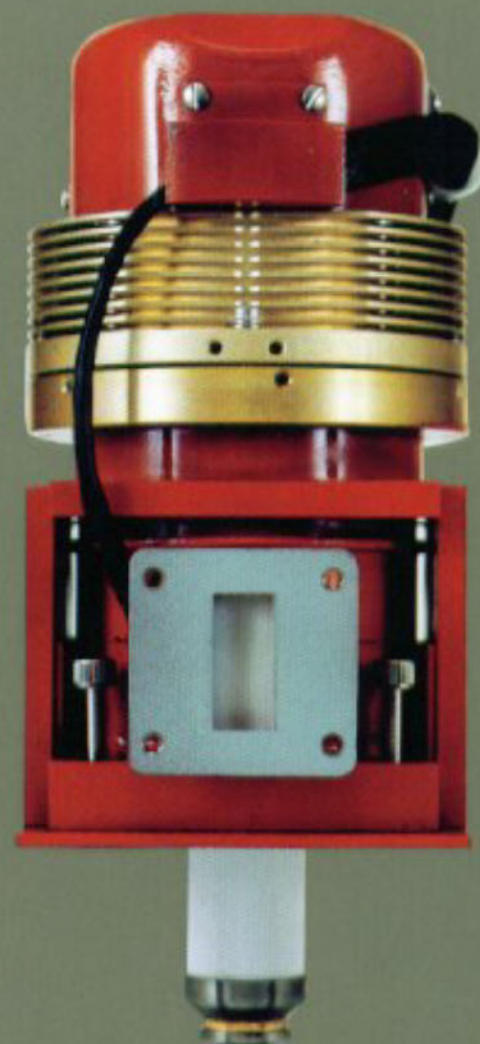


ACCUSWEEP™ MAGNETRONS



Application
and
Operation
Data



*Communications & Power Industries
beverly microwave division*

ACCUSWEEP™ MAGNETRONS

APPLICATION AND OPERATION OF ACCUSWEEP™ MAGNETRONS

Introduction

Accusweep™ magnetrons represent a new tuning technology using a linear motor that increases tube life and reliability and improves system tuning capability. The technology evolved from analysis of magnetron needs in present, new and upgraded systems. Typically, Frequency Agility has been used in magnetron radars to improve target visibility in clutter and to provide anti-jam capability. The coaxial magnetron has proven to be a highly reliable tube with a very long life. This type of magnetron has been combined with many different mechanical tuning systems to provide agility. These tuning systems typically use rotary systems with rotary-to-linear motion converters which result in low reliability of the complete tube package even though the power generator (the coaxial magnetron itself) would otherwise exhibit good reliability. The Accusweep™ magnetron is designed to minimize mechanical wear and provide long life as a complete tube, comparable to the base coaxial magnetron. An example of a 90 kW X-band magnetron follows:

TABLE I - MTBF COMPARISON

LINEAR MOTOR	MAGNETRON MTBF	18,000 HRS.
	ACCUSWEEP™ ACTUATOR MTBF	152,000 HRS.
	TOTAL MTBF	16,100 HRS.
ROTARY MOTOR	MAGNETRON MTBF	18,000 HRS.
	ACTUATOR MTBF	13,000 HRS.
	TOTAL MTBF	7,500 HRS.

Table I shows how an Accusweep™ magnetron becomes a major part of a reliability upgrade. There are more reasons.

WHY ACCUSWEEP™ MAGNETRONS SHOULD BE CONSIDERED:

The reliability upgrade of existing tuners is a major reason for using Accusweep™ tubes. To see this advantage we need to examine prior art actuators and their failure mechanisms.

A good example is the tunable dither design approach on a coaxial magnetron. Dither tubes are a mature technology with acknowledged life and design limitations. In a dither magnetron (Figure 1), two mechanisms combine to drive the tuner either rapidly (30 MHz at 200 Hz) or slowly (1000 MHz at .03 Hz). These mechanisms have 20 mechanical joints, ball bearings, threads, gears, etc., and all have wear-out potential.

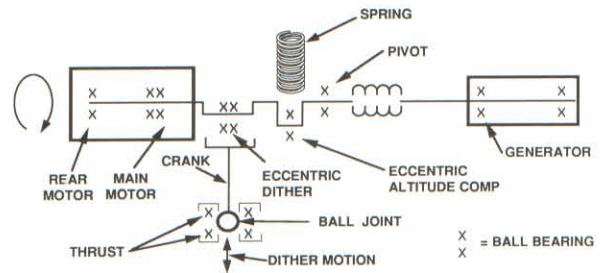


FIG. 1a - MECHANICAL DITHER TUNING (Rotary) 12 Wear Surfaces

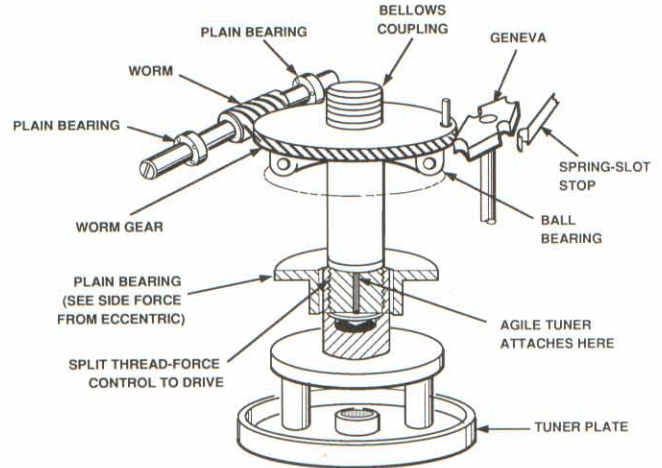
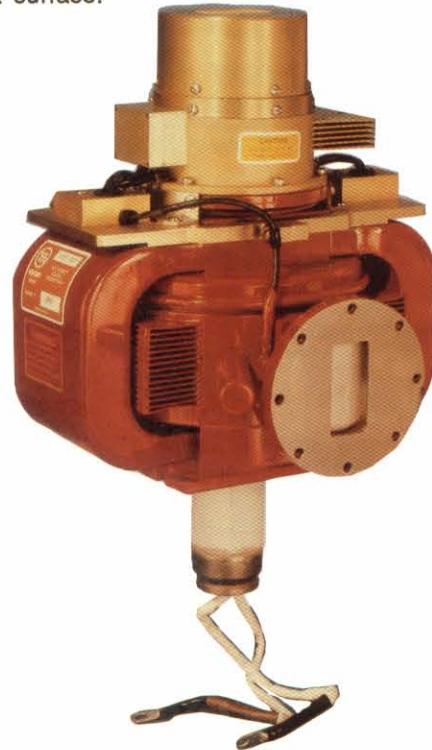


FIG. 1b - SLOW TUNER 8 Wear Surfaces

Details of a dither magnetron tuning drives illustrating contacting wear surfaces. The Accusweep™ has only one contact surface.



VMC-1587 - 200 KW C BAND ACCUSWEEP™ MAGNETRON

The VMC-1587 is designed for shipboard navigation radar and agile weather radar. It has a 400 MHz tuning range and can tune at 50 Hz.

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The Accusweep™ magnetron tuner/actuator uses a floating suspension. Only one plain bearing is used, and that bearing is in well-aligned condition. Comparable reliability figures for the two are as follows:

Dither and slow tuner 26,698 hrs. MTBF
 Accusweep™ actuator 152,000 hrs. MTBF

The Accusweep™ substantially improves MTBF (Mean Time Between Failure).

An important objective of the Accusweep™ design was to provide a short, compact tube with no physically exposed sensitive components. The advantages over older technology linear motor tubes can be seen in Figure 2. The major advances are:

1. More compact motor (uses rare earth magnet),
2. Better cooling,
3. Improved sensor spacing,
4. External bellows cell construction.

Note that the Accusweep™ tube actuator is totally enclosed to protect the sensitive sensors and components, and it has vastly superior handling properties. Use of rare earth magnets makes the tube completely resistant to de-magnetization even though the magnets in the actuator and tube interact.

We have concluded that Varian's Accusweep™ design has life and reliability and form factor advantages over the standard dither approach. The advantages of the Accusweep™, discussed above, also pertain to Accutune™ agile tubes. A good comparison of performance capability, which is significant in anti-jam applications, can be seen in Figure 3. Note that servo controlled tubes, such as the Accutune™ and Accusweep™ can tune sinusoidally at all values under the curve as well as randomly tune in either direction to a different frequency sub-band. Dither magnetrons can only tune rapidly in a fixed sinusoidal mode.

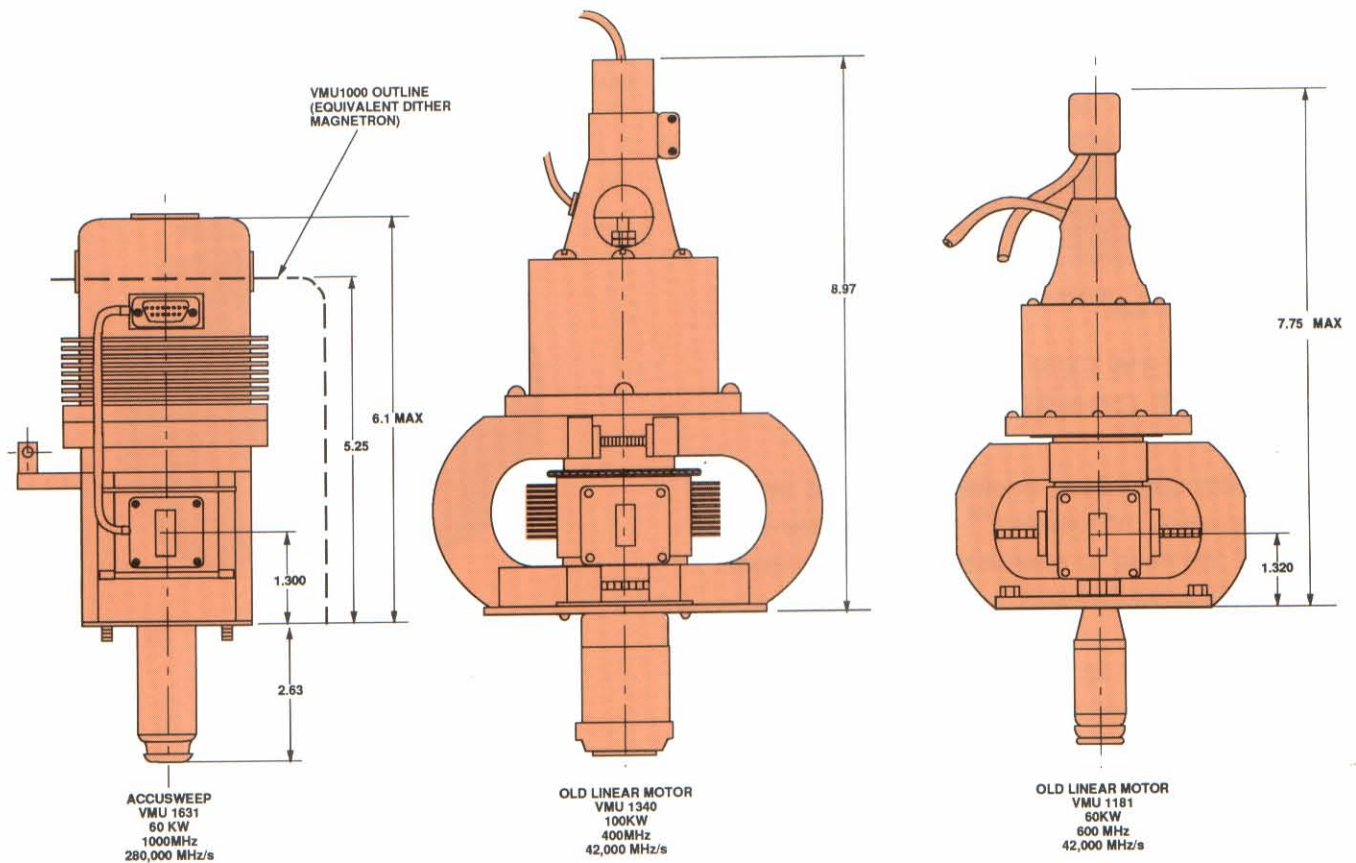


FIG. 2 - Height and Form Factor Improvements

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The third means of providing frequency agility is the "spin tuned" agile magnetron, VMX-1611, which can tune 500 MHz at 960 Hz. However, this magnetron is a much less reliable device. The VMX-1611 is also a dither tube based on conventional magnetrons with limited fixed frequency capabilities. In comparison, the Accusweep™ tube offers a life improvement factor of 10x in field service as well as significant random tuning advantages.

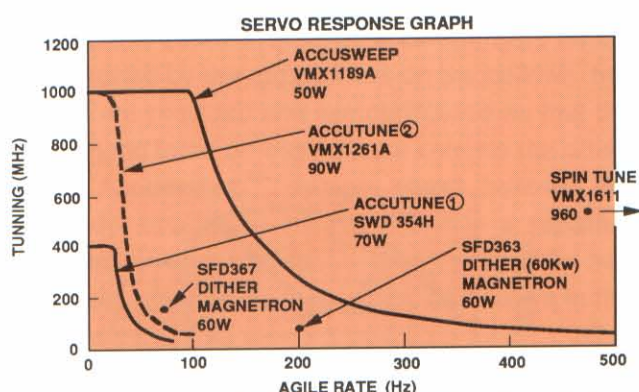


FIG. 3 - COMPARISON OF ANTI-JAM FREQUENCY AGILE CAPABILITY

Table II summarizes the major types of Frequency Agile tubes and their approximate properties. Accusweep™ tubes have been developed for S, C, X, Ku, and Ka bands. General performance capabilities are listed in Table III.

TABLE II COMPARISON OF FREQUENCY AGILE TUBES

TUBE	TYPE	APPROX LIFE (HOURS)	RANDOM TUNE	BW (MHz)	MTBF (HOURS)
ACCUSWEEP™	VMX-1189B	5,000	YES	1,000	16,000
DITHER	SFD-367	1,000	NO	1,000	1,000
ACCUTUNE™	VMX-1261A	2,000	SLOW	1,000	2,000
ACCUTUNE™	VMX-354H	2,000	SLOW	400	2,000
SPIN TUNE	VMX-1611	500	NO	500	<500

TABLE III ACCUSWEEP™ CAPABILITIES

FREQUENCY	TYPE	PEAK OUTPUT POWER (KW)	TUNING RANGE (MHz)	RATE (MHz/s)
S	VMS-1861	150	200	33,000
C	VMC-1587	200	400	40,000
X	VMX-1189B	200	1,000	200,000
	VMX-1567L	60	600	180,000
	VMX-1785	90	600	180,000
	VMX-1644	100	1,000	200,000
Ku	VMU-1568L	60	500	150,000
	VMU-1631	60	1,000	300,000
Ka	VMA-1791	100	1,000	300,000

HOW A SERVO SYSTEM WORKS

Figure 4a shows a simple position servo system. A voltage command (Figure 4c) is applied that is the reverse analog of a desired position. In the

Accusweep™ system, tuner position represents magnetron frequency. The tuning system contains an analog sensor which provides a voltage representation of the actual tuner position (Figure 4d). The desired tuner position (command) is compared to the actual position in an adding circuit with the result shown in Figure 4e. The actual tuner position that corresponds to the readout will continue to accelerate until it reaches the end of travel corresponding to the desired +5v command. The net signal (called servo error) of Figure 4d is now zero so no further acceleration occurs, but the motor is moving at a high velocity, and a reverse command to the servo will develop as the motor over shoots the desired position. This over shoot is called hunting.

The hunting or ringing is controlled by use of electronic damping or velocity feedback. (Mechanical damping is also possible but this is not conducive to optimum response.) Figure 4b shows a modified position servo with a damping or velocity feedback. The velocity profile is shown in Figure 4f. If we add enough velocity analog to the original adding circuit to cause the servo error (Figure 4e) to go to zero at mid travel, we have a situation where we accelerate 1/2 travel and decelerate 1/2 travel. The current drive to the motor (Figure 4g) will resemble the servo error curve of Figure 4e except when the amplifier reaches saturation. If we use large gains to obtain maximum speed of switching, saturated current is common. A well-adjusted servo is considered to be critically damped if no ringing occurs. Ringing will occur if we are under damped at the rate equivalent to the servo bandwidth of the position loop. This band width may be computed from the servo characteristics.

TYPICAL VALUES

G = position gain	36
R = motor resistance	2.45 V/A
Km = motor constant	2.77 lbsf/A
Kf = feedback constant	46.1 V/in
m = moving mass	4.84×10^{-4} lb-sec ² /in

$K_s = \text{servo constant} - G \times 1/12 \times K_m \times K_f$

Servo frequency (BW) = $1/2\pi \times (K_s/m)^{1/2}$ 313 Hz

This is a typical set of values which are obtainable in an Accusweep™ servo. Higher values require further considerations and will be discussed later.

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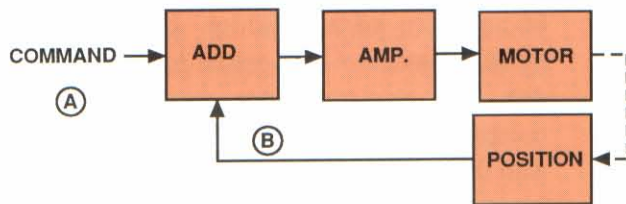


FIG. 4a POSITION FEEDBACK ONLY

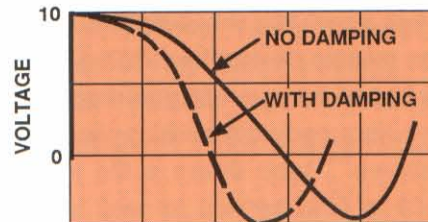


FIG. 4e (SERVO ERROR) COMMAND READOUT
 (A) - (B) or (A) - (B) - (C)

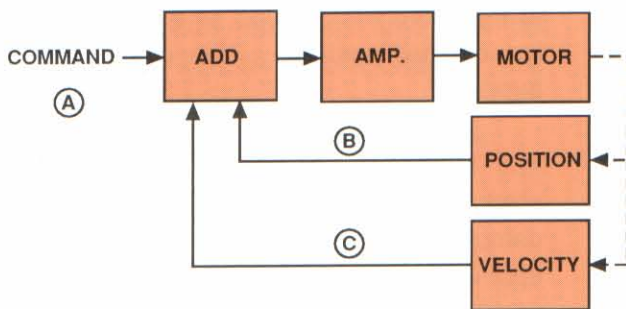


FIG. 4b POSITION AND VELOCITY FEEDBACK

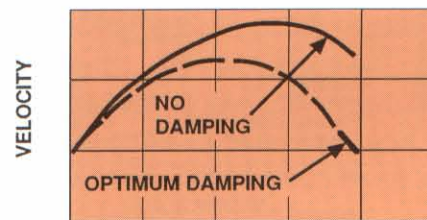


FIG 4f (C)

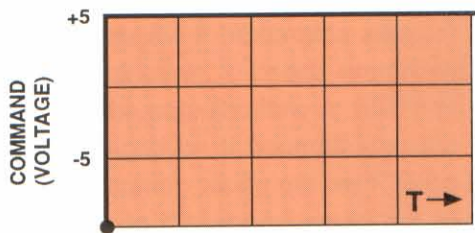


FIG. 4c (DESIRED POSITION) COMMAND (A)

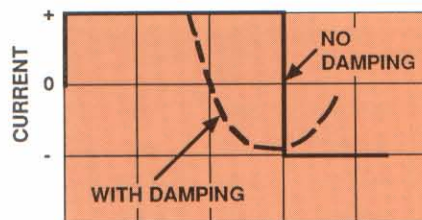


FIG. 4g CURRENT

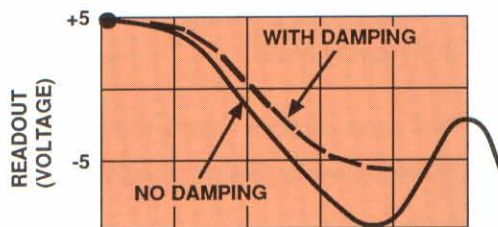


FIG. 4d READOUT (POSITION) (B)

FIG. 4

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DESIGN FEATURES THAT MAKE THE ACCUSWEEP™ WORK

A. Bellows suspension (US Patent #4527094)

The Accusweep™ magnetron actuator contains many new features that contribute to its superior performance. The linear motor is directly coupled to the shaft which is solidly attached to the internal tuning plunger. The vacuum integrity is maintained by the use of bellows. In order to compensate for the force exerted by the atmosphere on the bellows, two bellows are provided and are configured so that the atmospheric force on one bellows cancels the other. In the Accusweep™ design, these bellows are separated: one in the tube and one in a separate "cell," as shown in Figure 5. This system has significant advantages over using two bellows in the tube itself:

1. Separation of the bellows allows the tube manufacturer to accurately align the bellows and bearing. This significantly reduces friction and backlash. Bearing wear is minimal since the tuner effectively floats on an oil film.

2. Since only one bellows is used in the magnetron envelope, a short thermal path to a heat sink is available for tuner plate dissipation. This improves frequency stability during warm-up.

3. A more compact design (in height) is permitted because some functions can be telescoped efficiently. Where system height is restricted, an Accusweep™ design can be used.

4. The separated bellows provide exceptionally good vibration resistance in lateral planes.

B. Short thermal path using good conductors with low expansion coefficients.

Varian's Accusweep™ design insures low thermal drift which is caused by expansion of the moving tuner members. Heat is dissipated by RF loss on the tuning plunger and is conducted through good conductors to the heat sink area.

C. Plain bearing

Accusweep™ tubes use mated pairs of lightweight ,

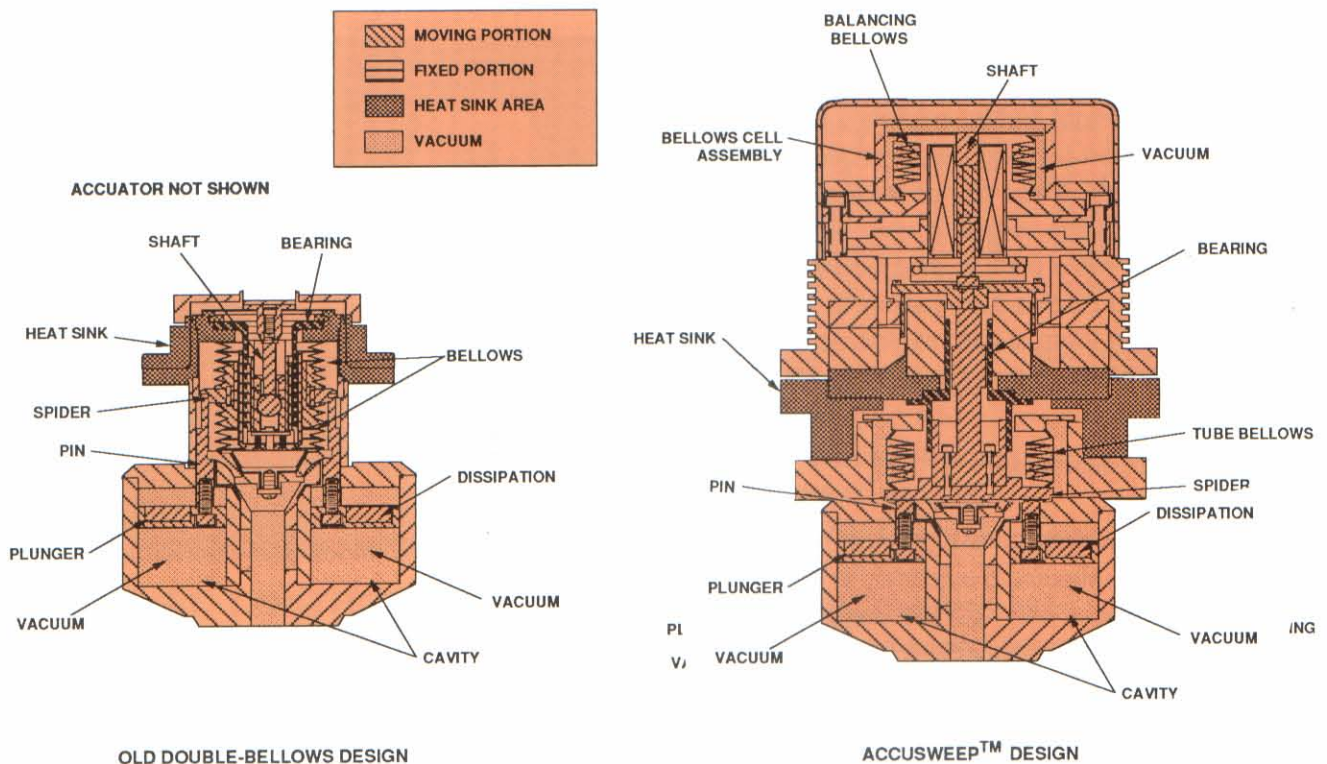


FIG. 5 - ACCUSWEEP™ ARCHITECTURE

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hard-tempered moving parts against oil-impregnated bronze. Low wear is assured by near-perfect alignment and superior anti-friction materials. The large areas assure good heat passage. Prior designs used linear ball bearings which have good anti-friction properties but very poor thermal passage ability. This is illustrated in Figure 6. In vibration, linear ball bushings are inferior to plain bearings since they can "Brinell" or wear grooves.

$$\text{Force} = B \cdot l \cdot i$$

where B is flux density

l is length of motor wire

i is current in the coil

Having achieved the best flux density, a computer trade-off of length versus current can be made.

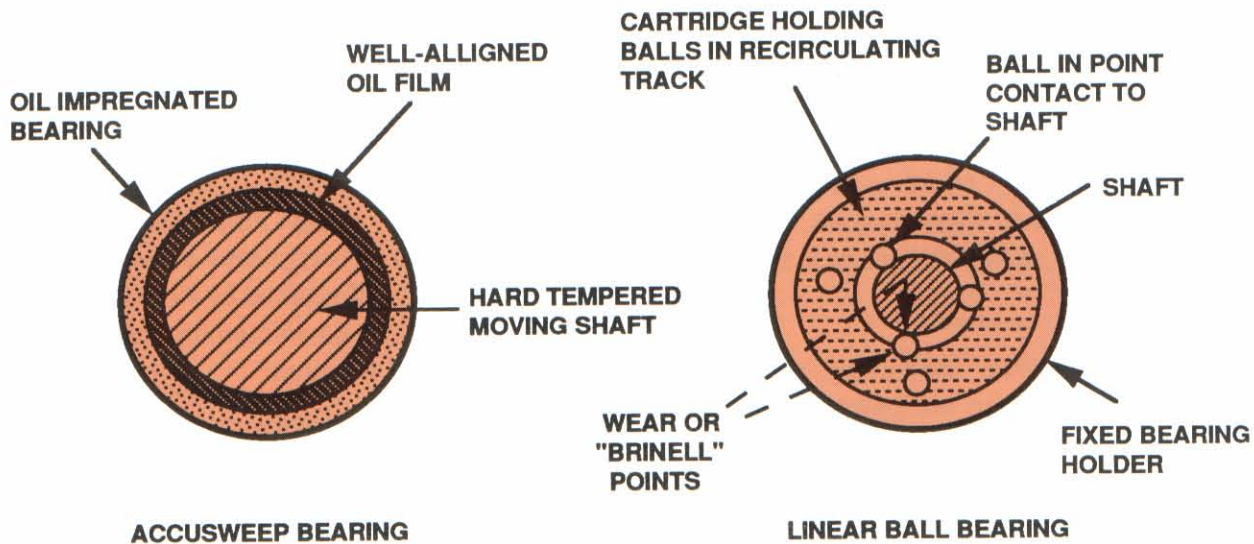


FIG. 6 - BEARING COMPARISON

D. Lightweight

A family of lightweight tuning plungers (Figure 7) have been designed to match each requirement in S, C, X and Ku band. These plungers are structurally strong and designed to exhibit a very high natural resonance. The X-band plate is designed to have its lowest mechanical resonant frequency at 2000 Hz. Use of a very short thermal path minimizes the need for heavy parts to remove tuner heat dissipation.

E. High Force Actuator Motor

In addition to lightweight construction, a high force actuator is desired. Maximum efficiency in the motor is assured through use of a high flux density. This is provided by a rare-earth magnet which is designed to provide the maximum practical gauss level (about 13,000 gauss). Prior designs used 3,800 to 8,000 gauss. Higher levels are impractical since iron saturates at nearly 13,000 gauss. The magnets used are short and do not have a large external field.

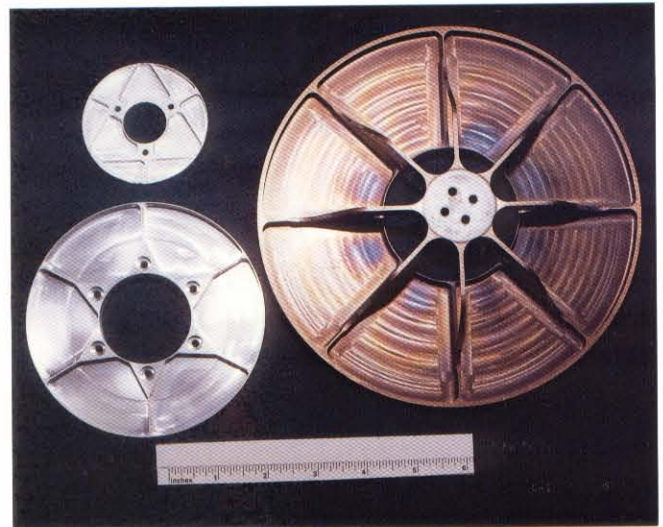


FIG. 7 - LIGHTWEIGHT TUNING PLUNGER
Rib design increases strength to weight ratio.
Plungers for S, C, and X band shown.

Optimum values provide the best response, minimize static current to tune the required band, and minimize dissipation.

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F. Compact Wire and Conduction Cooling Path

It is desirable to be able to use a maximum current in the coil to provide the greatest force. Conversely, if there is high dissipation capability and an efficient motor, only low dissipation is needed to satisfy many applications which do not require tuning at the highest bandwidth x rate product.

Previous linear motor tuners used round wire on a coil form. Heat was conducted turn to turn to the coil form and along the thin coil form to a radiator where forced air was directed into an open structure. The cooling efficiency was poor, typically $3^{\circ}\text{C}/\text{W}$.

The Accusweep™ actuator uses a compact design which is bonded into a thermal mass. The gap between the poles and moving coil uses a Varian proprietary heat transfer mechanism to pass heat. Heat travels radially into the pole which is thermally attached to the external heat sink. Forced air on the exterior yields a typical $1.3^{\circ}\text{C}/\text{W}$ rise. This covered construction keeps contaminants out of the moving mechanism. Figure 8 illustrates the comparison between designs.

loop servo and for pre-setting the radar receiver in Frequency Agile modes. Figure 9 shows the cross section of the LVDT used in the Accusweep™ magnetron. The LVDT is held rigidly and is thermally isolated to provide the enclosure with a temperature control scheme to keep the LVDT at a constant temperature. The LVDT exhibits a temperature characteristic, and therefore, best results are obtained if temperature is controlled. A temperature sensor (thermistor) and a heater are provided inside the holder, and temperature is controlled from a comparator and transistor switch in the electronics module.

COMPUTER DESIGNED COMPONENTS

Accusweep™ magnetrons require large servo bandwidths. This means that the moving members must have very high mechanical self resonances, and these resonances must be controlled. Varian uses computer simulation to identify and control mechanical resonances and diagnostic equipment to identify and quantify actual mechanical

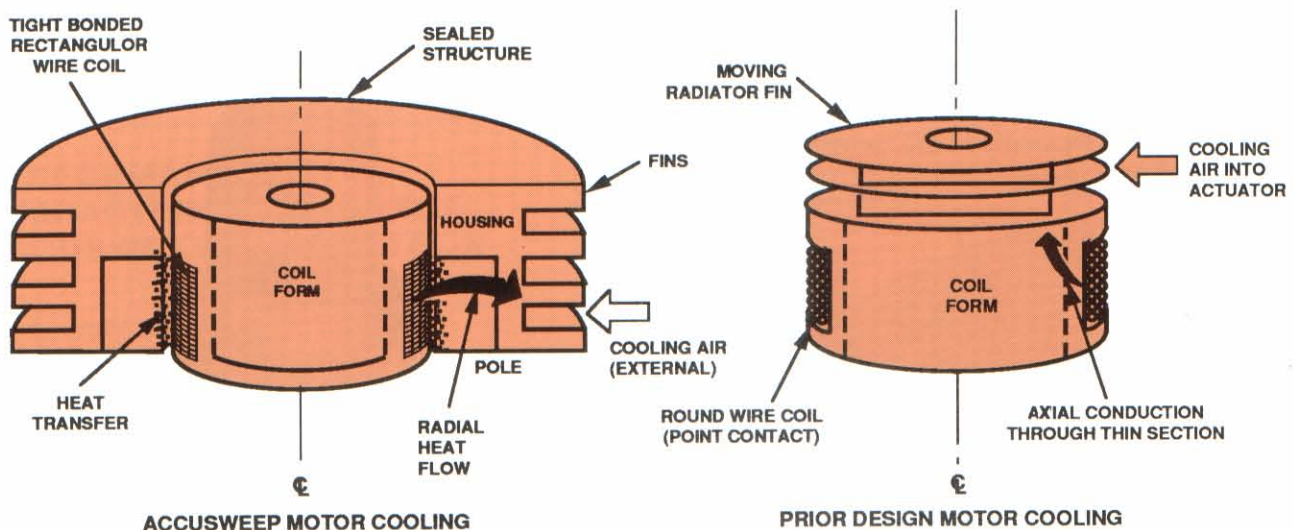


FIG. 8 - CROSS SECTION OF OLDER LINEAR MOTOR DESIGNS COMPARED WITH ACCUSWEEP™

TEMPERATURE CONTROLLED POSITION SENSOR (LVDT)

An LVDT (Linear Variable Differential Transducer) can be incorporated to provide position sensing for the Accusweep™ sensor. Basically, its detected output provides the frequency analog for the closed

characteristics. The latter will be illustrated under the section "Performance Characteristics" where the actual moving system response is given. Figure 10 is an illustration of the use of a Finite Element program to analyze the linear motor coil. This illustration shows a half section along a plane passing through the central axis. Since the wire and coil form are firmly

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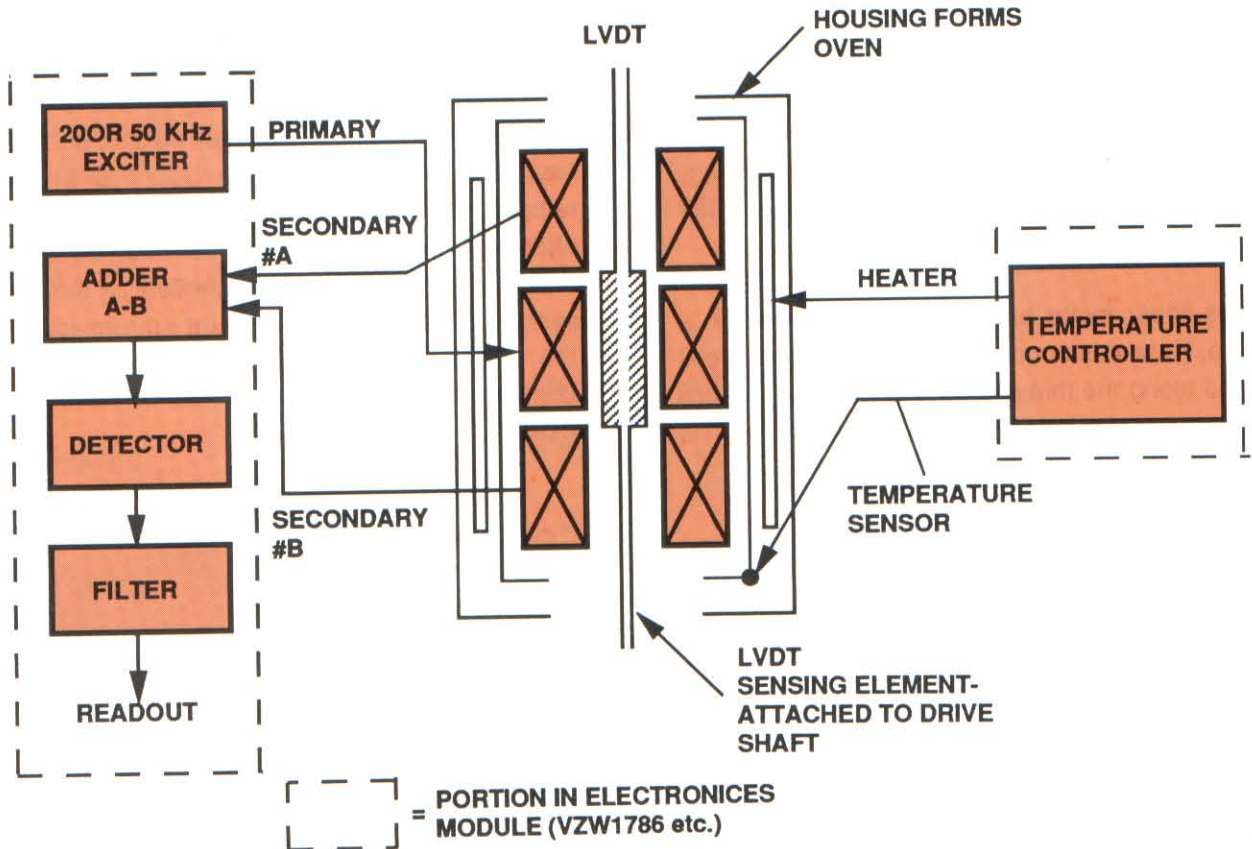


FIG. 9 - LVDT AS USED IN ACCUSWEEP™ MAGNETRON
 1. Performance enhanced by temperature control.
 2. d.c. readout forms frequency analog.

bonded, a simple model combining these materials suffice to allow prediction of resonant behavior. Resonances in the moving coil are generally in the 3500 Hz region and above.

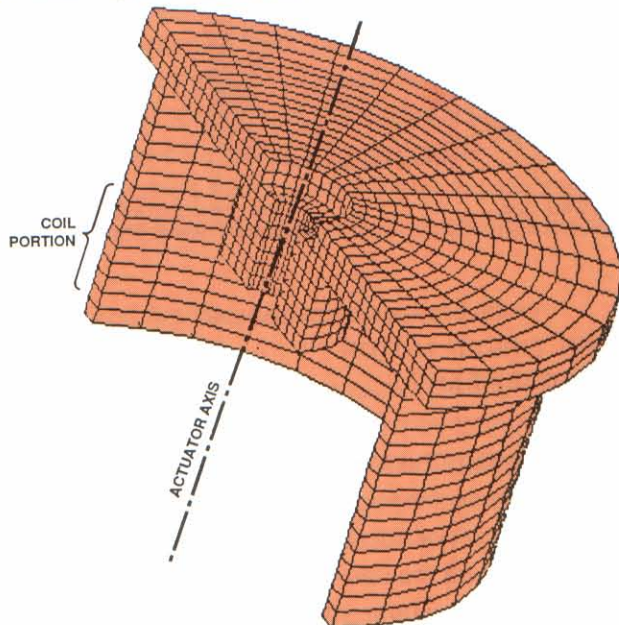
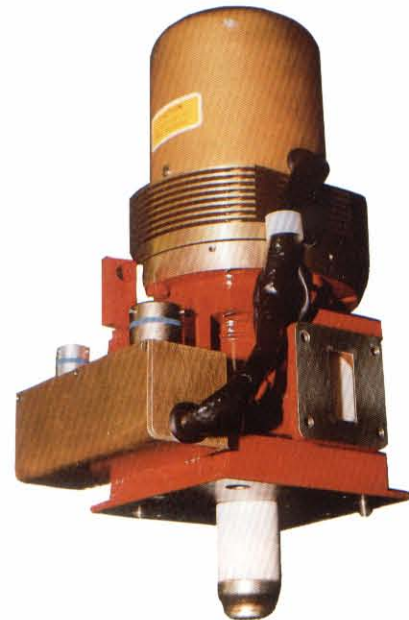


FIG. 10 - VOICE COIL MODEL
 Element definition for computer analysis



VMX-1785 - 90 KW X BAND ACCUSWEEP™ MAGNETRON
 The VMX-1785 is a 600 MHz tube capable of 120 Hz operation. It features rare earth magnets and high-rel construction. It is designed for multi-mode airborne radar applications.

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A second key area where computer structural analysis has helped provide a superior product is the static or non-moving portion of the tube. Figure 11 shows test results of the tube structure where vibration is along the tuning or principal axis. No resonances occur up to 1900 Hz. In a special test, a tube with a tuner locked mechanically at the actuator was vibrated using a 2G sine survey, and no Frequency Modulation resulted above 200 kHz until the 1900 Hz was reached and FM was 400 kHz. This favorable result was obtained by carefully analyzing the structure and eliminating all low frequency resonances. This structure allows use of the servo alone to maintain frequency and to validate computer predictions of performance under environmental conditions.

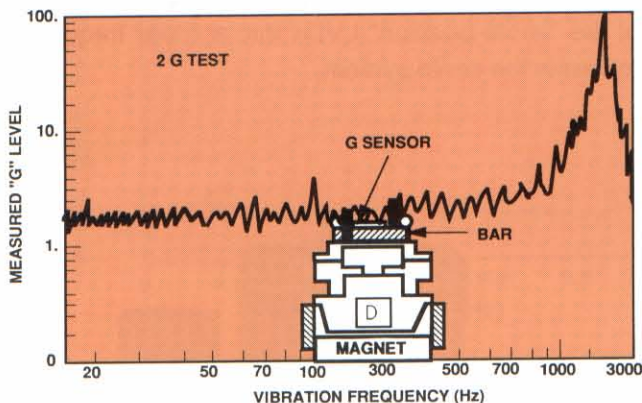


FIG. 11 - VMX-1785 VIBRATION SINUSOIDAL SEARCH
Low frequency resonances eliminated.

PERFORMANCE CHARACTERISTICS OF THE ACCUSWEEP™ MAGNETRON

Frequency Agility

Figure 12 shows typical performance of an X-band Accusweep™ tube. This is similar to Figure 6 where only the 50 watt input data is shown. Clearly, the linear motor approach is the most energy efficient means of providing tuning where a totally random capability is desired.

Accuracy of Reset

Accuracy is both the conformance to an ideally desired specification as well as the ability to return to the same setting repeatedly. The VMX-1785 (X-band) conforms to a tuning equation ± 10 MHz. It, however, repeats a previous calibration ± 3 MHz.

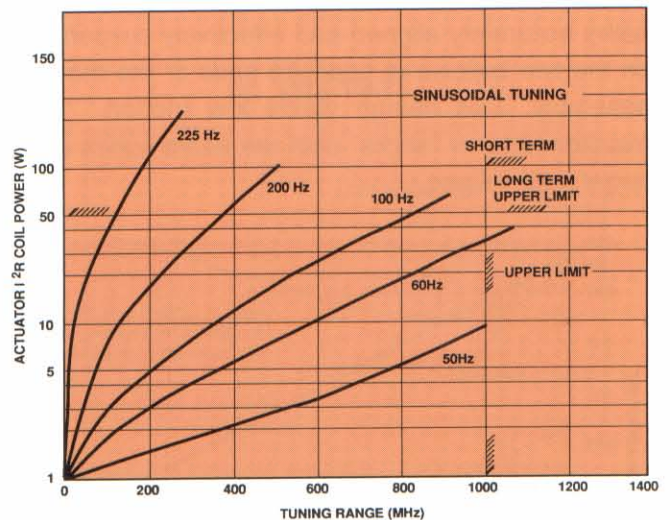


FIG. 12 - VMX-1644/VMX-1189A ACTUATOR PERFORMANCE
Temperature of motor coil produces limit for long term applications.

This is illustrated in the automated test results of Figure 13, which shows two successive tests, their deviation from the ideal as defined by the equation, and the reset-ability from one test to the second. The example shows that deviation from the equation is about -2, +4.5 MHz with the reset error less than 0.5 MHz. Low friction and high, stable servo gain make this possible.

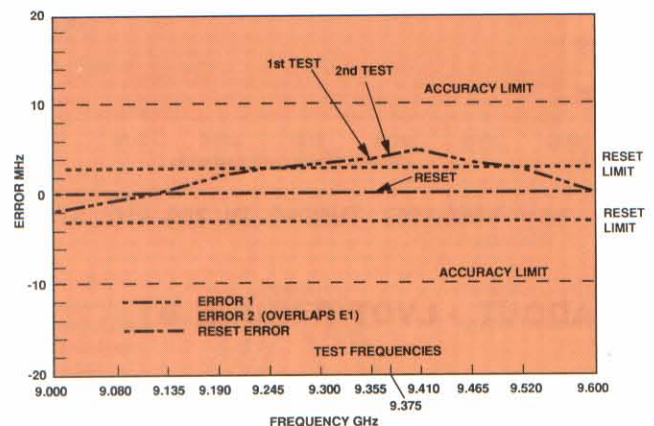


FIG. 13 - VMX-1785 ACCURACY OF X BAND ACCUSWEEP™
Technique is to perform two calibrations and compare difference.

Automated testing, such as that used in the accuracy of reset test, makes backlash testing more reliable. Figure 14 shows two tubes: one with the actuator misaligned to illustrate appreciable backlash and one standard X-band tube. The test consists of 10 small tuning increments of 200 KHz in one tuning direction and a repeat test in the opposite direction. The performance achieved results from the actuator

ACCUSWEEP™ MAGNETRONS

being accurately aligned and effectively suspended on the two bellows at opposite ends of the moving assembly. This design yields low friction. The misaligned tuner "sticks" until the servo builds up a larger error voltage.

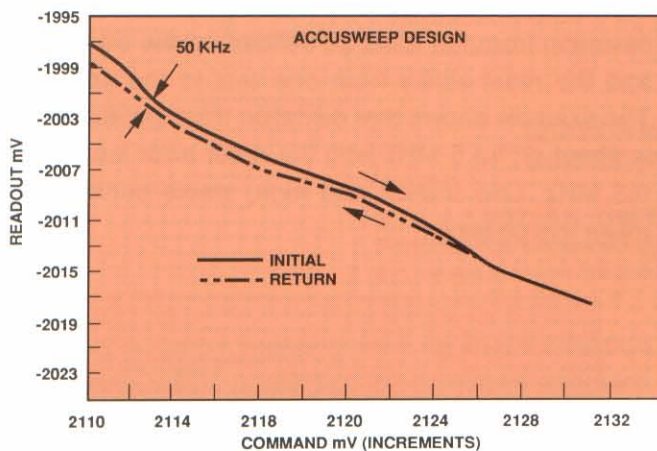
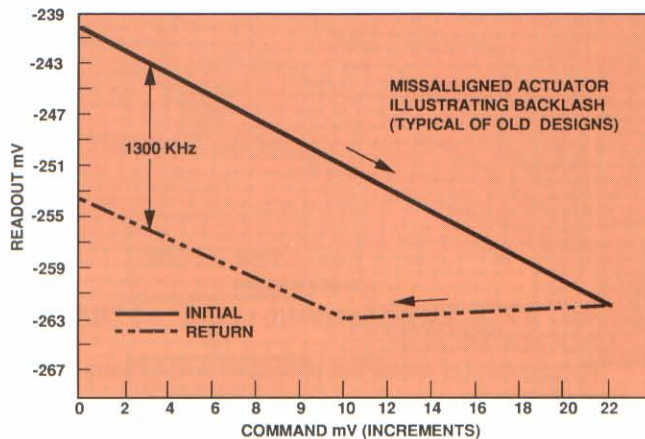


FIG. 14 - VMX-1567 TUNING IN 200 KHz STEPS

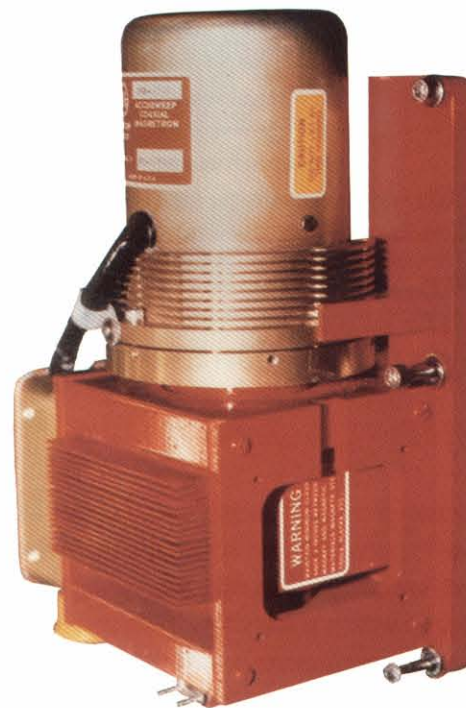
READOUT - LVDT (FIGURE 9)

The readout or frequency analog of the tuner position is developed from an LVDT. Two types of LVDTs can be provided: one which provides a linear distance to voltage characteristic and one that provides a linear frequency to voltage characteristic. LVDTs are basically transformers with a moving core. At center frequency the two secondaries are equally excited by the core. As tuning proceeds in one direction, one secondary (S_1) output exceeds the other (S_2), and an "in phase" output develops when S_1 is subtracted from S_2 . In the opposite direction, $S_1 - S_2$ yields a 180° phased output. A d.c. signal is developed by a synchronous detector and filter. The two types of LVDTs are illustrated in Figure 15.

The preferred approach uses the LVDT as a true linear distance to voltage transducer. This approach is the most economical and offers the best reproducibility both unit to unit and lot to lot.

Alternately, it is possible to wind LVDTs to duplicate the magnetron tuning characteristic. Coaxial magnetrons use the TE 011 mode (wave-meter mode) and tune more rapidly at higher frequencies using this method. Figure 15 illustrates these two approaches installed in similar tube types.

The absolute accuracy of the linear position LVDT results because of imperfections in the linear frequency LVDT to perfectly reproduce the desired magnetron curve. A linearizing circuit or a PROM can be used to convert the non-linear frequency output of the "linear position" LVDT into a linear frequency format in the servo system.



VMA-1791 - 100 KW KA BAND ICEM ACCUSWEEP™ MAGNETRON

The VMA-1791 is a 1000 MHz tube designed for airborne, multi-mode radar applications. It features rare-earth magnets and high-rel construction. Its high reliability at Ka band is derived from the ICEM construction as well as the Accusweep™ tuner.

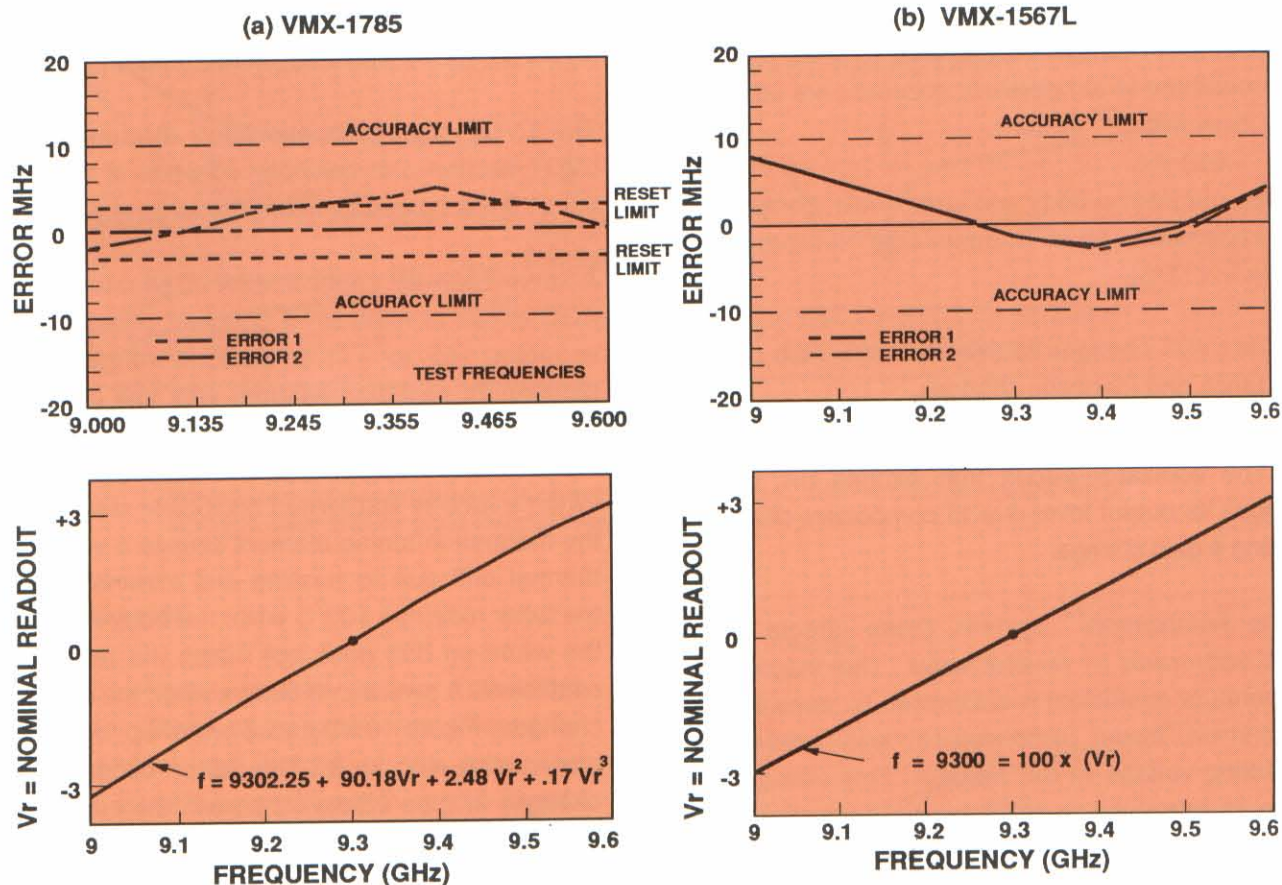


FIG. 15 - LVDT TYPES
 A. Linear position (Normal LVDT)
 B. Linear frequency (Specially wound LVDT)

LVDT design circuitry plays a critical role in frequency agile applications. When the user wishes to provide an AFC lead signal using the readout, a trade-off develops between filtering the A.C. component of the detected LVDT output and avoiding phase shifting the frequency agile signal. Consider Figure 16. A command signal is applied to the servo which responds after a servo delay with the actual tuner position (hence magnetron frequency). The LVDT output is a modulated carrier. After demodulation, the filter to remove the carrier also delays the envelope of the readout. The higher the carrier frequency, the easier it is to filter the carrier without causing a delay in the readout. For this reason, use of a 50 KHz carrier is preferred over lower frequencies such as 20 KHz. Since some loss of LVDT linearity is possible at high carriers, especially over a temperature range, Varian guards against this by temperature stabilizing the LVDT.

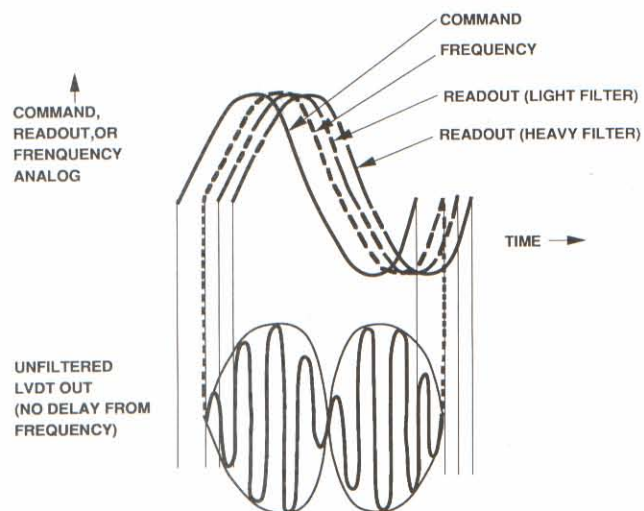


FIG. 16 - READOUT UNDER FREQUENCY AGILITY
 A. Delay of frequency from command is an inertial effect.
 B. Delay of readout from frequency is due to electronic filtering.

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Temperature Compensation and Thermal Drift

When ambient temperature changes, several items that contribute to temperature accuracy are affected in an Accusweep™ system.

1. The magnetron body and tuner scale themselves by expansion at a measurable temperature coefficient (T/C).
2. The LVDT changes its effective turns ratio due to resistance and magnetic changes.
3. The oscillator circuit that excites the LVDT changes its output level due to component changes causing a gain change.

In the Accusweep™ system, these effects have been addressed in several ways. The magnetron temperature coefficient is addressed by sensing the magnetron body temperature and adding a correcting voltage to the readout. This causes the servo to introduce a small tuning correction and restore the original frequency and readout. Figure 17 illustrates this action.

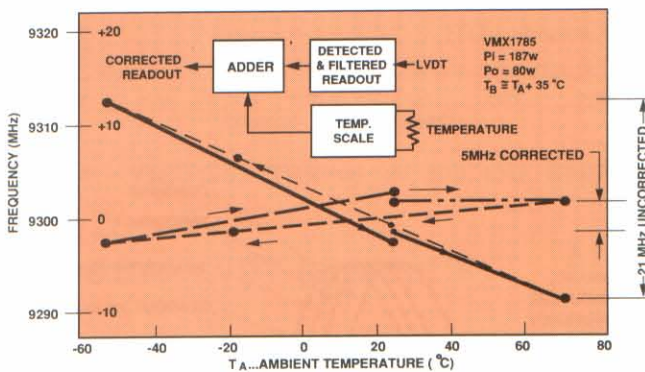


FIG. 17 - TEMPERATURE COEFFICIENT
This illustrates effect at T/C circuit which corrects readout and frequency with temperature change.

Typical temperature coefficients are shown in TABLE IV:

TABLE IV TEMPERATURE COEFFICIENT

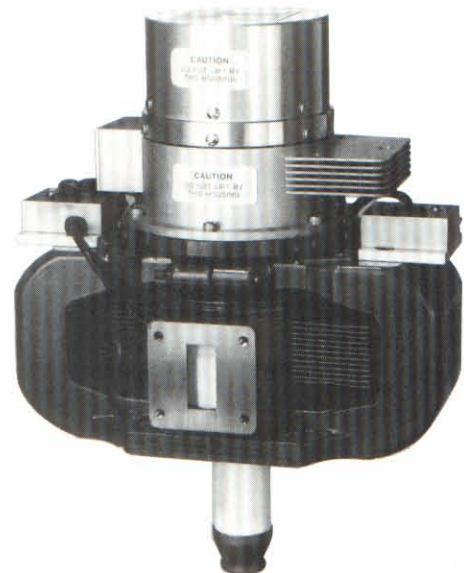
FREQUENCY BAND	T/C	TUBE TYPE	ANALOG	VOLT T/C
C	-.100 MHZ/°C	VMC-1587	8 V = 400 MHZ	-2 MV/°C
X	-.230 MHZ/°C	VMX-1189A	10 V = 1000 MHZ	-2.3 MV/°C
Ku	-.35 MHZ/°C	VMU-1631	10 V = 1000 MHZ	-3.5 MV/°C

These coefficients are converted to a volts/°C change according to the individual tube type temperature coefficient and the scale factor used to relate voltage to frequency in the readout.

The LVDT correction has been discussed in the LVDT section and basically consists of controlling the LVDT temperature with a heater to about 70°C.

A servo such as Varian's VZW-1786 uses a stable AGC circuit to maintain a constant output over the expected -55 to +71°C ambient range. Careful component selection assures very low changes in the excited level.

When a tube is first turned on, power dissipated on the magnetron tuning element causes a warm-up or thermal drift due to heating and expansion. Since the tuner may rise 100°C while the body rises 50°C, the warm-up drift does not match the temperature coefficient. A similar drift occurs when the duty factor changes. Figure 18 illustrates warm-up, duty tuning, and post-tuning drift. The latter occurs due to changes in tube efficiency across the tuning range and changes in the incremental tuning rate. These problems are best handled by providing efficient cooling means for the magnetron tuner. The Accusweep™ magnetron's short thermal path™ (Figure 5) achieves efficient cooling by removing as much heat as possible consistent with low moving mass.



VMX-1189A - 200 KW X BAND ACCUSWEEP™ MAGNETRON

The VMX-1189 tunes 1000 MHz at 100 Hz. It is designed for airborne and shipboard radar applications. The VMX-1189B is interchangeable with the VMX-1189A and offers compact, high-rel construction similar to the VMX-1785.

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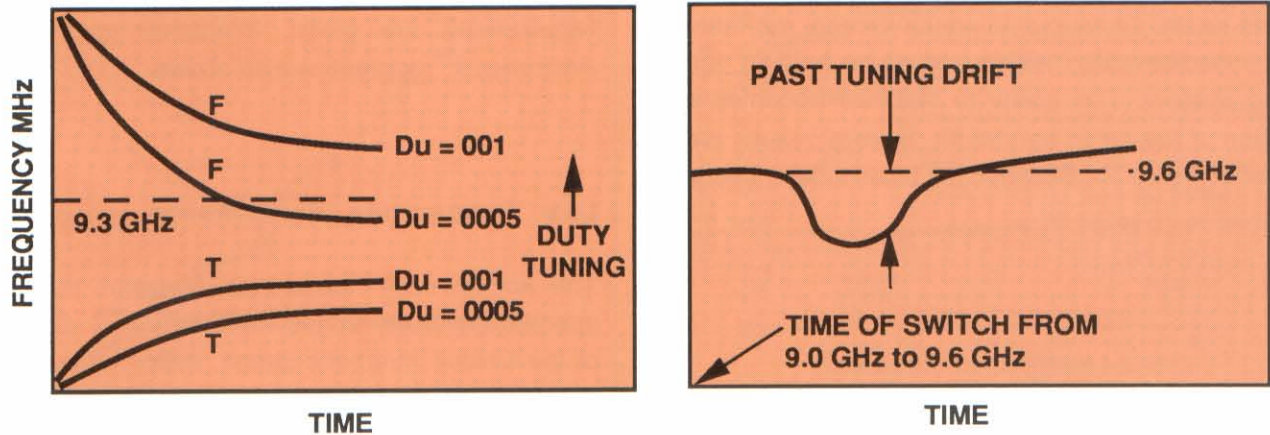


FIG. 18 - THERMAL DRIFT, DUTY TUNING, AND POST TUNING DRIFT
While steady-state temperature is corrected by T/C circuit, thermal change in warm-up or tuning is minimized by good thermal design in tuner.

Velocity sensing

Use of a velocity sensor is an important consideration. Three approaches are offered by Varian. The cost and height of the tube and performance (stability) govern which choice should be made. Table V shows the three types with design considerations:

TABLE V LVT APPROACH

TYPE	SCALE	COST	HEIGHT	COMMENT
VELOCITY CIRCUIT	.05 V-S/IN	LEAST	SHORT	LOWEST SERVO BW <300Hz
LOW OUTPUT	.10 V-S/IN	MODERATE	+1 IN	MODERATE SERVO BW <300 - 600 Hz
HIGH OUTPUT	.6 V-S/IN	HIGHEST	+1.5 IN	HIGH SERVO BW <600 Hz

Vibration and Shock - Internal Stops

Accusweep™ tubes have tuners capable of reversing travel direction rapidly. These turn forces exceed 100 Gs. The most susceptible portion, the magnetron tuner plate, has been designed with a ribbed construction to withstand these force levels. Since a misfire in the servo could drive the tuner into the tuner mechanical stop, an even higher G-force could result. Accusweep™ tubes use energy absorbing stops to cushion over-travel. The static force profile of an Accusweep™ tube is shown in Figure 19.

Accusweep™ tubes are designed to withstand high vibration levels. With the tuner mechanically held,

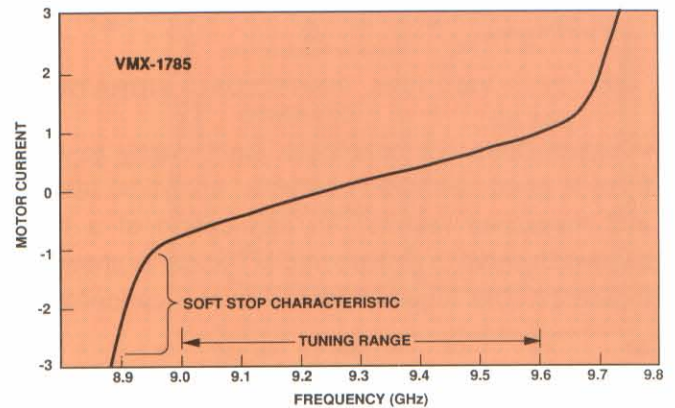


FIG. 19 - EXTENDED CHARACTERISTIC CONTROL
Soft drop acts as an energy absorbing spring.

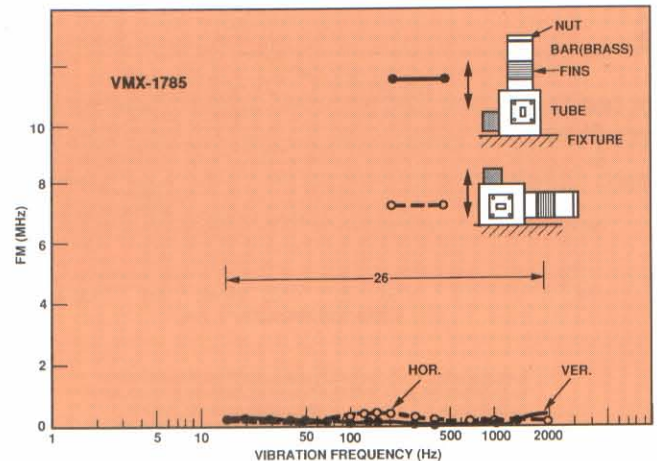


FIG. 20 - VIBRATION RESULTS WITH ACCUSWEEP™ TUNER MECHANICALLY HELD.
A very powerful servo can approach these results (Fig. 21)

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vibration data on an X-band tube is shown in Figure 20. Note that good control in both lateral and coaxial planes exists. Of course, in actual service, the tuner is not mechanically held but must be held by the servo system. The ability to stabilize becomes a function of the servo bandwidth. Several results are shown in Figure 21. Because the basic tube or lateral

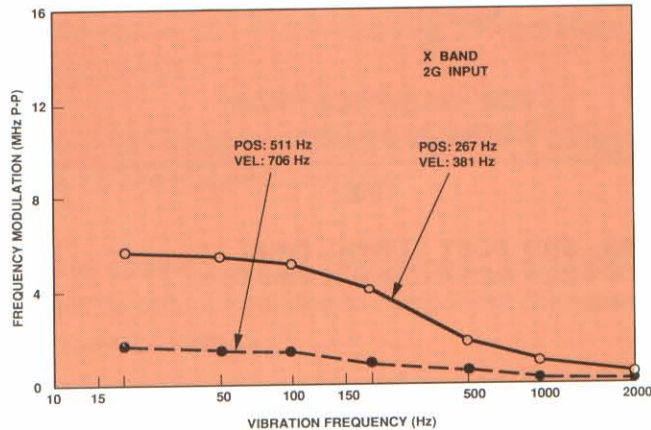
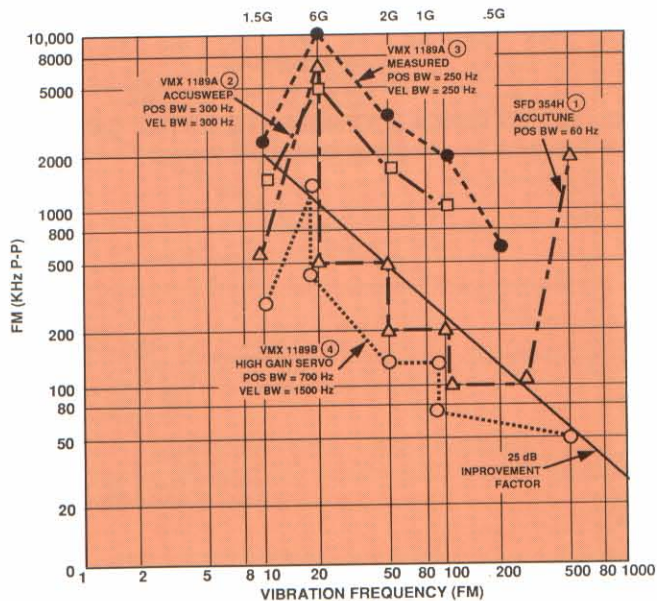


FIG. 21 - VMX-1785 SINUSOIDAL VIBRATION

vibration does not contribute significantly to FM, there is good correlation between analytical results and measured results. An application of a high bandwidth servo to a shipboard MTI radar is shown in Figure 22. The requirement for an MTI cancellation



APPLICATION OF ACCUSWEEP AND ACCUTUNE MAGNETRONS TO SHIPBOARD M.T.I. SYSTEM CURVES COMPARE ACCUTUNE MAGNETRON (1) WITH BOTH MEASURED AND CALCULATED DATA ON 250-300 Hz SERVO. HIGH GAIN SERVO (4) IS ALSO SHOWN.

FIG. 22 - APPLICATION OF ACCUSWEEP™ AND ACCUTUNE MAGNETRONS TO SHIPBOARD M.T.I. SYSTEM

factor of 28 dB is shown, and test results on an Accutune™ magnetron that currently satisfies this requirement are given. Predicted data on an Accusweep™ upgrade is also shown.

Low Temperature Performance

The Accusweep™ magnetron operates over MIL spec temperature ranges -55°C to $+71^{\circ}\text{C}$. Because of the unique magnetic circuit, motor force is also constant over the operating range. This means the required motor current to hold tuner position stays virtually constant (Figure 23).



VMU-1568L - 60 KW KU BAND ACCUSWEEP™ MAGNETRON

The VMU-1568L is a 500 MHz tube designed for airborne terrain following applications. The VMU-1631 is a 1000 MHz version and can be tuned at 150 Hz.

Many frequency agile mechanisms exhibit difficulty at low temperatures such as -55°C due to hardening of the lubricants. Varian's Accusweep™ design uses fluids selected for their best properties (lubricating,

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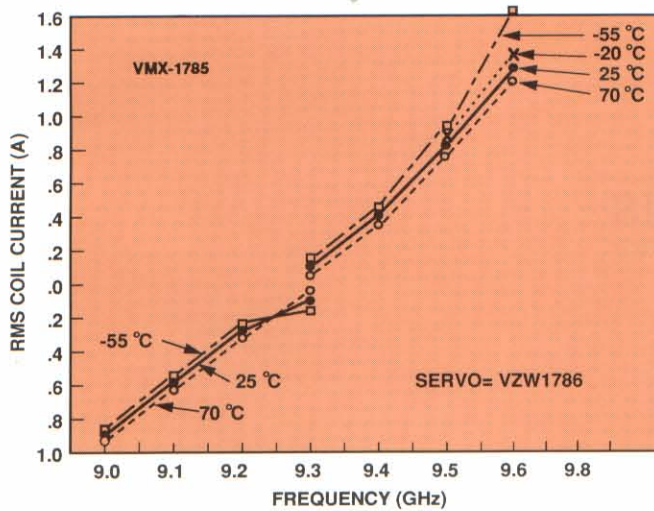


FIG. 23 - COIL CURRENT vs. TEMPERATURE
Data from switching servo to illustrate that variation with temperature is low.

etc.) at -55°C consistent with minimal viscous friction. A typical result is shown in Figure 24. Here Accusweep™ tubes are given small signal tuning requirements and exhibit delay before normal amplitude is reached. This characteristic is assured through process control of the quantity and type of fluids. When large tuning amplitudes are required, the actuator is taken to maximum force condition, and a nearly normal response results immediately as illustrated in the step command of Figure 25.

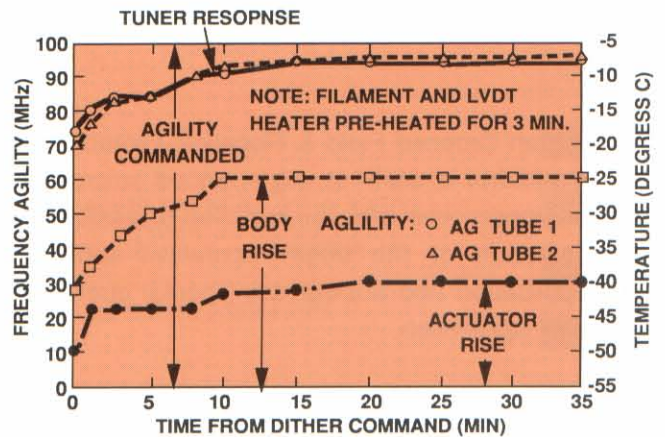


FIG. 24 - VMX-1785 LOW TEMPERATURE FREQUENCY AGILITY (SINE WAVE DRIVE)
This illustrates low temperature behavior of Accusweep™ fluids. Amplitude of peak to peak agility is plotted as a function of time at an ambient of -55°C .

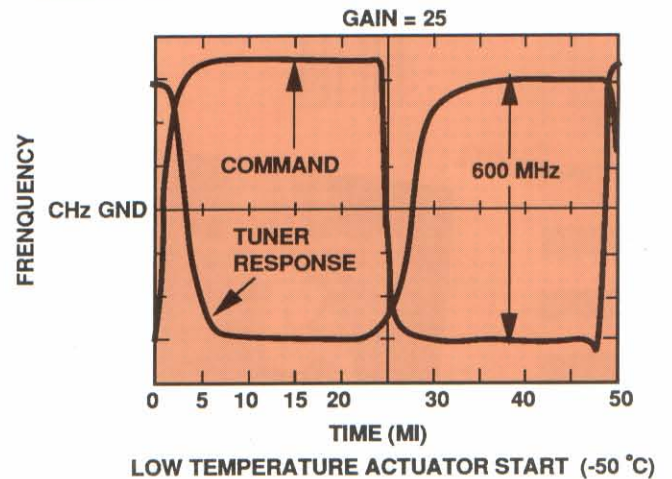


FIG. 25 - LOW TEMPERATURE ACTUATOR START (-50°C) VMX-1785
Low temperature performance is very good for large signals. Square wave command results in 7 ms switch at -50°C ; room temperature switch is 5ms.

Note:

Mean time between failure (MTBF) predictions for the magnetrons in this article are derived from Varian in-house cycled life test data on coaxial magnetrons. These tubes have similar or greater Pf^2 (Power x

frequency²) ratings. Actuator MTBF is calculated as uninhabited air cargo aircraft using MIL-HBK-217E and NPR-3 Non-electronic parts reliability data, Reliability Analysis Center, RADC.