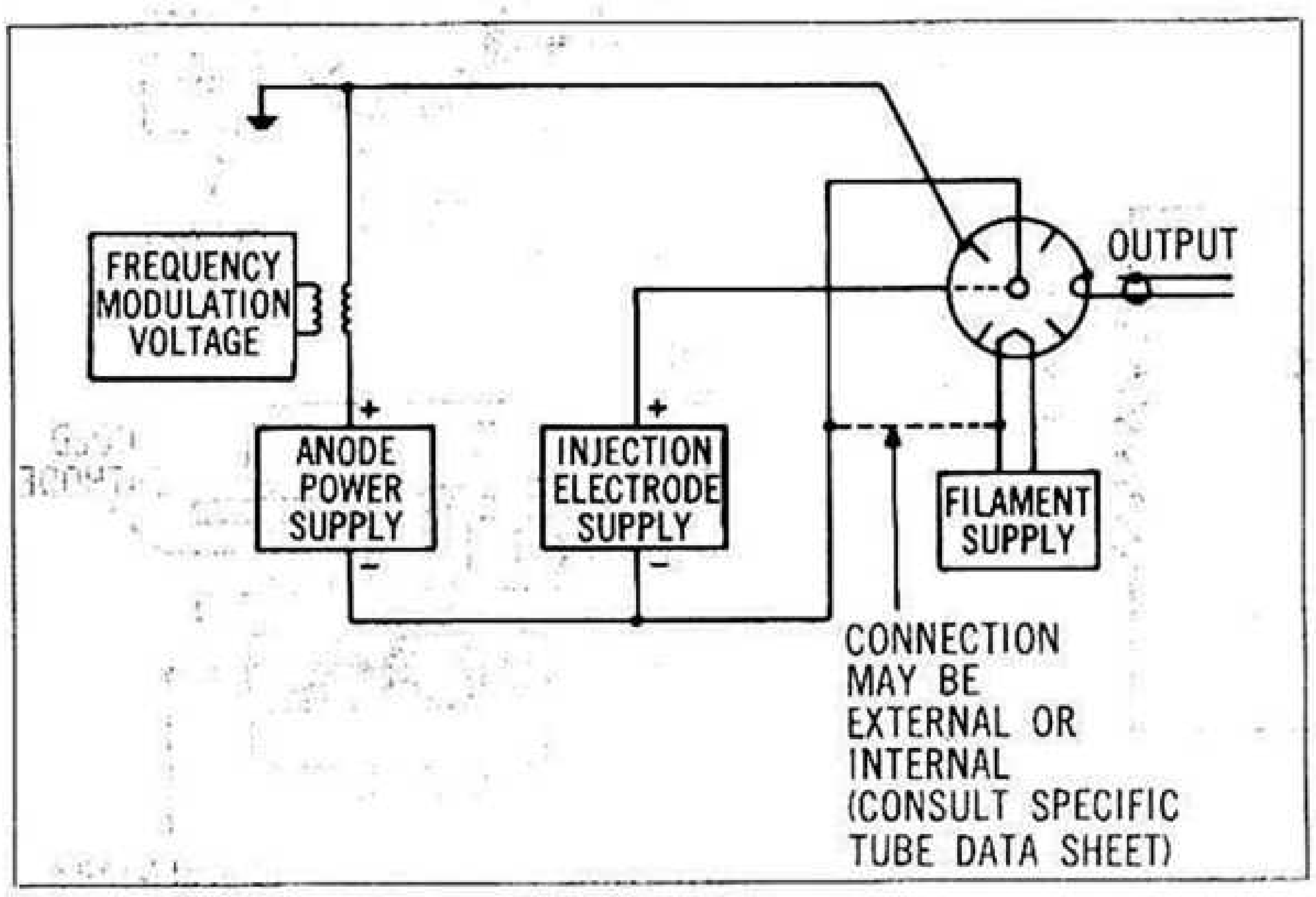


Figure 8—Power Supply Connections for Testing with Low Frequency Modulation and Independent Injection Electrode Supply

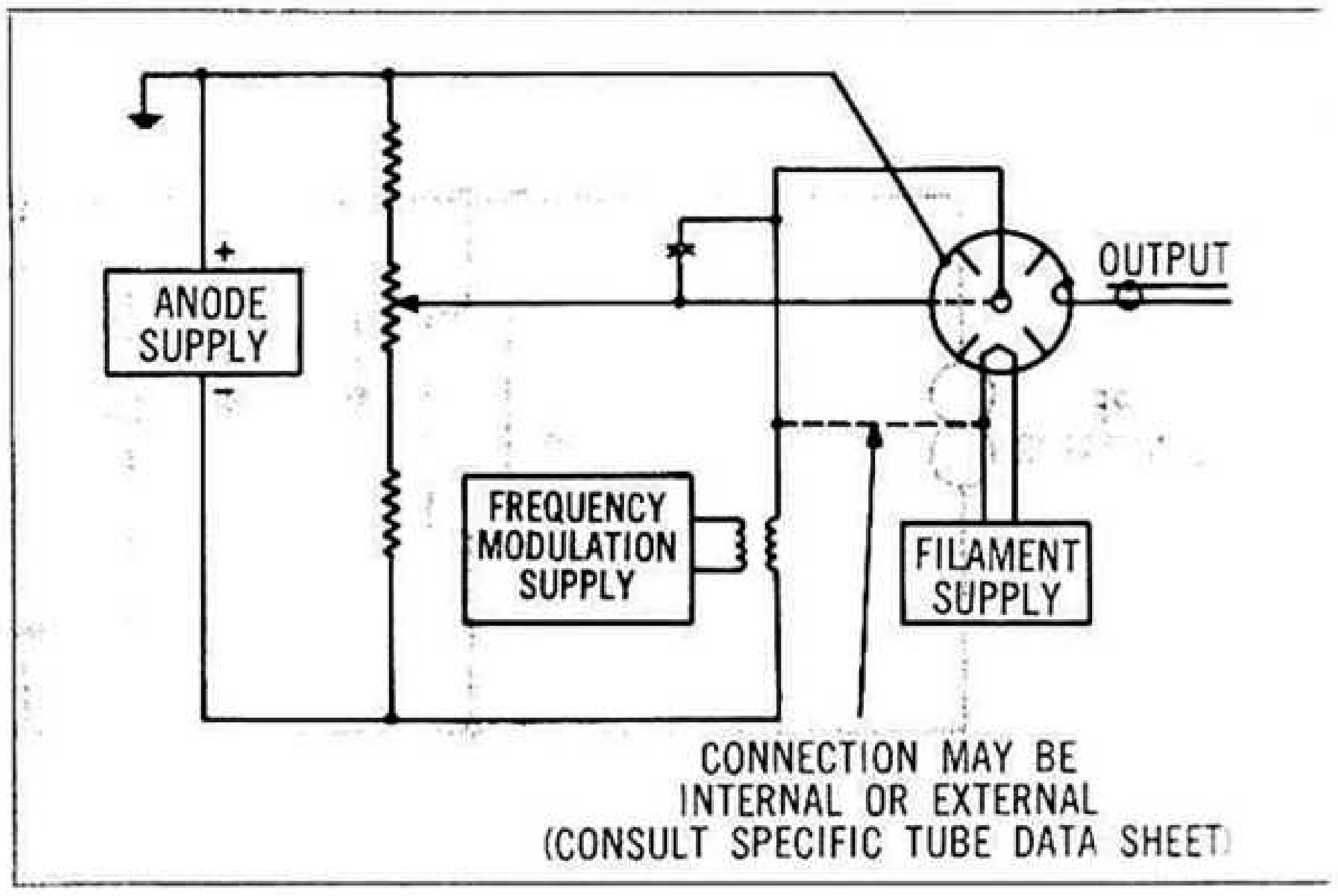


Figure 9—Power Supply Connections for Operation with High Frequency Modulation and Tapped Bleeder Supply for Injection Electrode

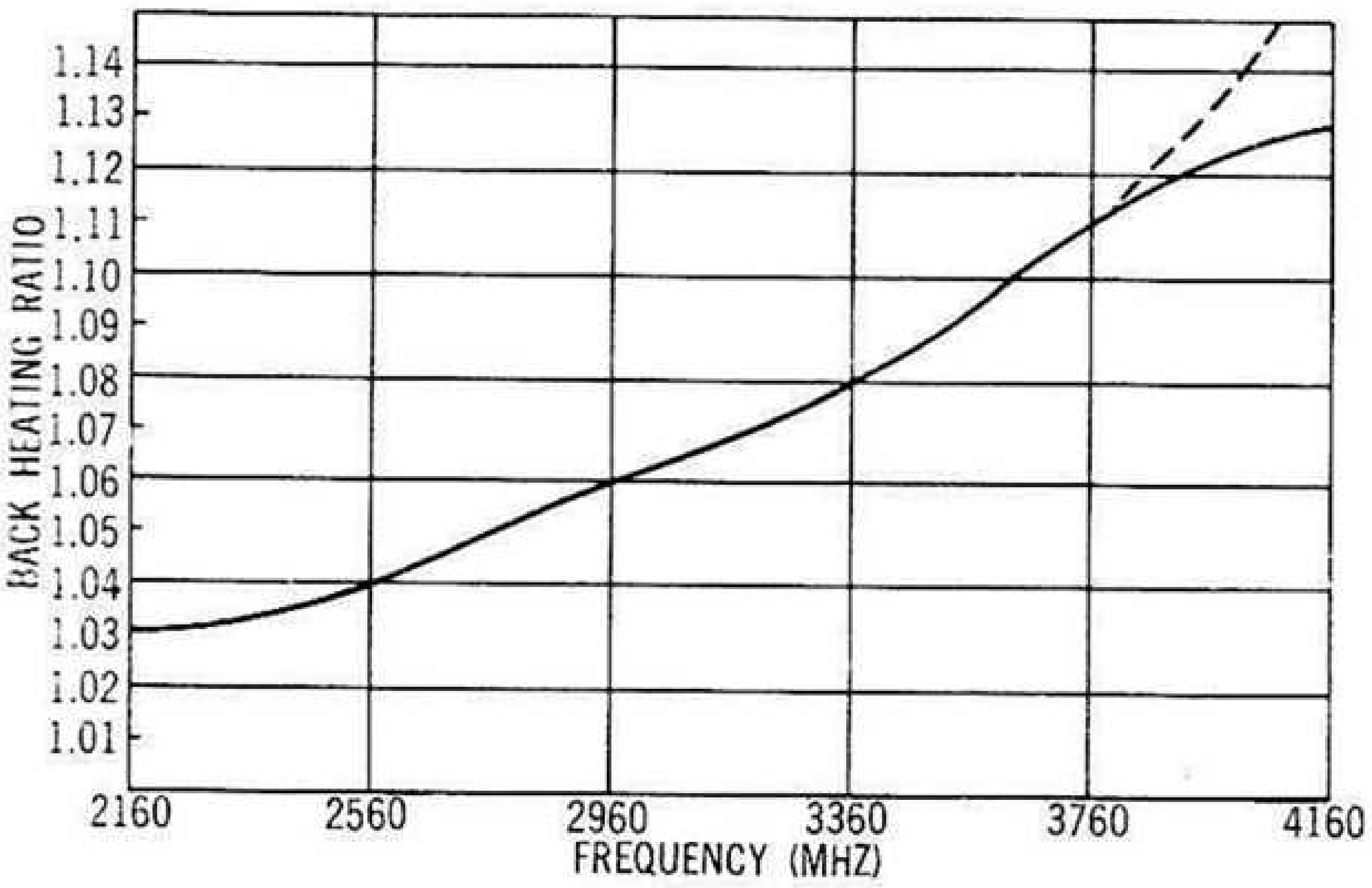


Figure 10—Back Heating Ratio vs. Frequency

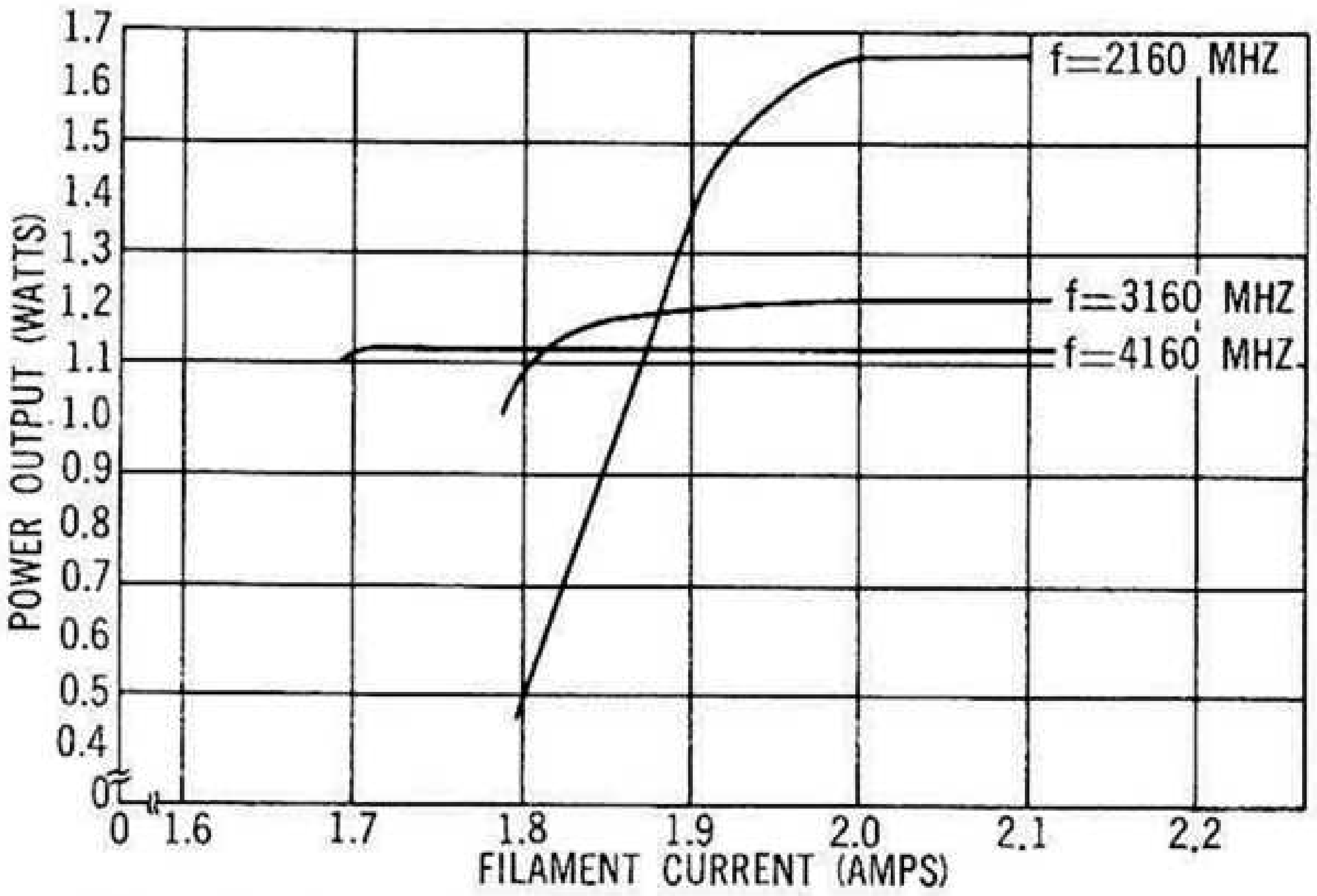
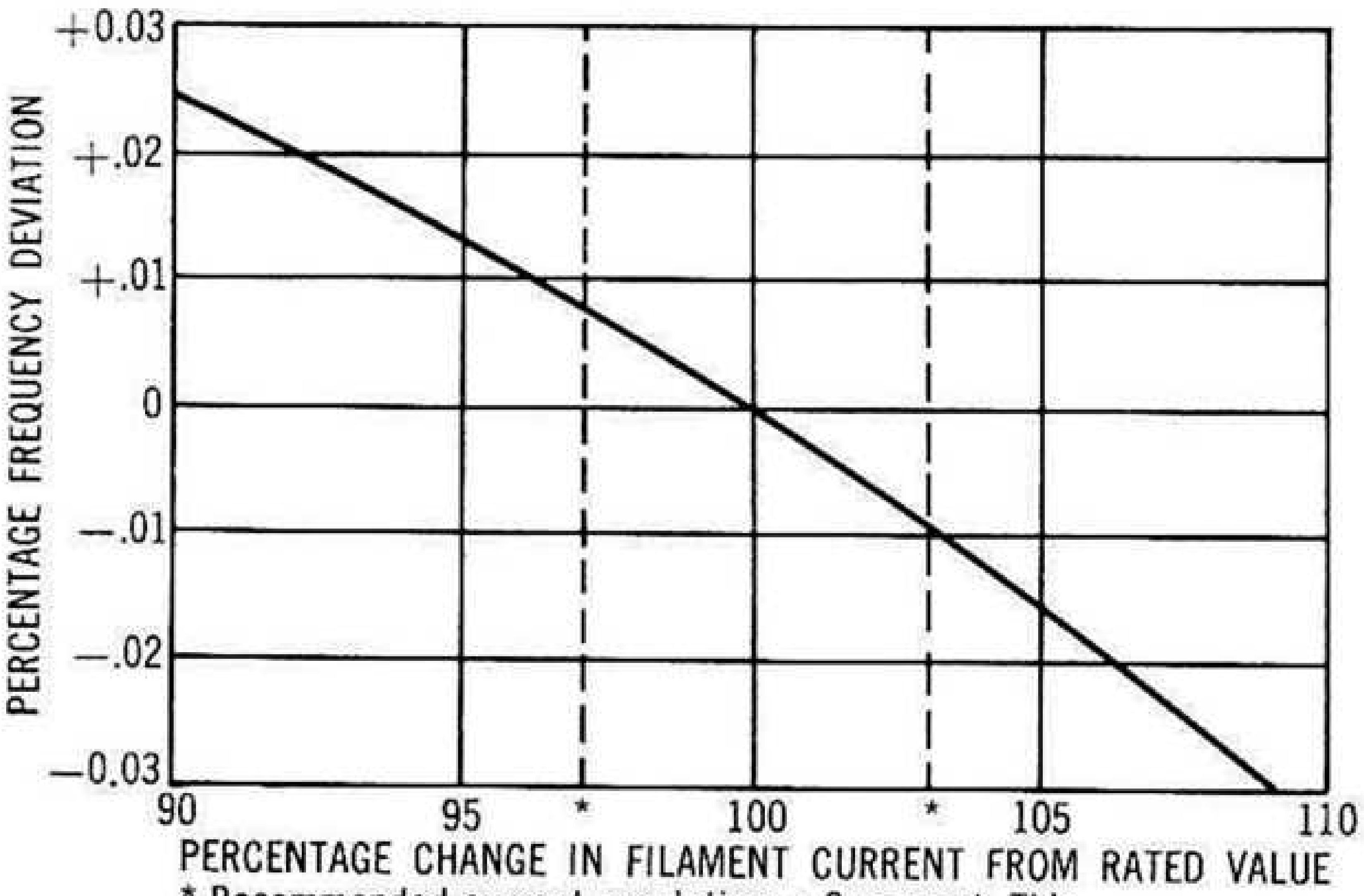


Figure 11—Power Output (emission) vs. Filament Current



* Recommended current regulation ±3 percent. This corresponds to a voltage regulation of ±5 percent.

Figure 12—Pushing Effect of Filament Current

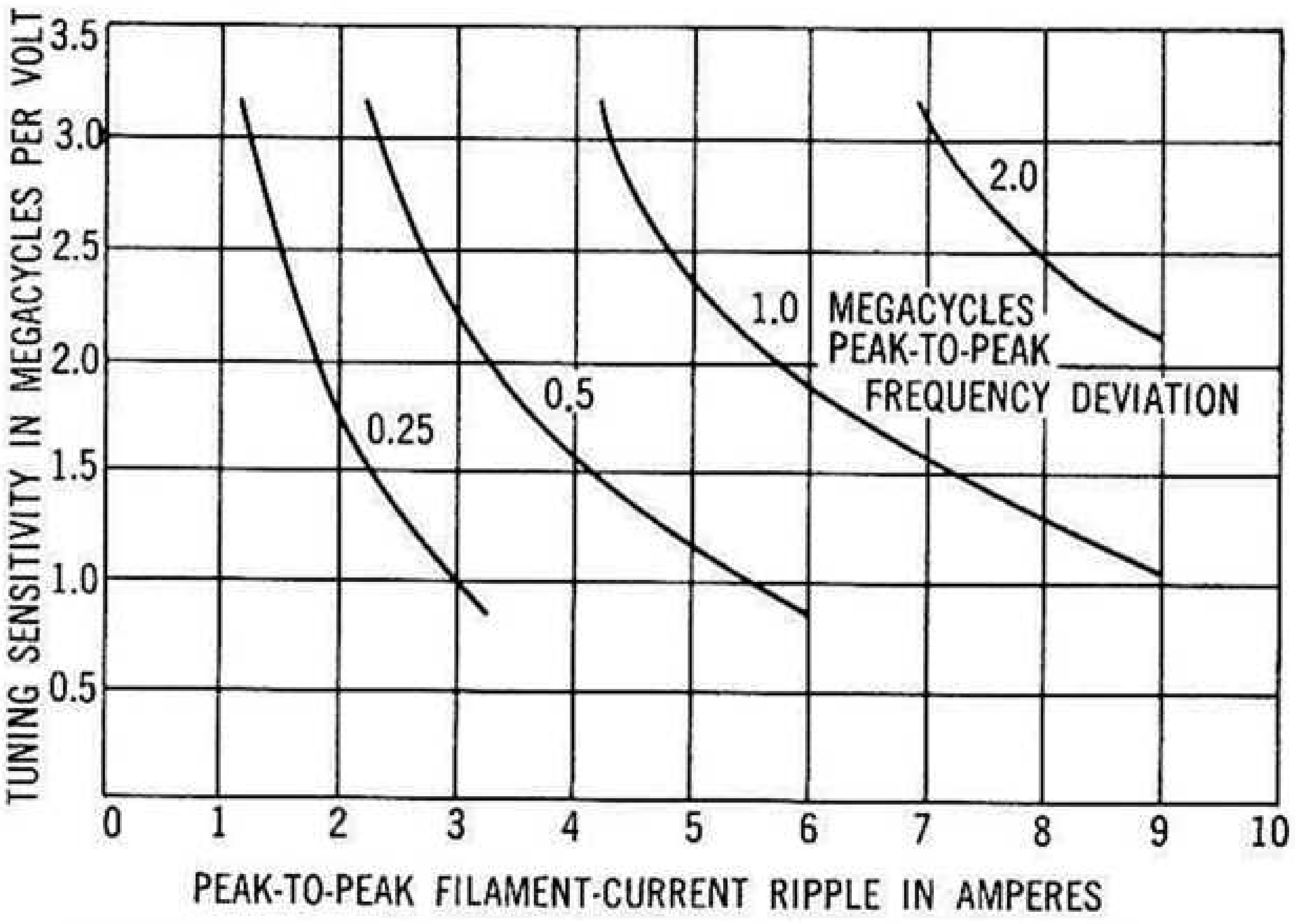


Figure 13—Peak-to-Peak Frequency Deviation Due to Filament

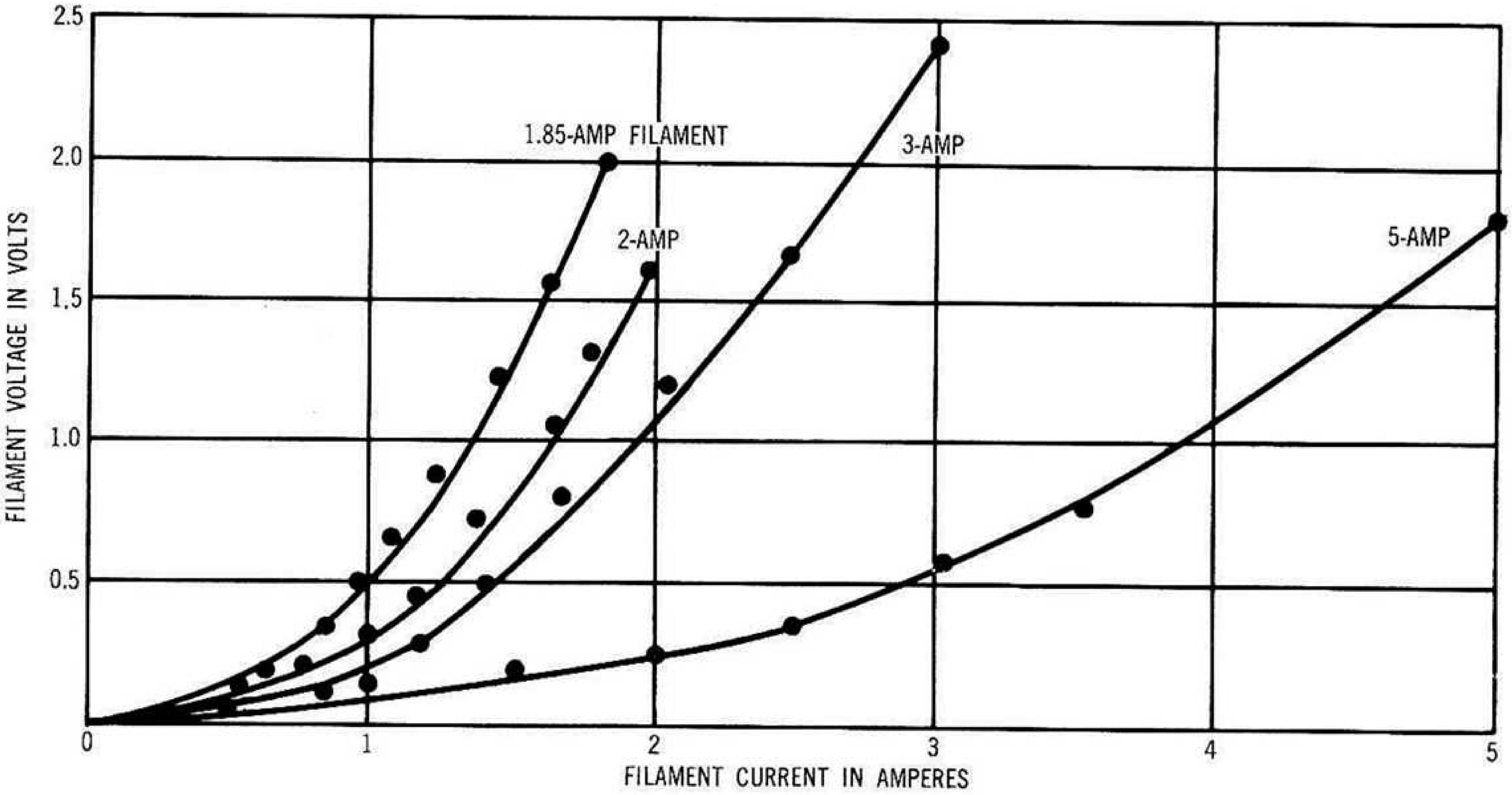


Figure 14—Filament Voltage-current Characteristics

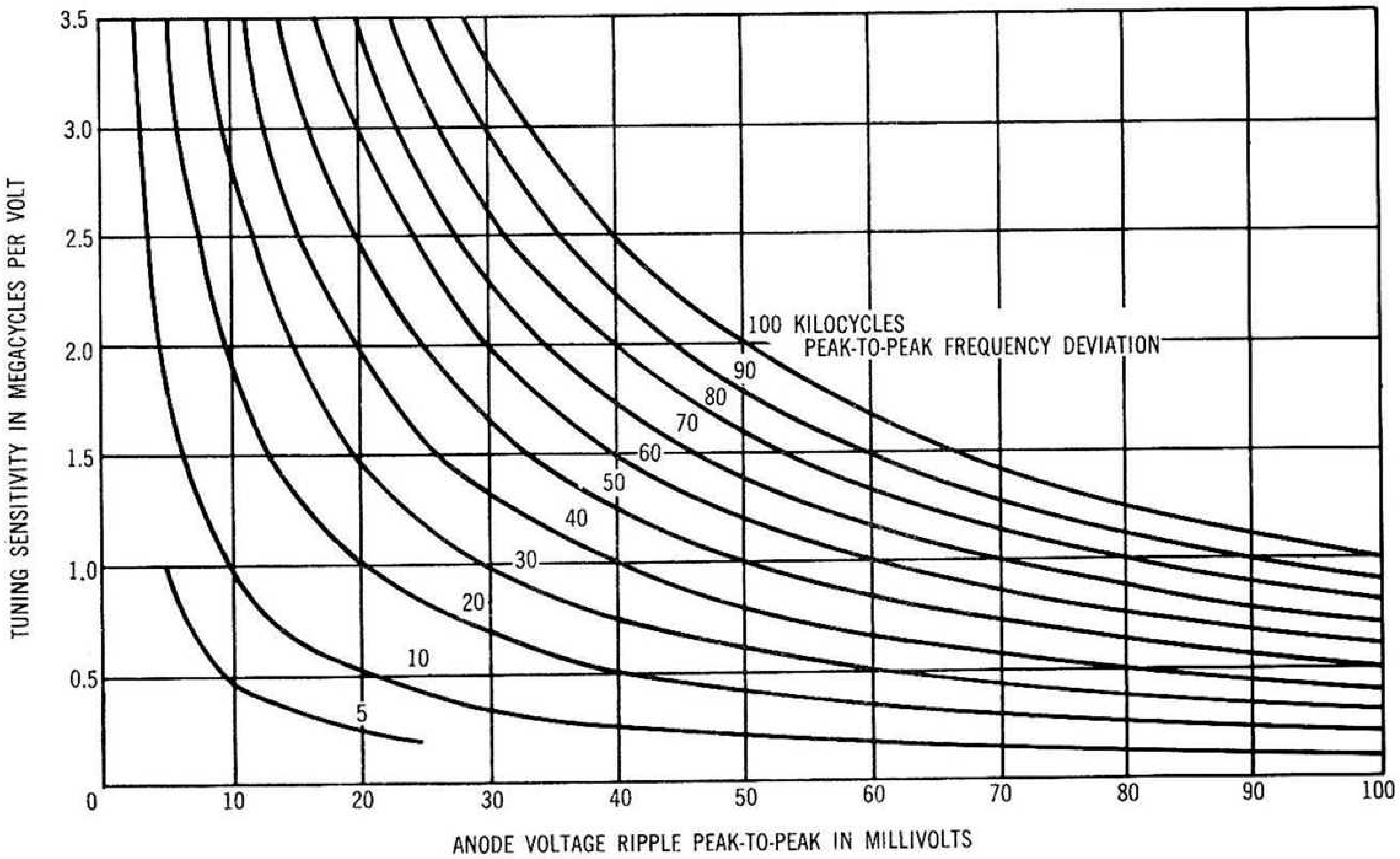


Figure 15—Peak-to-peak Frequency Deviation due to Anode Voltage Ripple

determines the anode current and power level at which the VTM will operate. This change of power with change in injection voltage is essentially a linear function, but its rate will vary from one VTM type to another depending primarily on the normal power output of the VTM at a particular frequency. As discussed in the section on Amplitude Modulation (See Page 16), the VTM is limited in both pulsed and amplitude modulated operation by the small power variation available. This is due to the requirements of electron current for coherent oscillation. When the injection voltage is set too low, too few electrons are injected into the interaction region to permit VTM oscillation. When the injection voltage is set too high, too many electrons are injected into the interaction region to permit the required bunching action to take place. The VTM spectrum breaks up and the tube then becomes noisy or unstable, or drops out of oscillation entirely. In high power tubes the power output may reach a saturation level without break up of the spectrum.

A 3- to 6-db power variation capability appears to be a practical limit for broadband tubes. Such a variation will generally result in a less than one per cent frequency shift due to the pushing effect.

ANODE SUPPLY

The anode-to-cathode voltage (often referred to as the anode voltage) controls the frequency of oscillation of the VTM. One of the VTM's advantages is that its change in frequency with the change in anode-to-cathode voltage is a linear function. Anode-to-cathode voltage actually controls the angular velocity of the electron beam in the interaction area and thereby controls the frequency. In most applications the anode is operated at ground (as shown in Figure 8) with the cathode at a B-minus setting. Modulation is applied between ground and the cathode to vary the velocity of the electron beam, and thus sweeps the tube between prescribed band limits. Further discussion on this operation may be found in the section on Modulation (See Page 15).

The electronic tuning feature places a firm regulation requirement on the anode to cathode power source in order to keep the incidental frequency modulation to a minimum. The peak-to-peak voltage ripple will cause a peak-to-peak frequency change which depends on the tuning sensitivity of the tube as well as on the magnitude of the ripple. Figure 15 indicates what deviations may be expected. Select the tuning sensitivity for which the VTM has been designed and, by intersecting this value with the power supply ripple value, one can determine the peak-to-peak deviation. In addition to frequency and power level control, the VTM is also sensitive to power supply characteristics for starting conditions. Starting can be defined as the ability of the VTM to assume immediate coherent oscillation upon application of all required voltages. The voltage sequence and rise characteristics play an important part in starting the VTM. Should any starting problems arise, experience has shown that the best solution is to operate the VTM with the pertinent power supply while the VTM is being aligned at the factory. A further discussion on starting is presented in the section on Starting (See Page 16).

VTM WITH B+ SUPPLY

Many equipment manufacturers have designed power supplies which operate tubes from a B-plus rather than a B-minus source. In such cases the VTM can be adapted to operate with a B-plus supply as shown in Figure 16. Use of a d-c block will allow the VTM to be operated with a B-plus supply while the r-f hardware is at ground potential. Further modification of the VTM will allow the VTM case (dashed lines) to be operated at ground potential. (If the equipment is such that the VTM case can be "floated" then this latter modification is unnecessary.)

After these modifications are made. the VTM will operate in the conventional manner as it would with the B-minus supply. As shown in Figure 9, the injection electrode supply may be replaced by a tapped bleeder across the anode supply. In this case, a coupling capacitor is not strictly necessary although a bypass to ground may be helpful.

tuning characteristic

The tuning characteristic of the VTM is the curve relating frequency-to-anode voltage. A major advantage of the VTM lies in the fact that this characteristic is very nearly a straight line passing through the origin (i.e., frequency is proportional to voltage).

However, the first essential condition for voltage tunability (See Page 4)—namely that the anode circuit be loaded down to a low Q—implies that the performance of the tube is load-sensitive. It is therefore convenient to discuss departures from the ideal tuning characteristic and load mismatch effects at the same time.

Because of this inherent load sensitivity, the majority of VTMs are built with integral load isolation either in the form of an attenuator (in low power tubes) or of a ferrite isolator (in high power tubes). When a ferrite device is used it is physically a circulator, but with its third port matched so that it is functionally an isolator.

The following paragraphs discuss the effects of load variations applied directly to the VTM. To understand the nature of the problem, one should read them bearing in mind that for VTM packages with the integral isolation the effects will be similar in nature but numerically one or two orders of magnitude smaller. Under these conditions the load tolerances of the VTM is as good as that of other voltage-tunable devices.

The tuning characteristic is described by the following terms:

Tuning Sensitivity: defined as the slope (df/dv) of the best straight line through the observed frequency vs. voltage measurements.

Linearity: defined as the deviation in frequency of the actual tuning characteristic from the best straight line, expressed as a percentage of the center frequency.

Slope Deviation: defined as the deviation of slope of the actual tuning characteristic from the average tuning sensitivity expressed as a percentage of the tuning sensitivity.

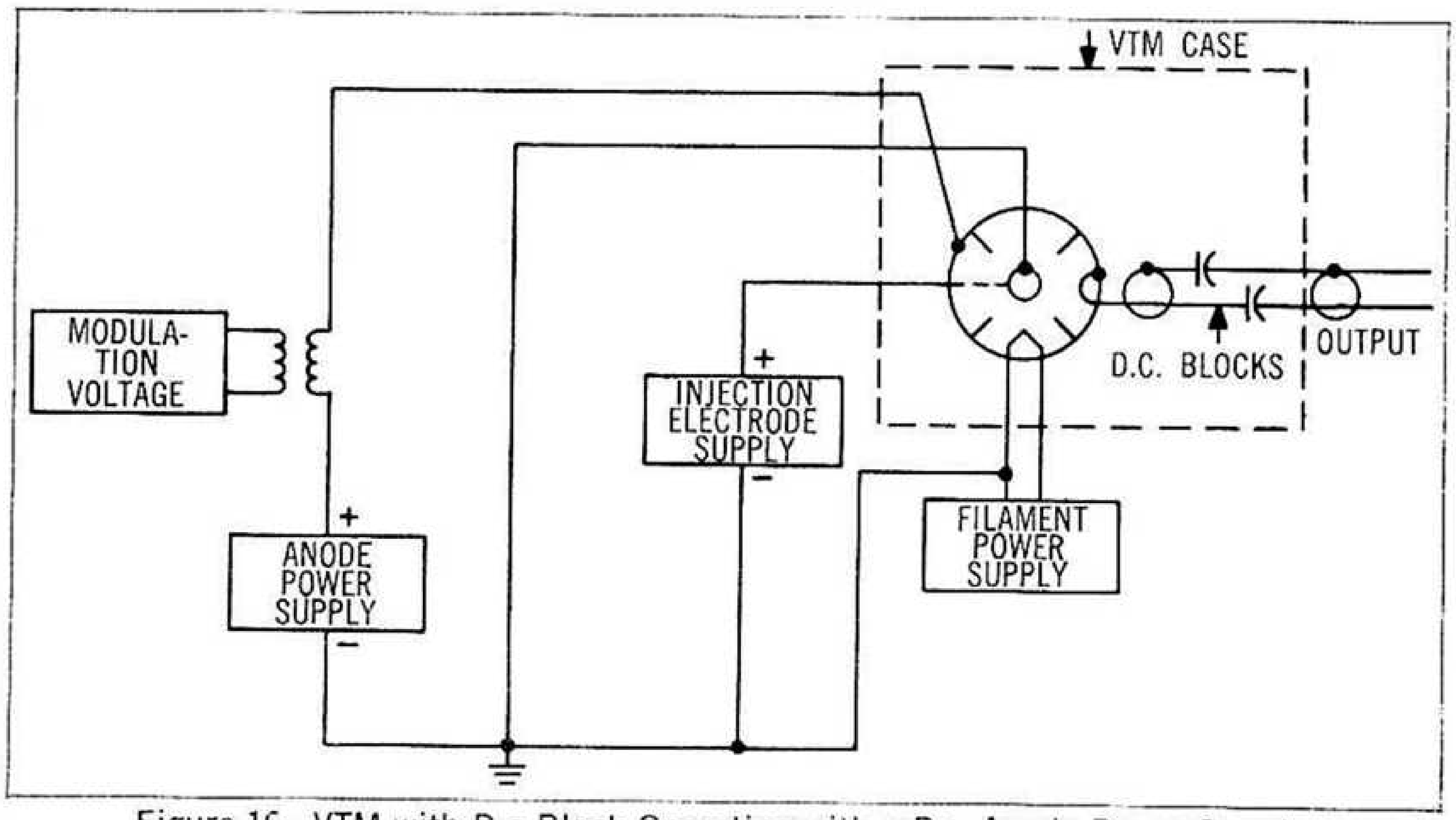


Figure 16—VTM with D-c Block Operating with a B+ Anode Power Supply

The last two terms are not independent: the Linearity is the integral of Slope Deviation normalized to center frequency. Both terms are in use, however—Linearity being a more convenient concept for some applications and Slope Deviation for others. Slope Deviation is sometimes referred to as fine grain Linearity.

TUNING SENSITIVITY

Since the tuning characteristic extended downwards passes close to the origin, the Tuning Sensitivity is closely equal to f/V. Differences from this value result mainly from the resonant properties of the anode circuit.

For octave band tubes this effect is negligible, but when high power tubes have Q values of 10 or more, this causes their Spot Tuning Sensitivity (measured over a small portion of the tuning range) to vary from about 10% below the average value at the low frequency to about 10% above at the high frequency end. Average Tuning Sensitivity (over the whole band) for these tubes is still close to f/V measured at band center. Normally the tuning sensitivity cannot be specified by the user. The basic requirements of frequency and power determine f and V; therefore, Tuning Sensitivity is fixed also. However, this value is considerably higher than the Tuning Sensitivity of a Backward Wave Oscillator (whether O or M type) operating at a comparable voltage. As a result, the modulation power at high modulation frequencies is much less for the VTM than for the other voltage tunable sources.

Figure 17 shows the tuning characteristics of two typical tubes: a wide band low power tube, the ZM-6223 with 2.65 mc/volt average tuning sensitivity; and the 75 watt ZM-6047 with 1.09 mc/volt across a 13% band.

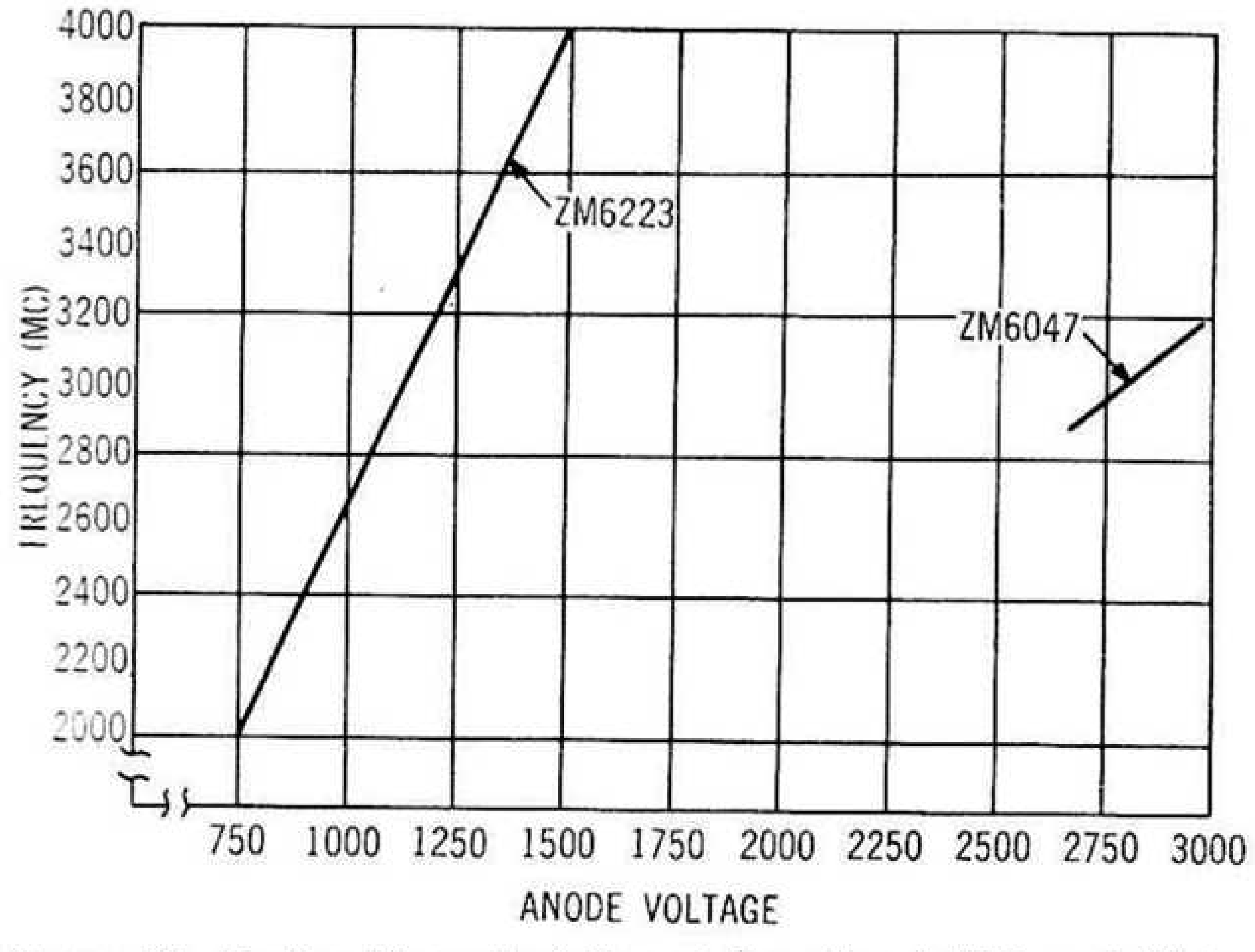


Figure 17—Tuning Characteristics of Broadband VTM and High Power VTM

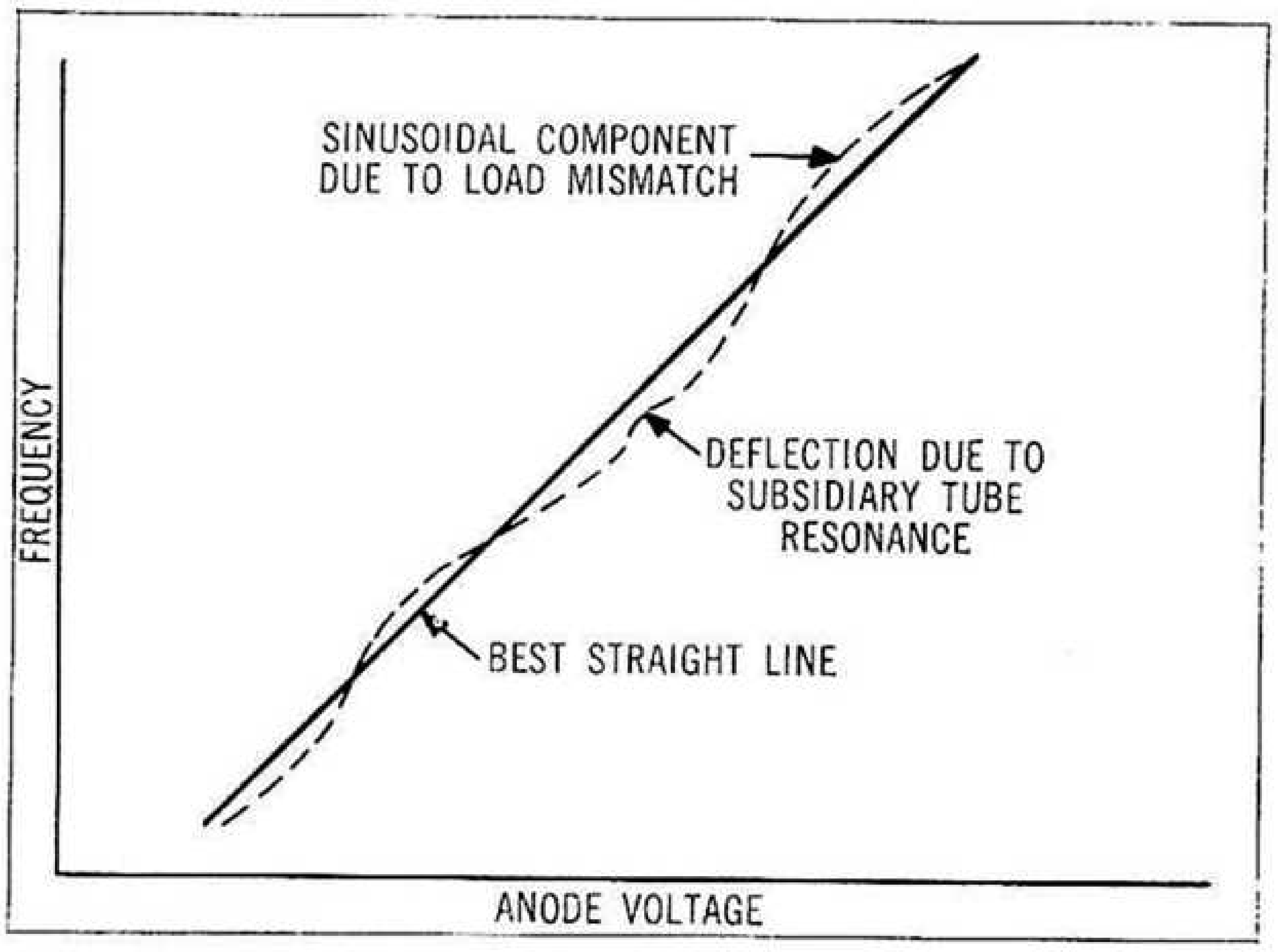


Figure 18—Deviation (exaggerated) of Actual Tuning Curve from Best Straight Line

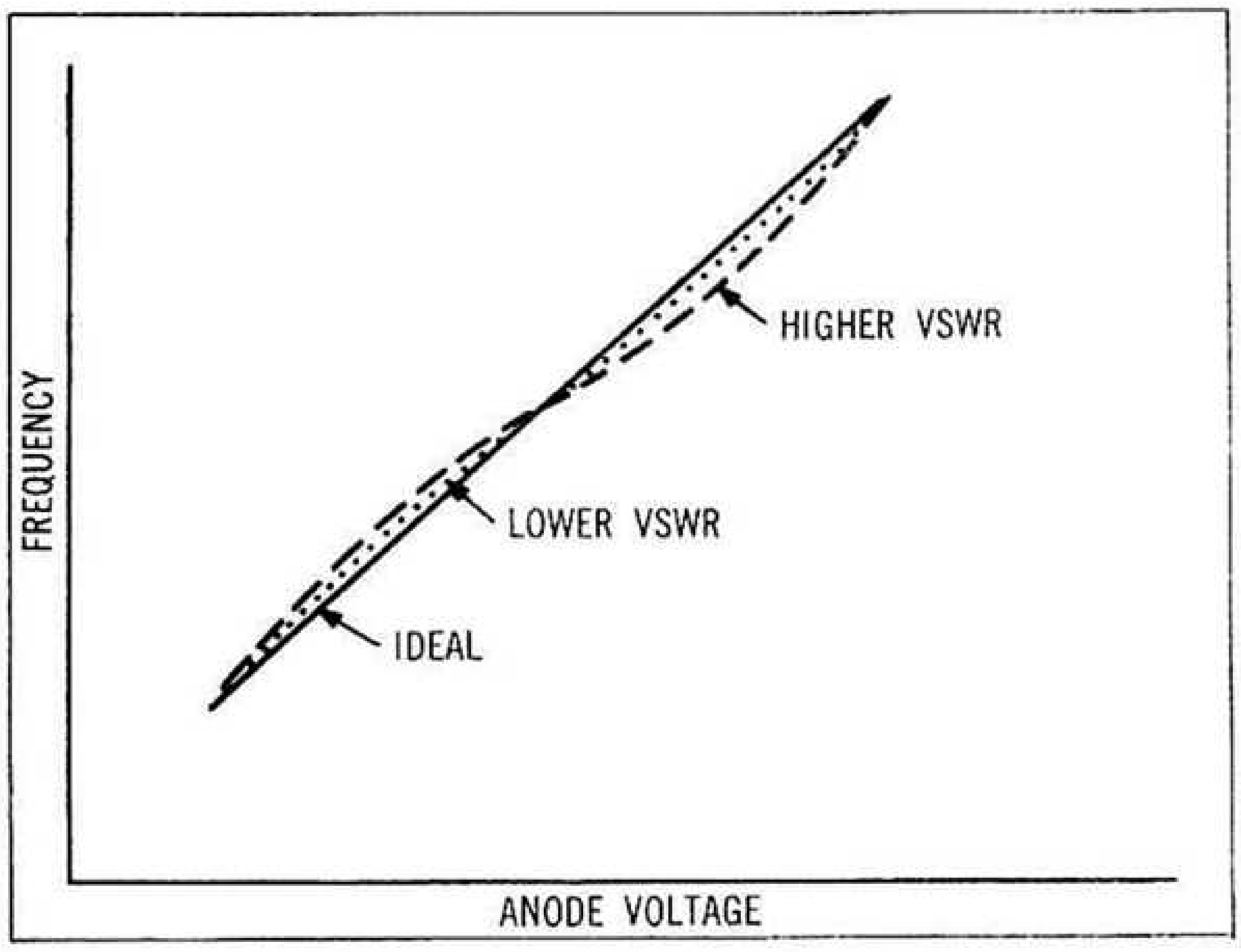


Figure 19—Effect of VSWR on Tuning Characteristic

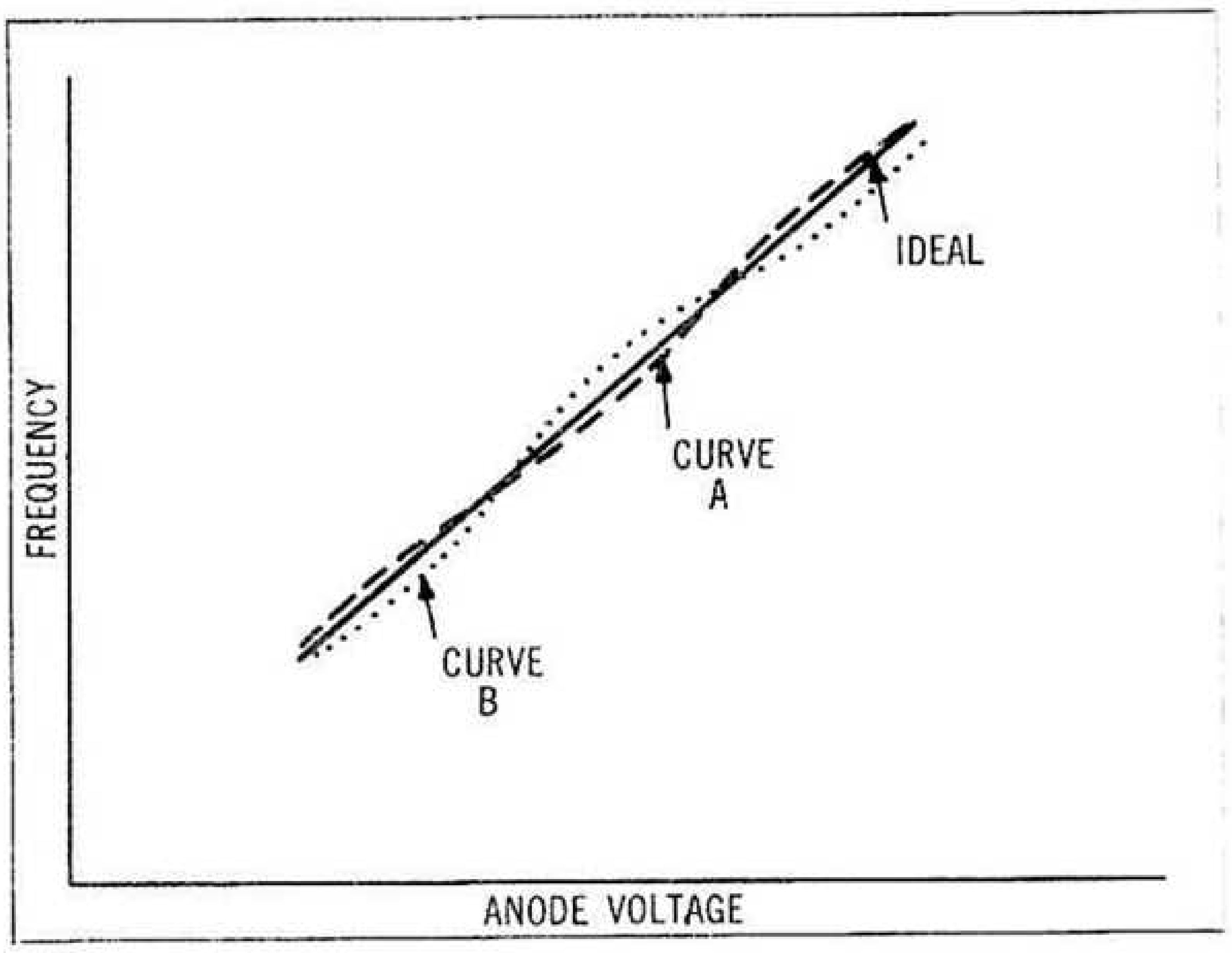


Figure 20—Effect of Phase Change on Tuning Characteristic

LINEARITY

The actual tuning curve departs from the best straight line as illustrated in Figure 18. Sinusoidal variation is associated with reflections from a mismatch in the output line, while isolated deviations may occur due to subsidiary resonances within the VTM. In a well-designed tube, the load reflection effects are the dominant ones; the amplitude of the deviations from the straight line is determined by the load VSWR (See Figure 19) and the direction of deviation (i.e., to higher or to lower frequency) by the phase of the reflection at each frequency.

Figure 20 shows a tuning characteristic (Curve A) measured when operating into a small mismatch whose phase varies slowly with frequency: If the load is then shifted so that the VSWR remains constant while the phases are changed through 180° the tuning characteristic will shift to curve B. Intermediate phase shifts will introduce corresponding small undulations in the tuning characteristic.

The periodicity of the sinusoidal variations is determined by the distance to the reflecting element. A smooth curve with low periodicity is obtained (See Curve A, Figure 21) if the line length is kept as short as possible. As the reflecting element moves further away, the "waves" will slide down the tuning characteristic and become shorter in length and, therefore, steeper. (See Curve B, Figure 21.) When the tangents at the steepest points become vertical, the curve breaks up into discontinuous segments with missing frequency bands (or "holes") between them. This is, of course, an unacceptable situation and the load VSWR must be kept low enough to prevent it. For a VTM without isolation this means a load VSMR must typically be held to 1.2:1 or less across the band—a very tight requirement. Thus the tube should either have the integral isolation or should look into a well-matched pad or load.

Linearity as defined here refers only to the absolute deviations of frequency produced by these effects from the best straight line. Figure 22 shows typical linearity limits of ±1% of center frequency imposed on the tuning characteristic. For narrow band, low power tubes, linearity limits of ±0.5% can be obtained.

SLOPE DEVIATION

The curve of Figure 18 can also be described by the variations in slope relative to the best straight line. This aspect is of greater significance when a problem of following a swept signal with an AFC loop exists; too great a slope may exceed the loop's gain limits. It becomes apparent that slope deviation is affected by load VSWR, and is affected much more than is Linearity by a distant load mismatch with its attendant rapid phase variations (see in Curve B, Figure 21).

For an octave band tube working directly into a 1.2:1 VSWR within a few wavelengths, slope deviation may be typically ±15%. For high power tubes with integral isolators, slope deviation due to load effects is very small but the consistent variation across the band due to the circuit resonance is about ±10% as mentioned under Tuning Sensitivity. (See Page 9.)

The low values of linearity and slope deviation mean that the problem of linearizing the tube by controlling the voltage sweep is much simpler than it is for tubes with inherently non-linear characteristics whose correction voltages are correspondingly large. This is most important to the design of equipments where precise calibration of the voltage with the actual operating frequency of the VTM is of considerable significance. This precision demands that a change in voltage produce the same change in frequency along the entire tuning characteristic and suggests that the slope deviation must be reduced to a minimum.

INITIAL ACCURACY

The VTM tuning characteristic can be held to a high degree of uniformity from tube to tube. In typical production types, the VTM frequency versus anode voltage characteristic does not deviate from the design value by more than ±2.5%. This is of particular importance to manufacturers involved in production quantities of equipment. It facilitates the calibration of the equipment, helps to standardize on manufacturing procedures, and, in general, reduces manufacturing time and costs.

REPEATABILITY

The tuning characteristic of the VTM is repeatable to within ±0.1% of its initial value when the entire prescribed frequency range is swept. Such repeatability insures high accuracy on successive sweeps and better precision on resetting equipment for operation over portions of the band or for fixed frequency operation.

power variation

With proper loading (1.2 to 1 VSWR or better), an octave band VTM can limit its power variation to ±2 db over the band without any additional leveling equipment. A poor mismatch will cause considerable variations in the power-versus-frequency spectrum and, in extreme cases, may cause a break up of the spectrum. (See Figure 23.) The mismatch actually produces variations in the impedance presented to the VTM's r-f current. This, in turn, causes a sinusoidal variation in the normal power

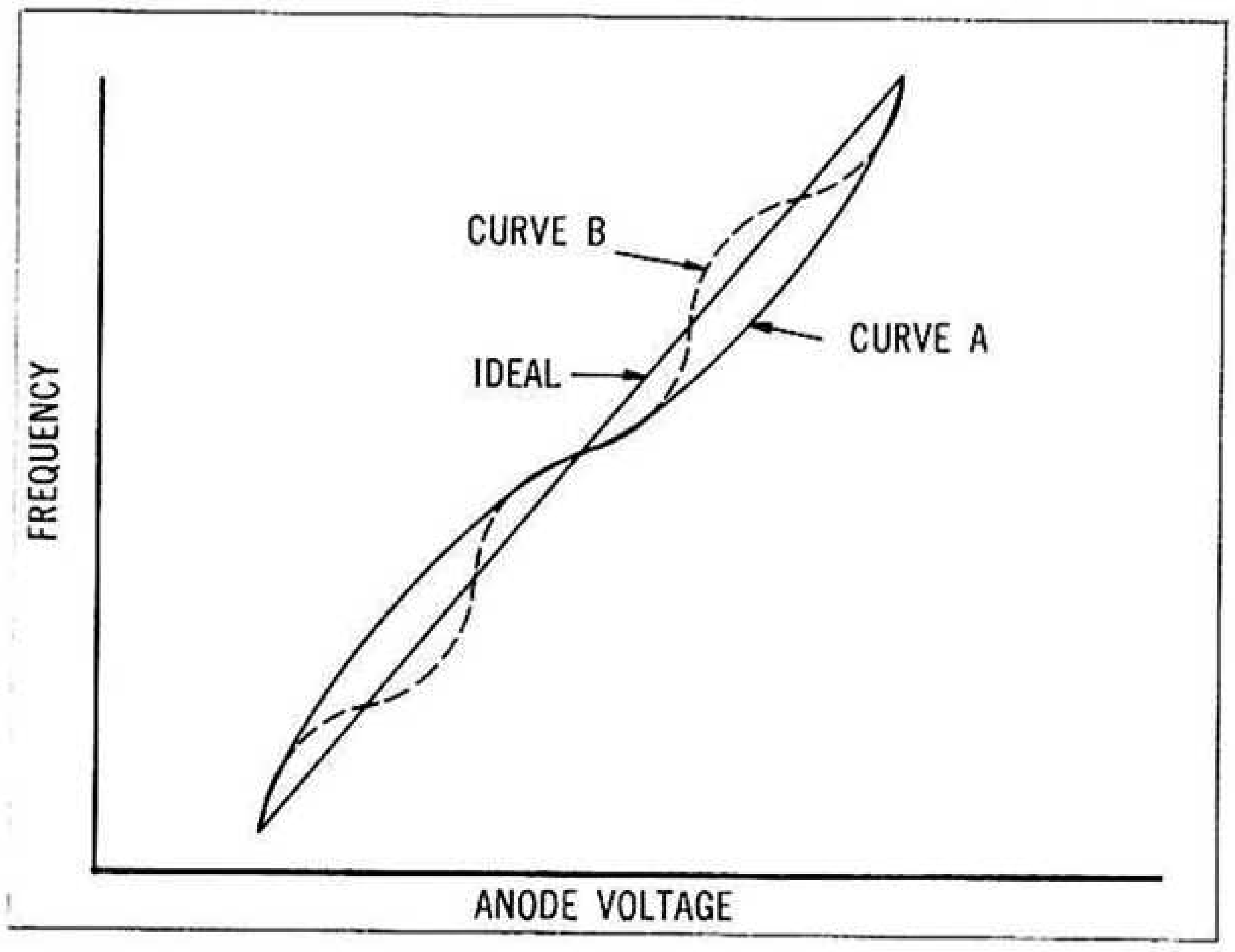


Figure 21—Effect of Load Position on Tuning Characteristic

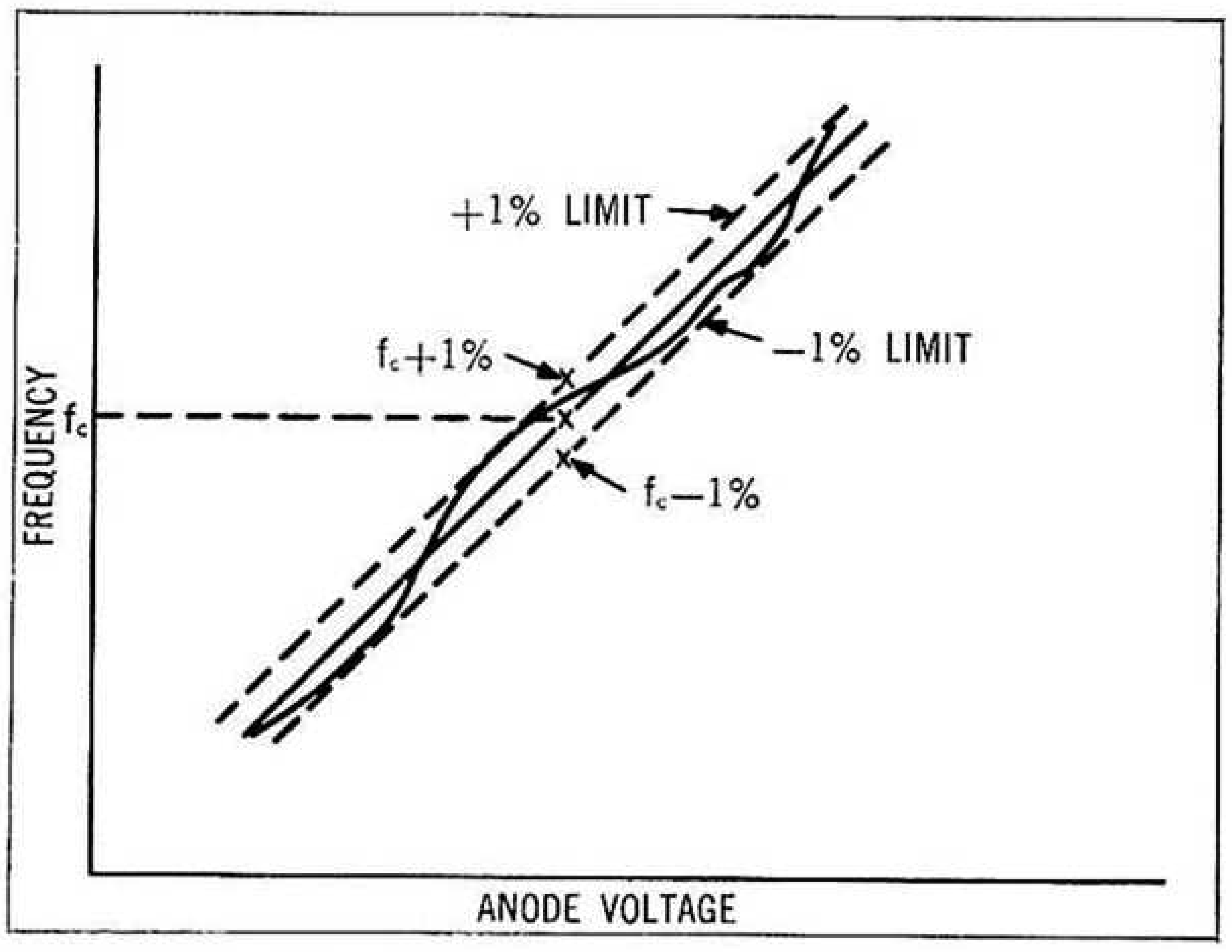


Figure 22—Tuning Linearity Limits

output spectrum. The worse the match, the more severe the variation becomes until a spectrum break occurs. Changing of the load phase will also affect this parameter, and this becomes especially important when the change in phase is coupled with a high VSWR (over 1.2 to 1). Should the loading to the VTM be poor, then isolation in some form is required.

The VTM is capable of being leveled by a feedback loop which controls the voltage on the injection electrode and, in turn, controls the power level. Average power amplitude variation of 3 to 6 db via the injection electrode is available with broadband VTM's, and narrow band VTM's will have a greater variation capability depending on the percent bandwidth. During VTM alignment at the factory, the power spectrum is monitored so that no abrupt changes in power level are present. This characteristic, coupled with the lower over-all power variation, places fewer demands on the leveling system and particularly on the amplifier. Since the injection electrode impedance is in the order of several megohms, a high impedance feedback system can be used.

power output and efficiency

General Electric is producing VTM's with power levels ranging from tens of milliwatts to hundreds of watts.

High powered (75 to hundreds of watts) VTM's with 15% bandwidth have practical conversion efficiencies of 65%, and developmental VTM's (500 watts) have operated at conversion efficiencies of over 70%. (Conversion efficiency is defined as the power output divided by the product of the anode voltage and anode current). These high power, high efficiency devices have found successful application in active electronic countermeasures and can also be used as high level, injection locked oscillators for telemetry and communications.

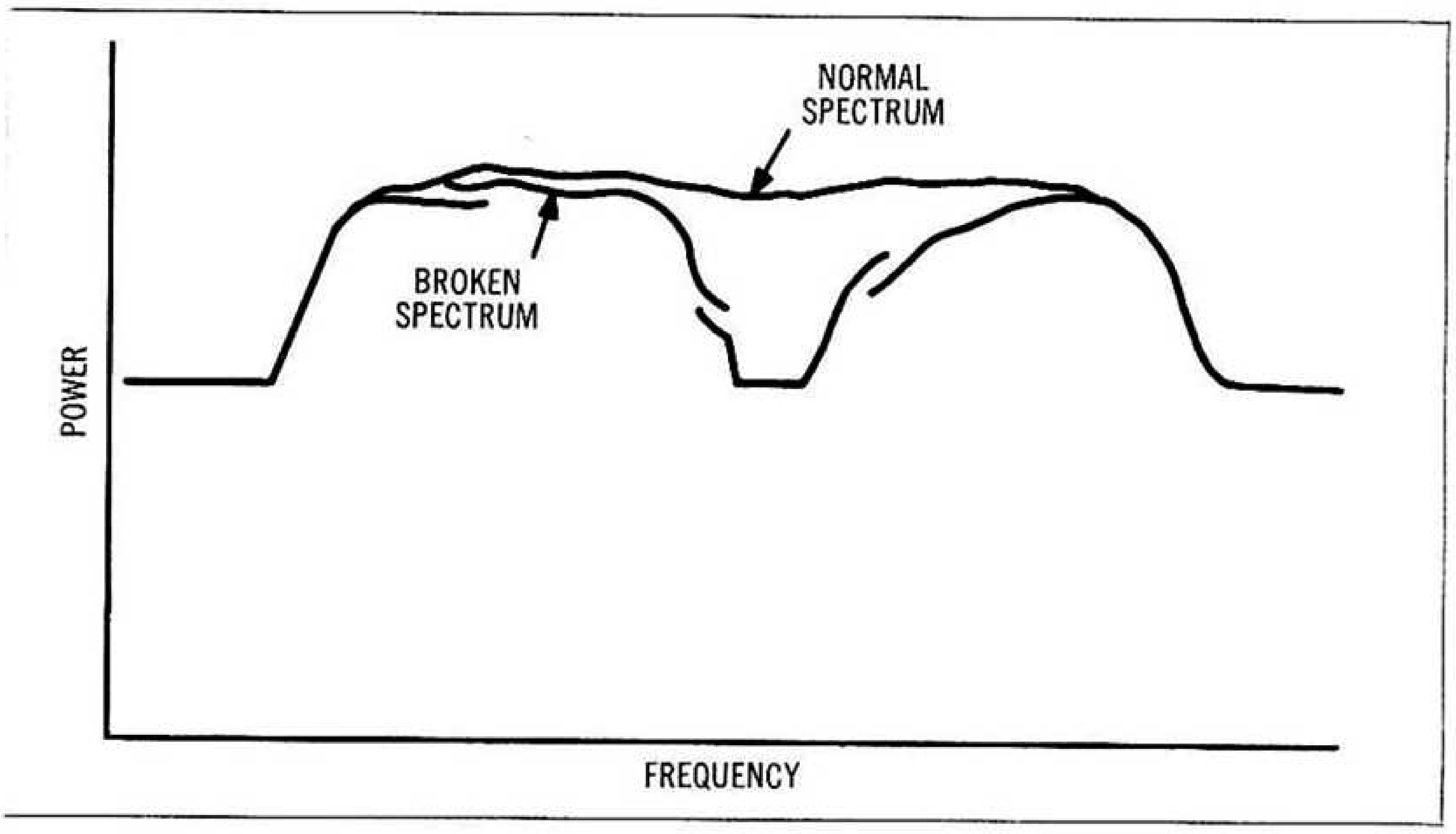


Figure 23—Breakup of Power Spectrum Due to Mismatch

Intermediate power VTM's (approximately 1 to 10 watts) have efficiencies (which are a function of both power and bandwidth) ranging from 15% to 40% when operated over 30% to 50% bandwidths in L or S band.

Low power, 100 mw VTM's, operating over octave bandwidths, will have efficiencies ranging from 5 to 15%.

effects on operating frequency

PULLING

A change in the VTM operating frequency caused by external effects such as load variations is often referred to as pulling.

Load variations in the form of changes in VSWR, as well as changes in phase, will cause deviations in the VTM frequency. An S band VTM, operating into a 1.2-to-1 VSWR which is varied through all phases, can change frequency by ±0.5%. A VSWR of 1.05-to-1, will decrease this change to 0.09% when operated through all phases. Thus the preference for a low VSWR becomes evident; furthermore, a load with a fixed phase will also decrease the pulling of the VTM. In addition to the change in frequency caused by reactive variations in the impedance, the pulling phenomena will produce variations in the power output because of changes in the load resistance. (See the Power Variation Section, Page 10 and the load sensitivity section, Page 13.)

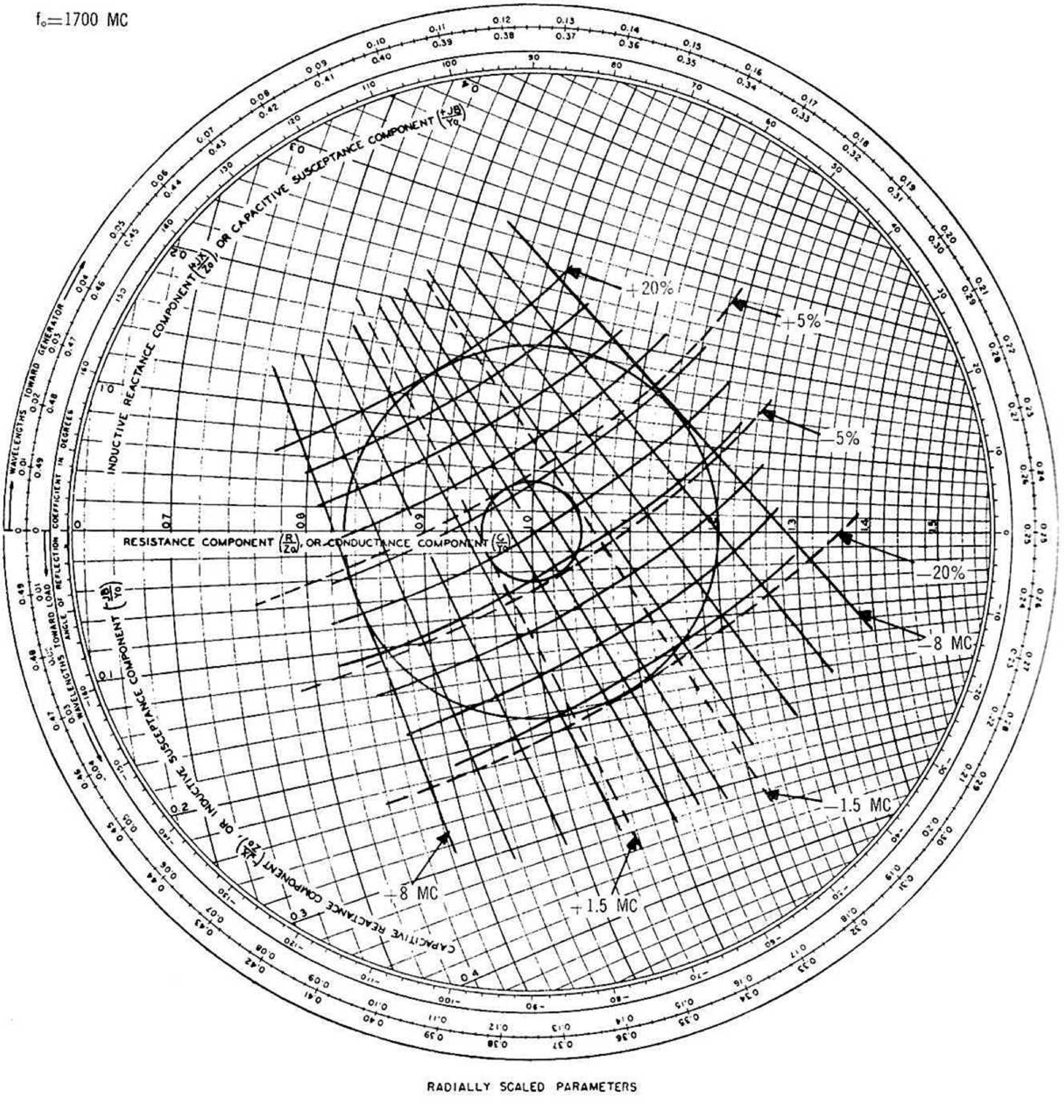


Figure 24—Effect of VSWR and Phase on VTM Power and Frequency

Another effect must also be considered in frequency pulling—the long lines effect present when the load is many electrical wavelengths from the VTM. This causes variations in the tuning characteristic (as discussed in the sections on Linearity and Slope Deviation), and consequently in the VTM operating frequency. Ideally the load should be as close to the VTM as possible.

In many cases where mismatches are part of the system, VTM packages built by General Electric contain an integral attenuator, isolator or circulator to reduce loading sensitivity.

PUSHING

This magnetron characteristic can be defined as a change in operating frequency due to internal effects on the VTM. Two main internal sources of pushing are changes in filament temperature and changes in injection voltage. Both cause variations in anode current and operating frequency.

The rate of frequency change with heater current depends on the filament being used in that particular type of VTM.

In low power VTM's the injection electrode can cause pushing at a 0.2 mc/v rate; hence, changes of 50 volts which may change the power output by 3 db will shift the frequency by 10 mc. Thus in S-band, with a nominal injection voltage of 200 volts a 25% change in injection voltage will produce a frequency shift of approximately 0.3%.

load sensitivity

The voltage tunable magnetron is a load sensitive device. Its parameters—such as the tuning characteristics, power output and operating frequency—depend on both phase and VSWR of the load. Some of these effects have been presented previously.

An indication of the effect of mismatch and change of phase can be seen by consulting the Reike Diagram in Figure 24. Assume you are operating a 3 watt VTM at one frequency (in this case f_0=1700 mc). A mismatch of 1.2-to-1 VSWR will produce a set change in frequency and power depending on the phase being reflected back to the VTM. If the load undergoes a 360° change in phase (represented by traveling completely around the 1.2-to-1 VSWR circle) then the VTM frequency and power will be pulled continuously by the amount shown on the orthogonal lines representing percentage changes in power and absolute changes in frequency. Orientation of the orthogonal frequency and power lines depends on a combination of the load and operating frequency. A change in the operating frequency, with the load remaining fixed, will rotate the entire set of the orthogonal lines to a different position. Furthermore, the entire representation does not necessarily have to be centered on the Reike Diagram as has been done here for simplicity purposes. This example assumes that these conditions exist on the anode vanes of the VTM and that the resistance is equal to the characteristic impedance (Z_0). The entire presentation will move away from the center for a normalized resistance other than one.

Reduction of the VSWR will decrease changes in frequency and power considerably (see VSWR of 1.05-to-1). This indicates the importance of using a well matched load or isolating the VTM with a properly matched attenuator, isolator or circulator.

VTM noise

Noise is generally put into two categories with respect to VTM's: IF noise and spurious output. IF noise is that which is integrated over a prescribed bandwidth at a specific center frequency above and below the carrier. The noise level is referenced to the carrier power and is expressed as a signal-to-noise ratio in db/mc.

Noise in narrow band VTM's has been measured at 100 db/mc below carrier at 30 mc from carrier. Wide band VTM's are capable of noise 90 db/mc below carrier at 30 mc or 60 mc from carrier. Broadband IF noise integrated from 100 KC to 100 mc from carrier has been measured 65 decibels below the carrier level. A typical noise measurement system is shown in Figure 25. Here the output of the VTM is fed into a mixer where the noise of the VTM beats against the carrier. The IF amplifiers will pass the noise components whose frequencies are within the particular IF bandwidth. These are displayed on the oscilloscope. A calibrated signal, generally from a signal generator with a calibrated attenuator, will also be presented on the scope. The level of the calibrated signal is adjusted until it is equal to the noise, whereupon a reading of the attenuator dial will indicate the noise level with respect to the signal generator's unattenuated output. This is then referenced to the carrier level of the tube fed into the mixer.

Spurious output results from an interaction of the electron beam with narrow band impedance of adequate magnitude to produce appreciable signal levels. These signals may be of sufficient strength to produce false indications in a sensitive, low noise receiver such as those used in radar surveillance. Spurious VTM output, which includes harmonics as well as other extraneous noise, is measured at about 60 decibels below carrier. On octave band tubes, the second harmonic is approximately —45 db. The measurement of spurious output is accomplished by noting the spurious signal level across the entire bandwidth and in specific cases, the harmonics, when the VTM is operated at a number of equally spaced, fixed frequencies within the specified bandwidth. A substitution method employing a calibrated attenuator

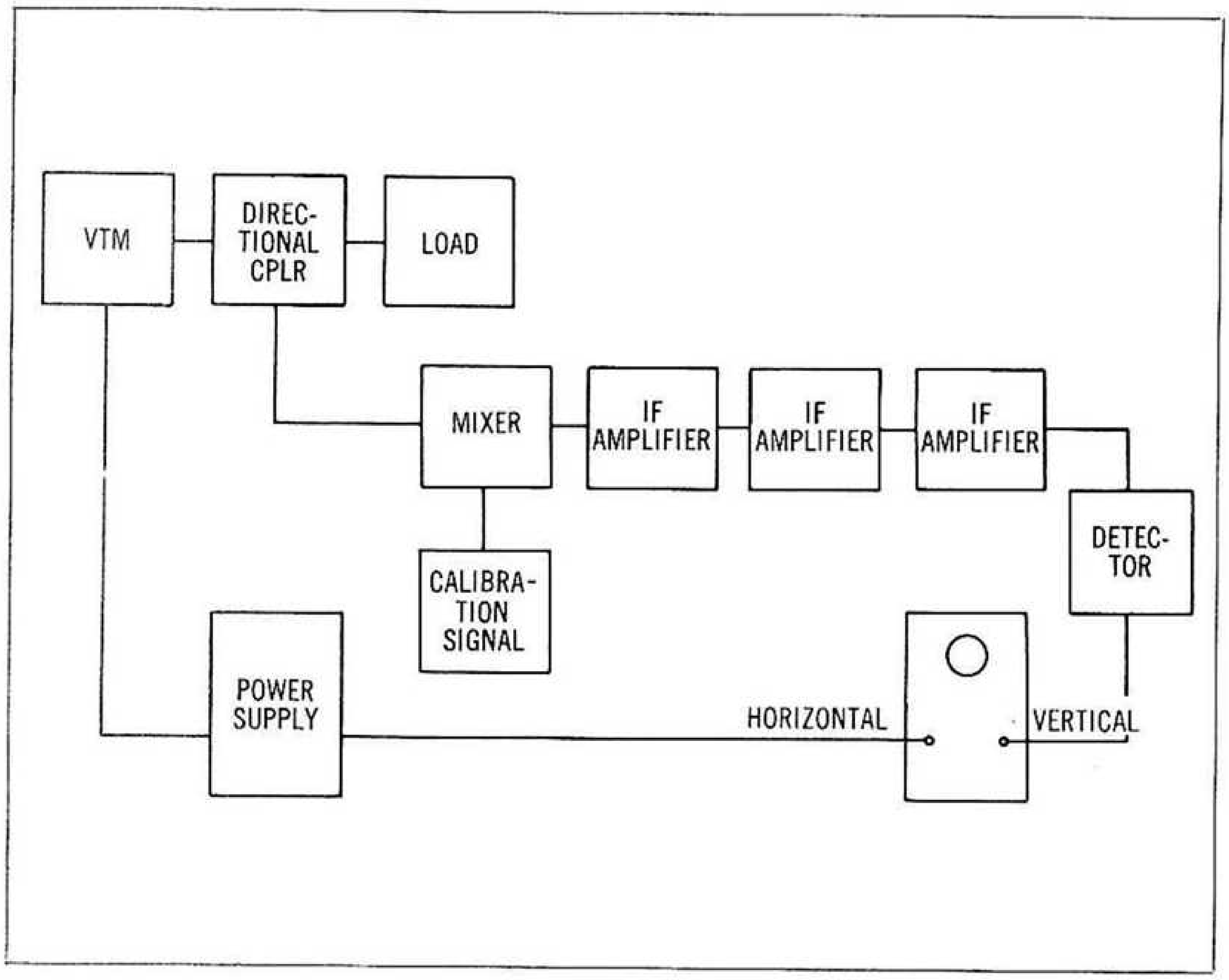


Figure 25—IF Noise Measurement System

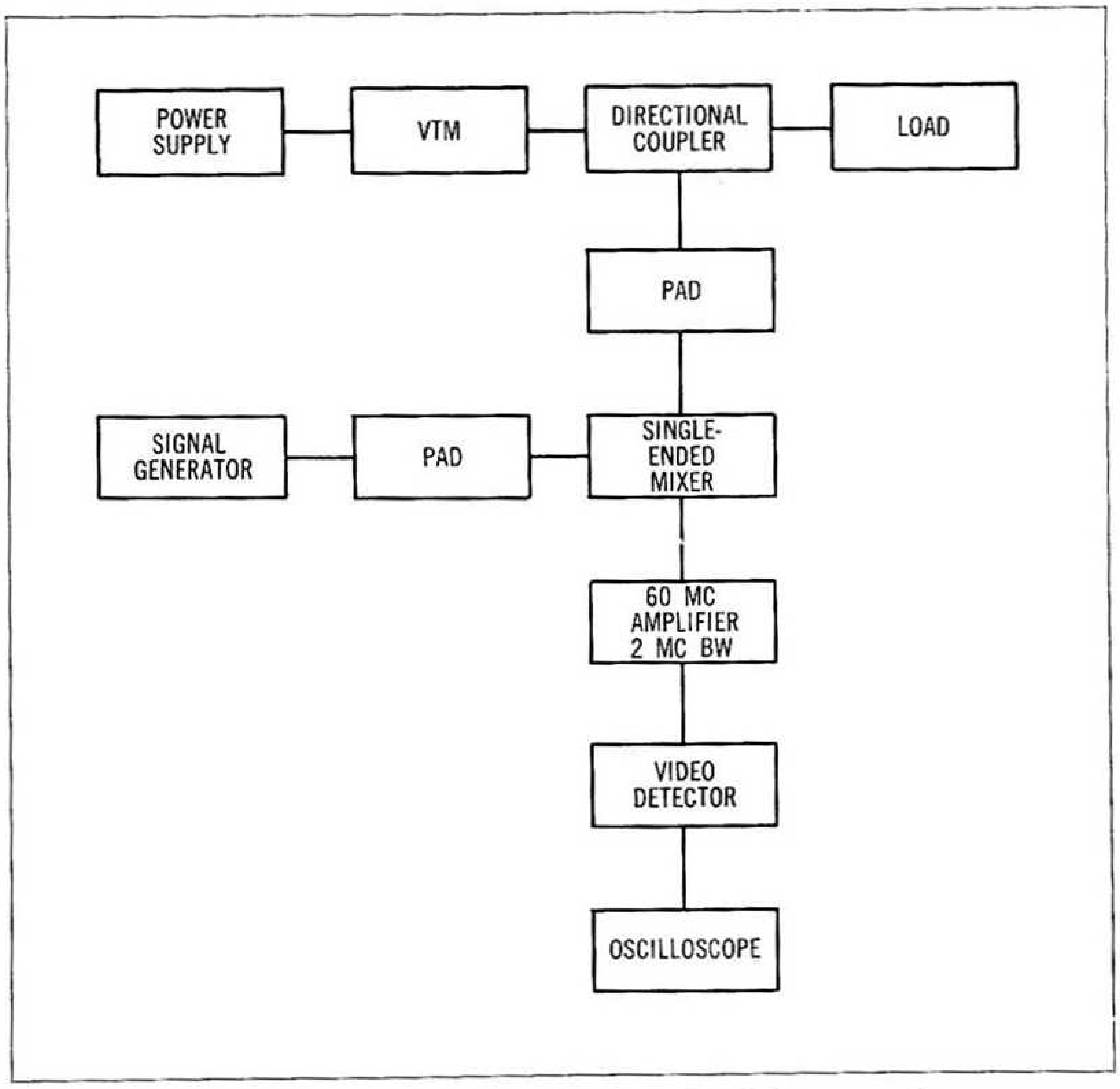


Figure 26—Block Diagram of Spurious Signal Measurement

on a signal generator and a suitable superheterodyne detector are used. (See Figure 26.)

VTM noise only tens of kilocycles from the carrier is important in many test equipments such as sweepers and spectrum analyzers. One basic problem in aligning the VTM for low noise close to carrier has been the lack of a dynamic method for measuring the noise as the VTM is being swept over the prescribed band. The previously used IF method of measurement breaks down. (See Figure 25.) Response of an IF amplifier operating at these low frequencies is so slow that the sweep modulation rate on the VTM must drastically be reduced. Unfortunately this slow sweep rate does not provide an adequate scope presentation of the swept noise characteristics which must be monitored while the VTM is being aligned. Thus the ultimate capability in this area is relatively unknown when compared with the noise levels measured further from carrier. All present evidence points to a higher noise content close to carrier—approximately 50 db/mc below carrier at 10 KC from carrier. Reduction and flattening of the noise level takes place further from carrier. From 100 KCS out to 100 mc and beyond, IF noise levels of 90 db/mc on wide band VTM's are practical; and apparently, at frequencies greater than 100 mc from carrier, there is very little improvement in noise performance.

For optimum, low noise performance a VTM should be factory aligned with the actual loading into which the tube will be operating.

environment

Temperature-compensated tubes will limit their frequency change to 0.2% over the range from −20°C to +80°C. Thus, a VTM operating in S-band will not shift frequency by more than 6 mc during a 100°C change in temperature.

RADIATION RESISTANCE

On-site testing at a pulsed reactor facility proved that VTM's are capable of withstanding high levels of gamma and neutron radiation. Repeated exposures to gamma rates up to 1.68×10^7 rads per second and neutron intensities up to 2.55×10^8 rads per second did not affect VTM operation. The threshold of radiation levels that might affect the General Electric VTM's, in fact, could not be determined at this pulsed reactor facility. VTM magnets containing cobalt exhibited no induced radiation activity after the repeated exposures and were not considered a personal hazard.

VIBRATION

The hard mounted VTM will operate at 10g vibration levels from 5 to 2000 cps. When isolation-mounted, the maximum FM from a VTM can be held to 0.1% at levels of 7g from 200 to 2000 cps.

SHOCK

VTM's shocked at 1600g levels have continued to operate normally. One test type had been shocked 45 times—with 30 of these shocks above the 1000g level—and its operation after these tests remained normal.

ALTITUDE

General Electric VTM's have been designed and produced to operate in missile as well as airborne environments.

TEMPERATURE

Depending on its power requirements, the VTM may operate at −55°C to +125°C with only conduction cooling required.

shielded VTM's

VTM operation depends on maintaining the same magnetic field used when aligning the VTM at the factory. During this alignment, the tube's parameters must be carefully monitored on oscilloscopes and meters, and recordings must be made of the operating voltages and currents required to produce a package which meets specifications. Any subsequent change in, or distortion of, the magnetic field destroys the careful factory alignment and degrades VTM performance; also failure to keep ferro-magnetic materials at suggested distances from the VTM packages or use of ferro-magnetic tools and dynamic fields (such as those generated by transformers) can adversely affect the magnetic field of the VTM.

MAGNETICALLY SHIELDED VTM'S

Magnetically shielded VTM's will provide a solution to the above problems. General Electric has developed a VTM package with improved magnetic circuitry and new (but inexpensive) magnetic materials which lend themselves to shielding techniques never before possible. Shielded VTM's can be stacked one on top of the other with no degradation in performance, and this package will be unaffected by transformer fields normally found in many electronic systems. Such a decrease in degaussing susceptibility allows the shielded

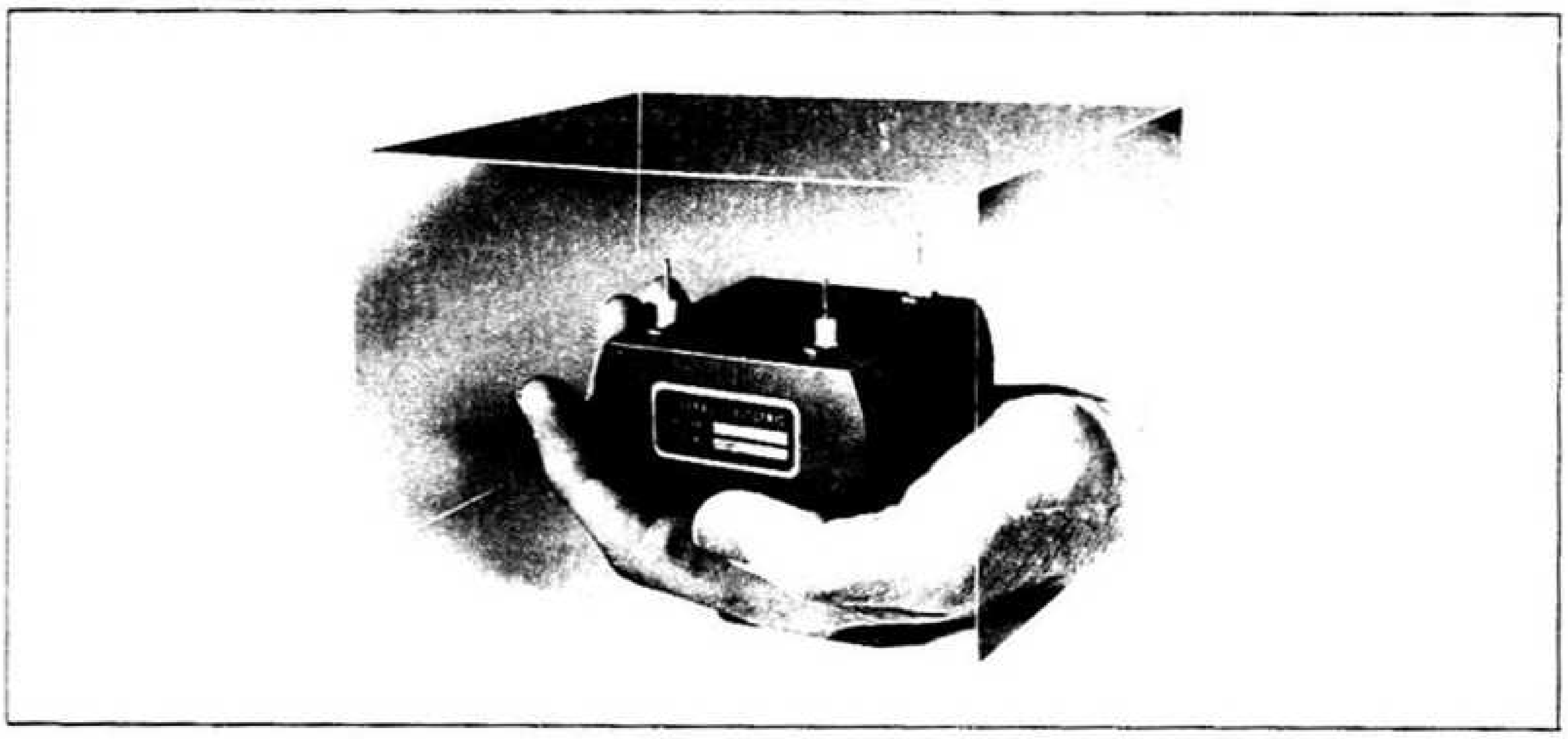


Figure 27—Shielded VTM Compared with Space Requirements for Conventional VTM

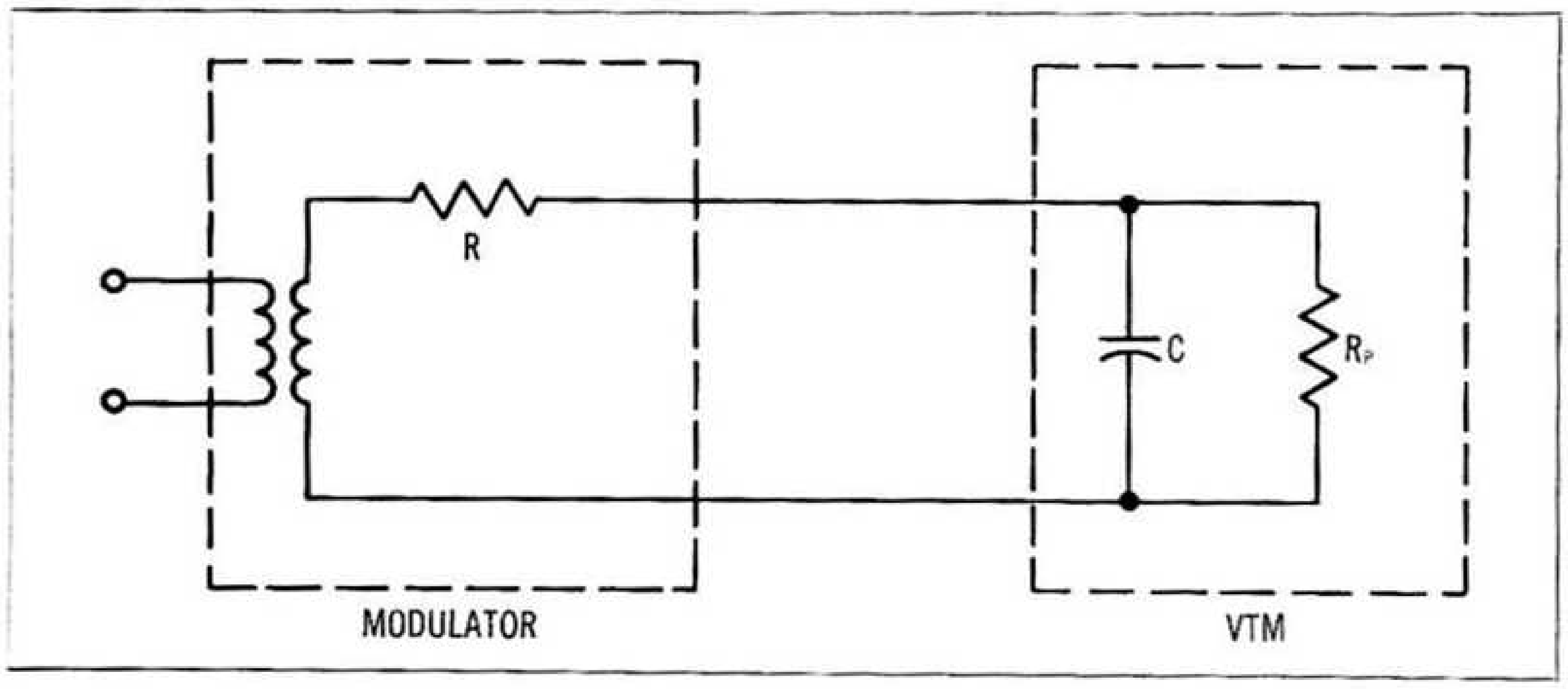


Figure 28—Equivalent Circuit for Frequency Modulating the VTM

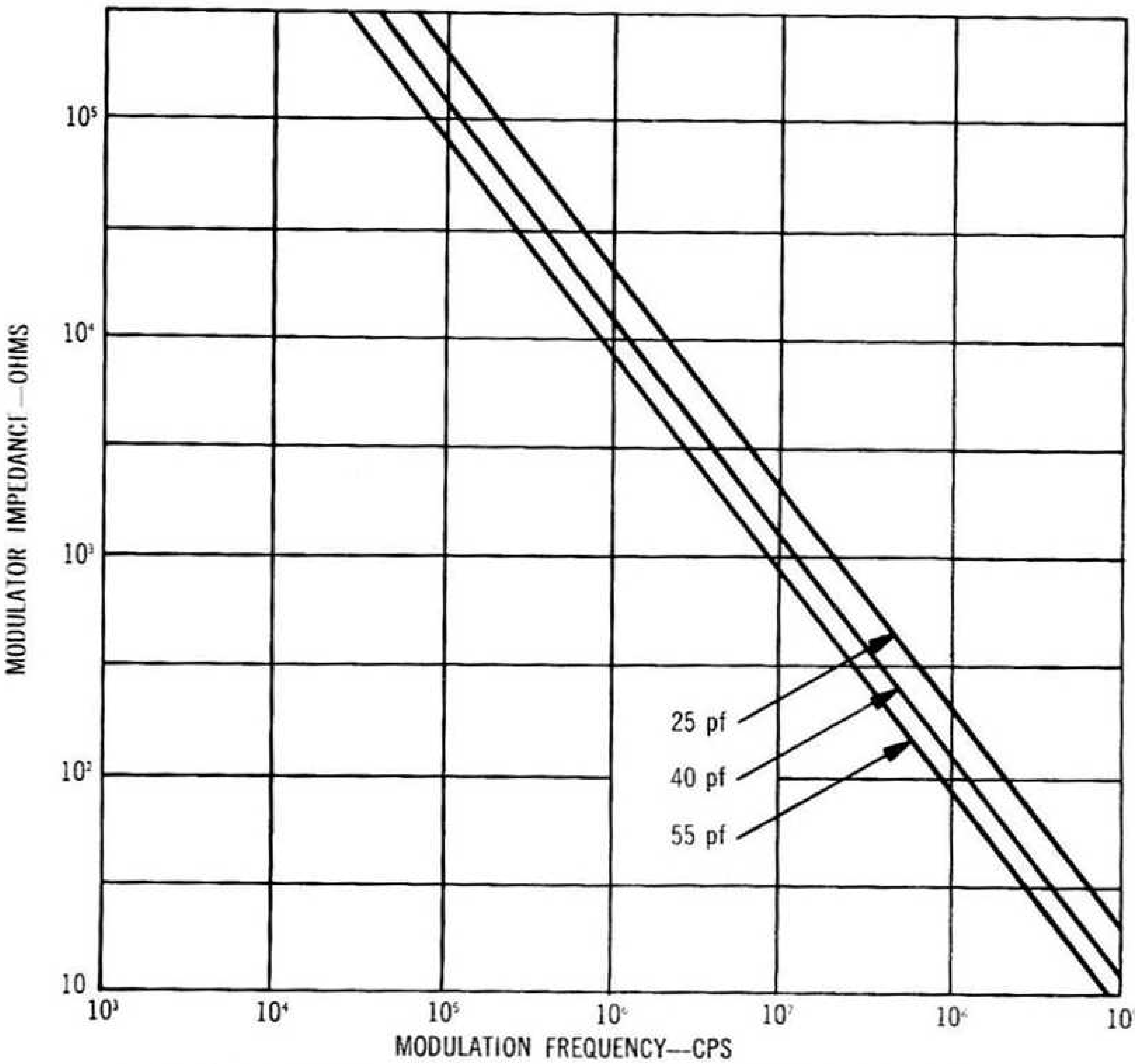


Figure 29—Maximum Modulator Impedance vs. Modulation Frequency

VTM to be used in compact, high density equipments where passive magnetic devices must come in direct contact with the tube. Previous requirements for minimum spacing or protective boxes are eliminated. Figure 27 indicates the reduction in space requirements now possible through integral magnetic and RFI shielding.

RFI SHIELDING

The magnetically shielded VTM also incorporates RFI shielding to attenuate stray RF on the d-c leads. This extraneous radiation is annoying as it can produce unwanted modulation, degrade receiver sensitivity and decrease accuracy of the system in which the VTM is operating. RFI shielding reduces stray radiation on the d-c leads to below minus 30 dbm. This attenuation—provided as an integral part of the VTM shielded package—will eliminate the radiation screens, shields and cages normally required with conventional, electronically tuned oscillators employing magnetic fields.

VTM modulation

General Electric VTM's have been modulated at 20,000 mc per microsecond rates thereby, making the VTM a candidate for frequency agility equipments such as broad band, surveillance receivers and electronic countermeasures systems. VTM's are frequency-modulated by changing the anode to cathode voltage. The voltage-frequency relationship is linear (as discussed in the section on Tuning Characteristic). In regard to modulation, the VTM can be presented as a capacitance and resistance in parallel. (See Figure 28.) At high modulation rates, the internal impedance of the modulator and lead impedances assume greater importance while VTM plate resistance (Rp) can be ignored. To increase the frequency, an increase in anode voltage is required and is obtained by charging the tube capacitance C. The time t for charging would be equal to RC where R is the modulator impedance. Thus "t=RC" is an approximation for increasing the VTM frequency at a constant rate. Since the time constant of the RC circuit represents approximately one-half a sine wave, the time for one period of oscillation would be 2t. Values calculated for several VTM types are shown in Table 1 (page 16). Figure 29 is a presentation of modulation impedance as a function of modulation frequency for three different values of VTM capacitance. Approximations were used to arrive at the maximum modulator resistance and a factor of 0.5 or 0.3 should be used to avoid modulation distortion.

MODULATION DATA FOR TYPICAL VTM'S

Tube Type	C Pf	R_P Kilohms	Maximum Modulator Impedance for Various Modulation Rates 1 mc Kilohms	 10 mc Kilohms	 100 mc Kilohms
ZM-6046	35	50	30	3.0	0.30
ZM-6047	35	50	30	3.0	0.30
ZM-6085	40	300	25	2.5	0.25
ZM-6205	110	100	9	0.9	0.09
ZM-6211	40	72	25	2.5	0.25
ZM-6222	140	90	7	0.7	0.07
ZM-6223	40	130	25	2.5	0.25
ZM-6222	140	90	7	0.7	0.07

Table 1

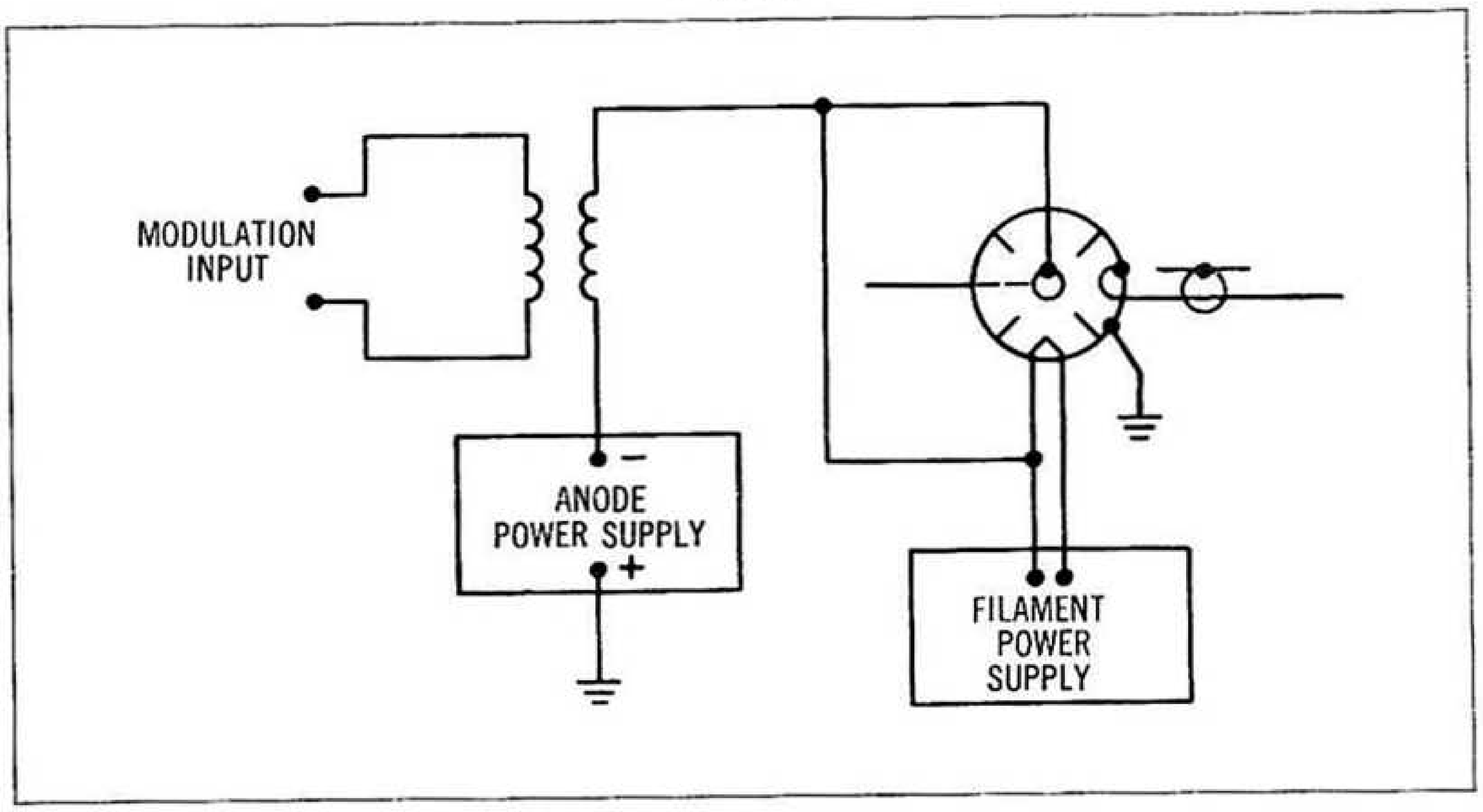


Figure 30—Series Transformer Modulation

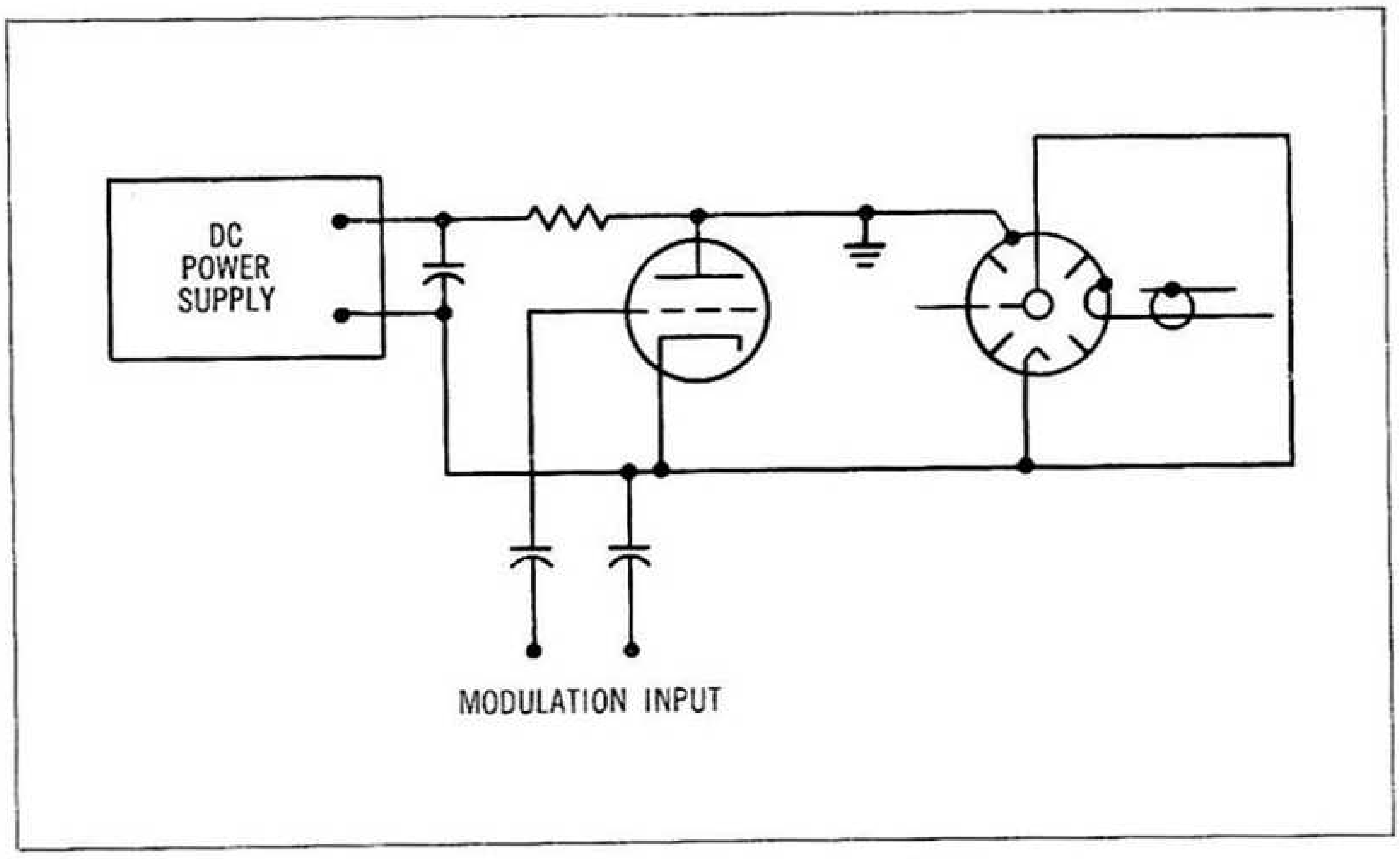


Figure 31—Series Resistor Modulator

FREQUENCY MODULATION

There are many methods for frequency modulating the VTM, but the simplest involves the use of a series modulated transformer where the transformer is connected in series with the power supply. (See Figure 30.) Another method utilizes a series resistor. (See Figure 31.)

AMPLITUDE MODULATION

Amplitude Modulation of the VTM must be limited to changes in power levels of from 3 to 6 decibels depending upon the power output and the bandwidth of the VTM being used. Thus pulsing or square-wave-modulating in the VTM is limited due to both small amplitude modulation capability and frequency pushing considerations.

STARTING

Another factor involved in pulsing and square wave modulating is the starting characteristic of the VTM; that is, the ability of the VTM to assume immediate coherent oscillation as soon as all required voltages have been applied. Broadband low power VTM's are most suspectible to starting problems. At the low end of the frequency range—normally the "hard starting" portion of the band—the space charge is close to the cold cathode and the circulating current and the r-f fields are small. All are poor conditions for starting. To improve them, it is necessary to fill up the interaction space between the anode and the cathode by dispersing the space charge away from the cold cathode. This increases both the r-f fields and circulating current. One way to accomplish this is to use the following voltage sequence for turning on the tube:

(1) apply the heater and injection voltage.

(2) turn on the anode-to-cathode voltage. For best starting results, one should first perform evaluation tests on the VTM with the power supply the VTM will be using in the equipment. Another approach which has produced excellent results is to perform the starting tests with the pertinent power supply while the VTM is being aligned at the factory.

Coupled with the r-f voltage and circulating current considerations for starting is the impedance presented to the current. If the impedance is low, even a moderate amount of current will not provide an adequate condition for starting. Furthermore, the impedance over the prescribed bandwidth has two restrictions in that (1) the power variations across the band must generally be kept to a minimum and (2) the tuning characteristic must be as linear as possible. Thus the impedance must satisfy power output, power variation, linearity and starting requirements. The cavity and circuitry must essentially shape the impedance characteristic across the band to meet all these requirements.

Once again, factory alignment of the VTM using the specific power supply involved will produce a VTM with excellent starting characteristics.

fixed frequency operation of VTM's

While VTM's are used predominantly in swept, broadband applications, they have also found use in fixed frequency operation. VTM's are also capable of being electronically switched from one method of operation to the other.

With a well regulated power supply, frequency variation can be held to ±0.03 percent and, if tighter limits are required, a feedback approach can be used to provide more precise control.

The following discussion of feedback circuits includes frequency comparison, phase comparison and injection locking. The general characteristics of each circuit are summarized in Table 2.

FREQUENCY COMPARISON

In a frequency-modulated telemetry system, frequency tolerances are small. Response time of the feedback loop must be slow enough to retain the lowest frequency components of the modulating signal. Within these requirements, the frequency comparison circuit in Figure 32 will provide satisfactory control.

In this circuit, alternate samples of the tube frequency and a frequency standard (such as a crystal oscillator) are compared by means of a trigger circuit at a rate determined by a square wave generator. Switching rates must be well below the lowest frequency-modulation rate of the system. The sampled signals are amplified and converted into voltage by a discriminator. This voltage is then amplified and oriented by a synchronous detector which transmits a correction signal to the modulator or power supply.

VTM's with this type of feedback circuit have been used successfully in a transmitter for communication in space. The critical center frequency is held to within 0.002 percent. To retain the lowest frequency modulation of 700 cycles per second, a 200 cps switching rate was used. In a frequency comparison circuit, the output voltage of the power supply must be relatively stable over one complete switching cycle since the circuit cannot sense rapid frequency changes. If the ripple frequency approaches or exceeds the frequency of the square wave generator, suitable power-supply filtering will be necessary.

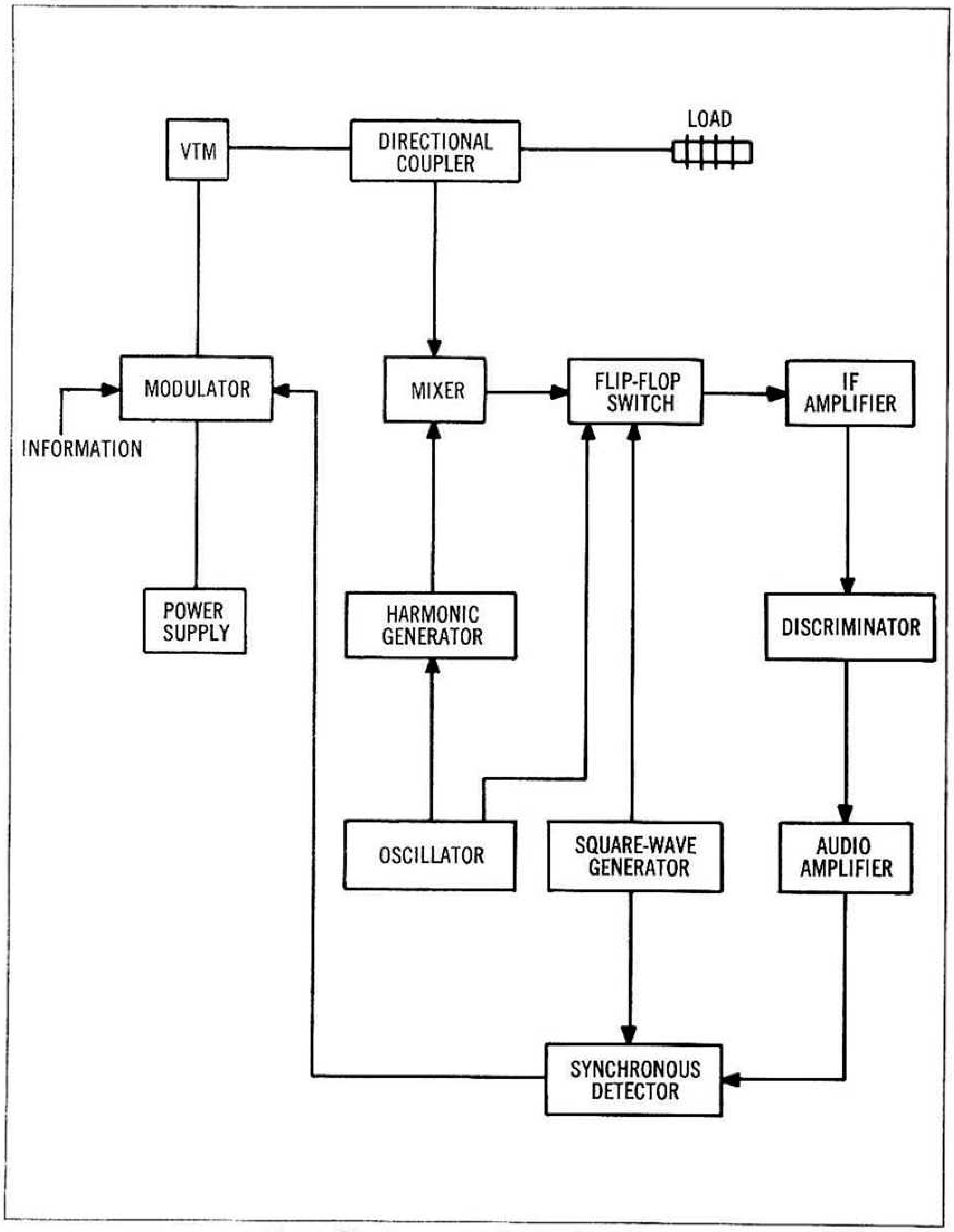


Figure 32—Frequency Comparison Chart

CHARACTERISTICS OF VTM FEEDBACK CIRCUITS

Circuit	Frequency Error	Ease of Modulation
Frequency Comparison	0.002%	Good at high frequencies. Limited at low frequencies by comparison rate
Phase Comparison	Crystal accuracy	Good at high frequencies. Limited at low frequencies by response speed of network
Injection Locking	Same as injection frequency within locking range	Good, by modulating injection frequency at any rate. The frequency deviation must be within the lock-in frequency range
No feedback	1.0%	Good

Table 2

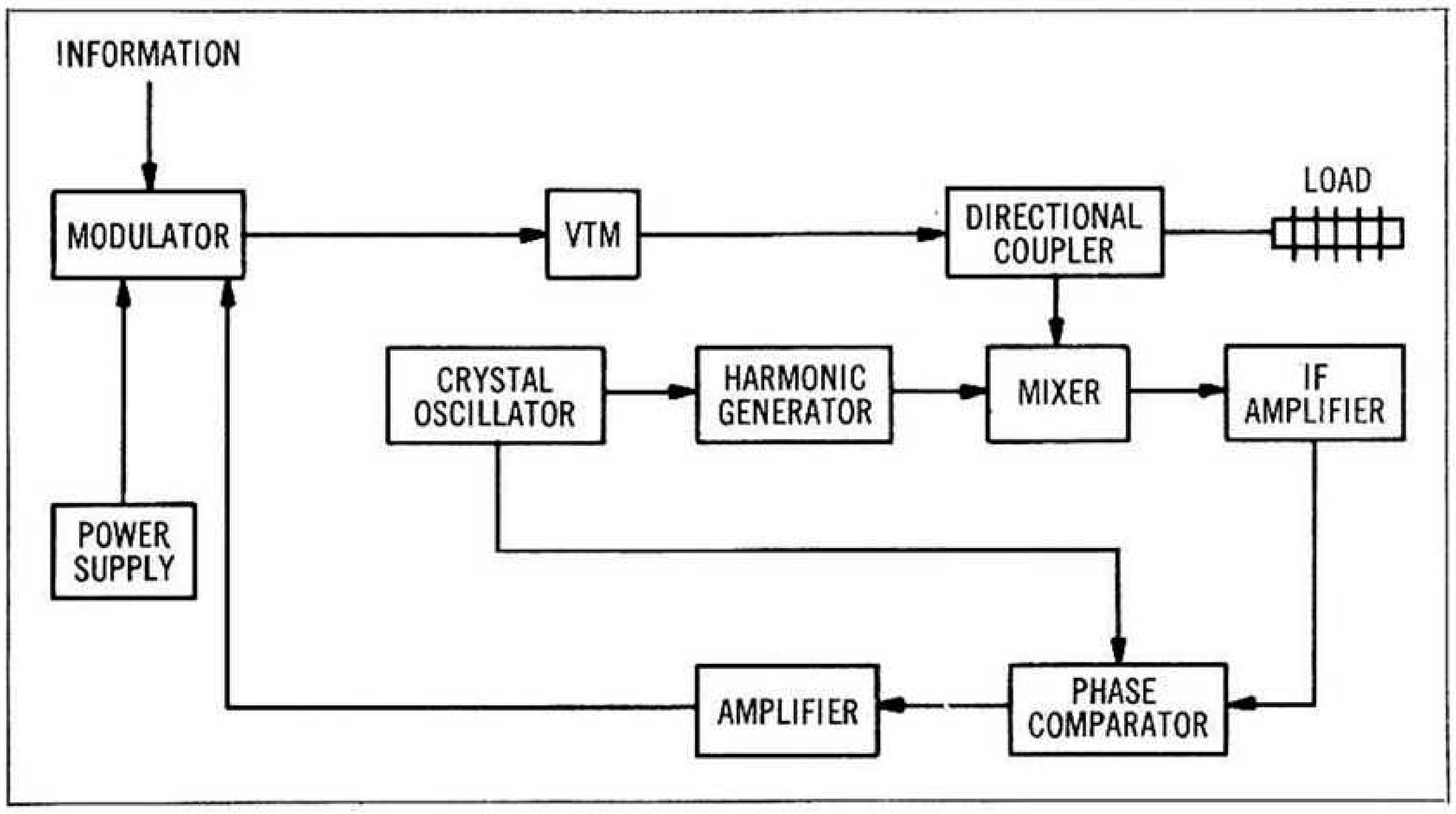


Figure 33—Phase Comparison Chart

An unbalanced condition may result when the frequency modulation rate approaches an odd harmonic of the switching frequency. This condition can be eliminated by a filter at the output of the synchronous detector.

PHASE COMPARISON

The phase comparison circuit in Figure 33 mixes a portion of the magnetron output with a harmonic of a crystal oscillator. The resulting signal is fed into an intermediate-frequency amplifier of the same frequency as the oscillator. Next, the amplified signal is phase compared directly with the crystal-output frequency, and the error signal is then amplified and fed back to the tube for frequency correction.

This circuit maintains the magnetron frequency at crystal accuracy. This accuracy can be maintained at regular intervals in the tuning range determined by the harmonics of the crystal; thus it is possible to phase-lock onto one frequency or step-tune the tube across its entire frequency range. In this service, the response time of the feedback circuit determines the lowest frequency modulation rate.

The allowable power-supply variations are determined by the crystal frequency and by the tuning sensitivity of the VTM. For example, a 60 megacycle crystal with a harmonic generator produces a signal every 60 megacycles in the desired frequency range. Here, a tube with a tuning sensitivity of 3 megacycles per volt will limit the power supply voltage variation to ±10 volts, and a greater voltage variation will cause the system to lock onto an adjacent harmonic.

INJECTION LOCKING

The VTM can be "slaved" to the frequency of a low level signal by injection locking. The effect of this method of operation on the normal tuning curve is shown in Figure 34. Figure 35, meanwhile, shows the trade-offs between lock-in range and gain. The locked frequency range depends on the injected power level, the power output of the VTM and its tuning sensitivity. Increased power output or tuning sensitivity will decrease the lock-in range of the VTM while an increased level of injection signal will increase the lock-in range, but at the expense of gain.

Without modification, a voltage tunable magnetron can be frequency-locked by simply feeding an injection signal through the output connector of the tube. This can be done with a circulator, a directional coupler or a tee. Advantages and limitations of each injection method are shown in Table 3 on page 19.

The preferred and most efficient method is with the circulator. The insertion loss is less than 1 decibel and the loss of in-

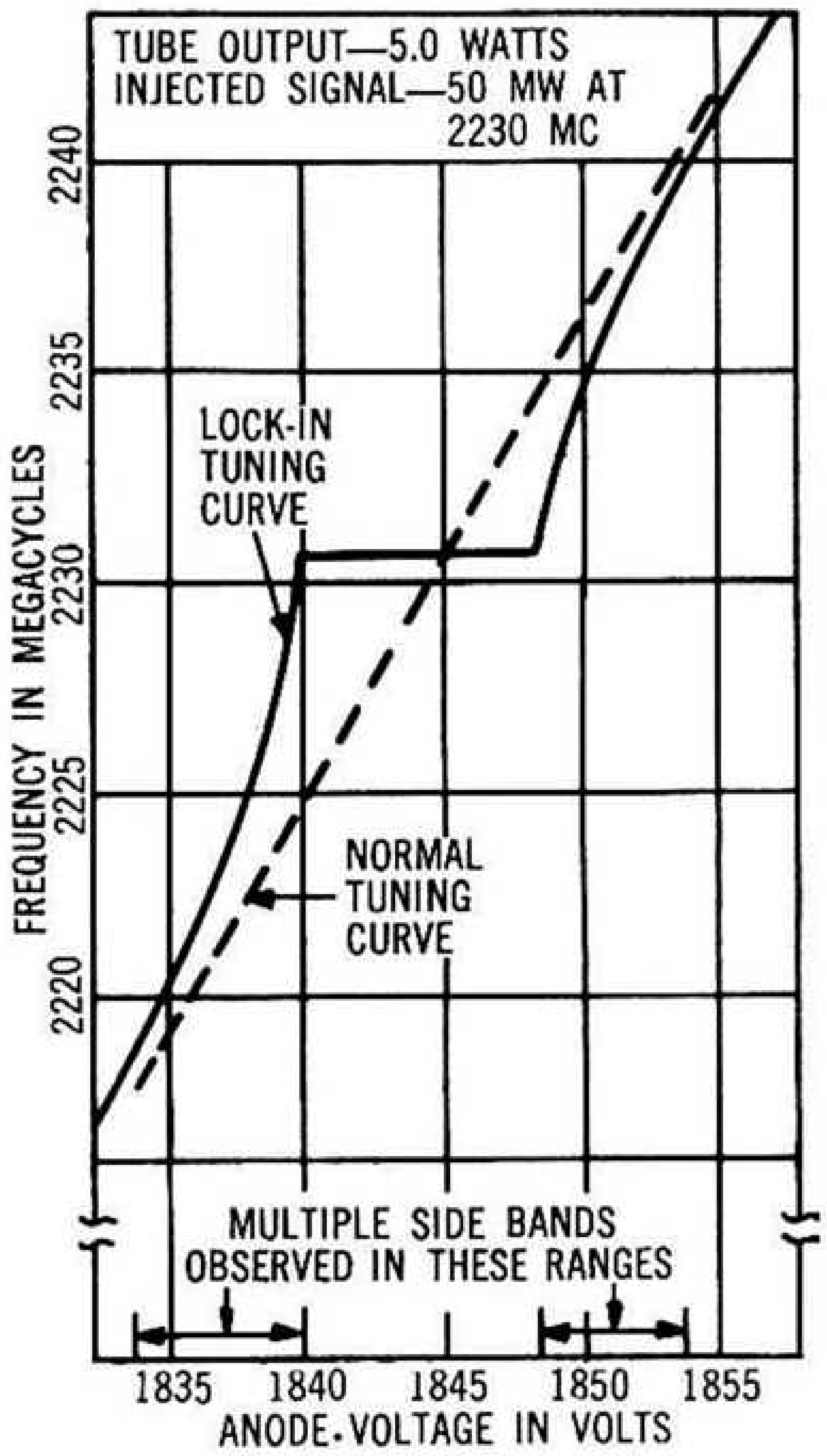


Figure 34—Effect of Injection-locking on Tuning Characteristic

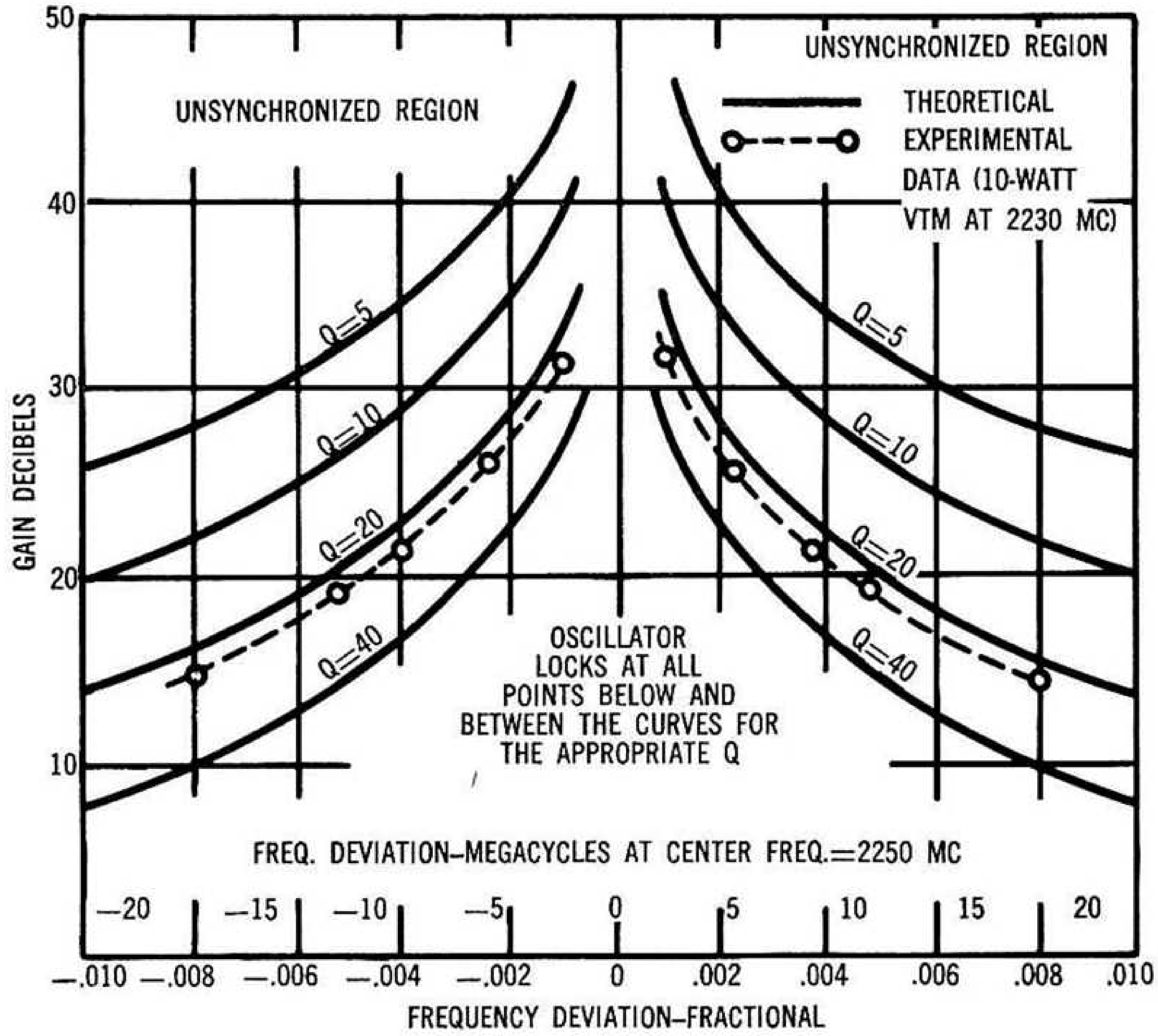


Figure 35—Injection Locking Capabilities

jection power only 2 decibels. Bandwidth is limited by the circulator—a particularly significant problem where temperature extremes are involved.

The directional coupler circuit offers octave bandwidth and low insertion loss, but the injection power loss is high. If a 6-db coupler is used, injection loss is 7 db; however, the insertion loss is only 1.6 db in a given octave of bandwidth.

The tee circuit has the widest frequency range of the three circuits although the insertion loss is high. In this circuit, an insertion loss of 3 db and an injection loss of 4 db can be expected.

typical telemetry performance

When injection-locking the VTM with the circulator (as shown in Figure 35), a typical telemetry VTM may have a center frequency (f_o) of 2250 megacycles, a Q of 10, a power output of 100 watts, a gain of approximately 25 db, and a lock-in range of 25 megacycles so that Δf_o equals 12.5 megacycles. Thus, a signal of one watt would be entirely adequate, and this performance would be at a conversion efficiency of approximately 65 per cent.

FREQUENCY RESPONSE

Another point of interest is the modulation capability of an injection-locked VTM. For a VTM with 20-db gain, center frequency of 2250 megacycles and Q of 10, the "pull-in" time is about 0.05 microseconds. This is the time required to sweep across the entire lock-in range and corresponds to one-half cycle of modulation. Thus, a maximum modulation frequency of approximately 10 megacycles is possible.

MULTIPLEX OPERATION

In addition to the VTM's low Q and high efficiency, another outstanding characteristic is its linear voltage tuning. The tunability feature, which will serve for drift correction, can also be used when a number of information channels are to be transmitted on a time-multiplex basis. Instead of sequentially modulating them on one carrier, they may be given separate carriers within the telemetry band being used. The VTM voltage can be stepped so that it locks to each carrier in turn for an appropriate time. (See Figure 36.) The time taken to re-lock to a new channel depends on the input capacity of the VTM and the current capability of the power supply. If the capacity is 35 pico-farads and the supply is capable of 100 milliamperes momentarily, a 300 volt-step can be completed in 0.1 microseconds. Thus, a one-megacycle switching rate is possible.

COMPARISON OF INJECTION CIRCUITS

Circuit	Insertion Loss	Injection Power Loss	Octave
CIRCULATOR	Less than 1 db	2 db	Octave
DIRECTIONAL COUPLER	20 db Coupler, 0.3 db	21 db	Octave
	10 db Coupler, 0.9 db	11 db	Octave
	6 db Coupler, 1.6 db	7 db	Octave
TEE	3 db	4 db	Greater than Octave

Table 3

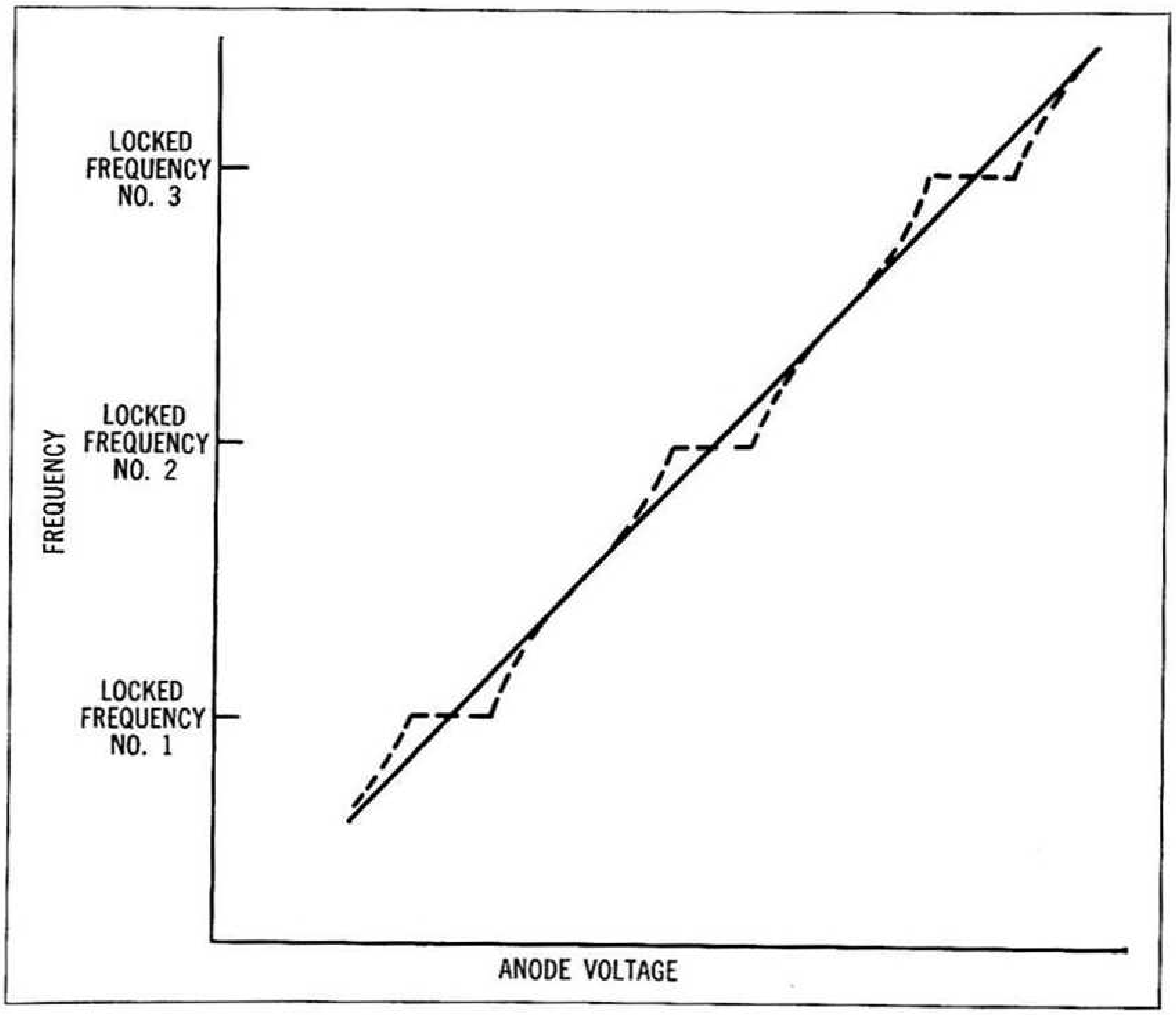


Figure 36—Step Injection Locking the VTM

specific applications

LOCAL OSCILLATORS

The VTM is used in low noise, broad band receivers as a local oscillator. The linear, electronic tuning simplifies calibration and equipment requirements. In addition the minimum power variation over the prescribed frequency reduces the demands on leveling circuits. Its broad band and rapid modulation make the VTM an ideal component for surveillance radar.

TEST EQUIPMENT

Power output in the watt region and octave tuning make the VTM attractive for signal generators and swept signal sources, or as a swept signal oscillator for test equipment.

ELECTRONIC COUNTERMEASURES (ECMs)

G-E VTMs with power levels approaching 500 watts and conversion efficiencies of 65% possess all the specifications for active ECM equipment requiring high efficiency, high power density, rapid tuning and low power variation.

The VTM's low noise, wide bandwidth, flat power spectrum and frequency agility meet the requirements of sophisticated ECCM equipment.

RADAR ALTIMETER & PROXIMITY FUSES

Accuracy in measurement results from the linear tuning characteristic and flat power spectrum of the VTM. Radar altimeters will also find that the VTM's electronic tuning overcomes the limitations of mechanically tuned components. High power and high efficiency VTMs further serve to reduce equipment size and weight without sacrificing long range capability.

TELEMETRY AND COMMUNICATIONS

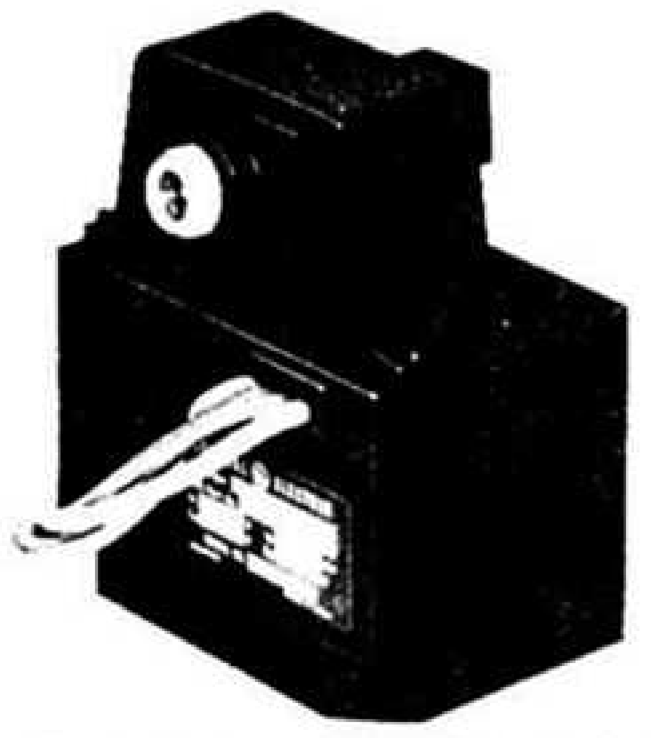
Injection locking the VTM suggests its use as a frequency modulated amplifier. The high efficiency and broad controllable frequency characteristics make the VTM suitable for communications.

Its tuning linearity, flat power spectrum and electronic tuning make the VTM a precise and flexible telemetry component. (A more detailed discussion of telemetry applications appears on page 19.)

typical package designs

MAGNETIC AND RFI SHIELDING

Becoming the standard for low and intermediate power VTM's. Rapidly replacing the conventional and unshielded E magnet VTM package. Package weights range from 1.5 to 3.0 pounds and nominal package dimensions are 3"x3"x2". Both weight and size depend on power, bandwidth and center frequency.



MAGNETIC SHIELDING AND INTEGRAL ISOLATOR

This design is being used primarily on high power VTM's although it is adaptable to low and intermediate power packages as well. The integral isolator allows the systems designer wider latitude in regard to VTM loading and eliminates an extremely important tube-systems interface. Typically a 100-watt, S-band VTM with 20% bandwidth will weigh 3.0 lbs. and measure 3" x 3" x 4" excluding isolator.

MINIATURIZED, SHIELDED VTM

Many applications place a premium on package size. Use of special magnetic materials enables a 10 watt, S-band VTM with 30% bandwidth to be packaged in a 1" x 1¾" x 1¾" size. As with the other shielded VTM's, this package lends itself to high density, compact equipments, where passive magnetic materials may be in contact with the VTM. The weight of this package is less than 1 lb.

For more information on VTM's, consult your nearest
General Electric Electronic Components Sales Office, or write to:
Microwave Tube Operation
General Electric Company
Building 269
Schenectady, New York 12305
or telephone: (518) 374-2211 Extension 5-3433 or 5-4273

GENERAL ELECTRIC