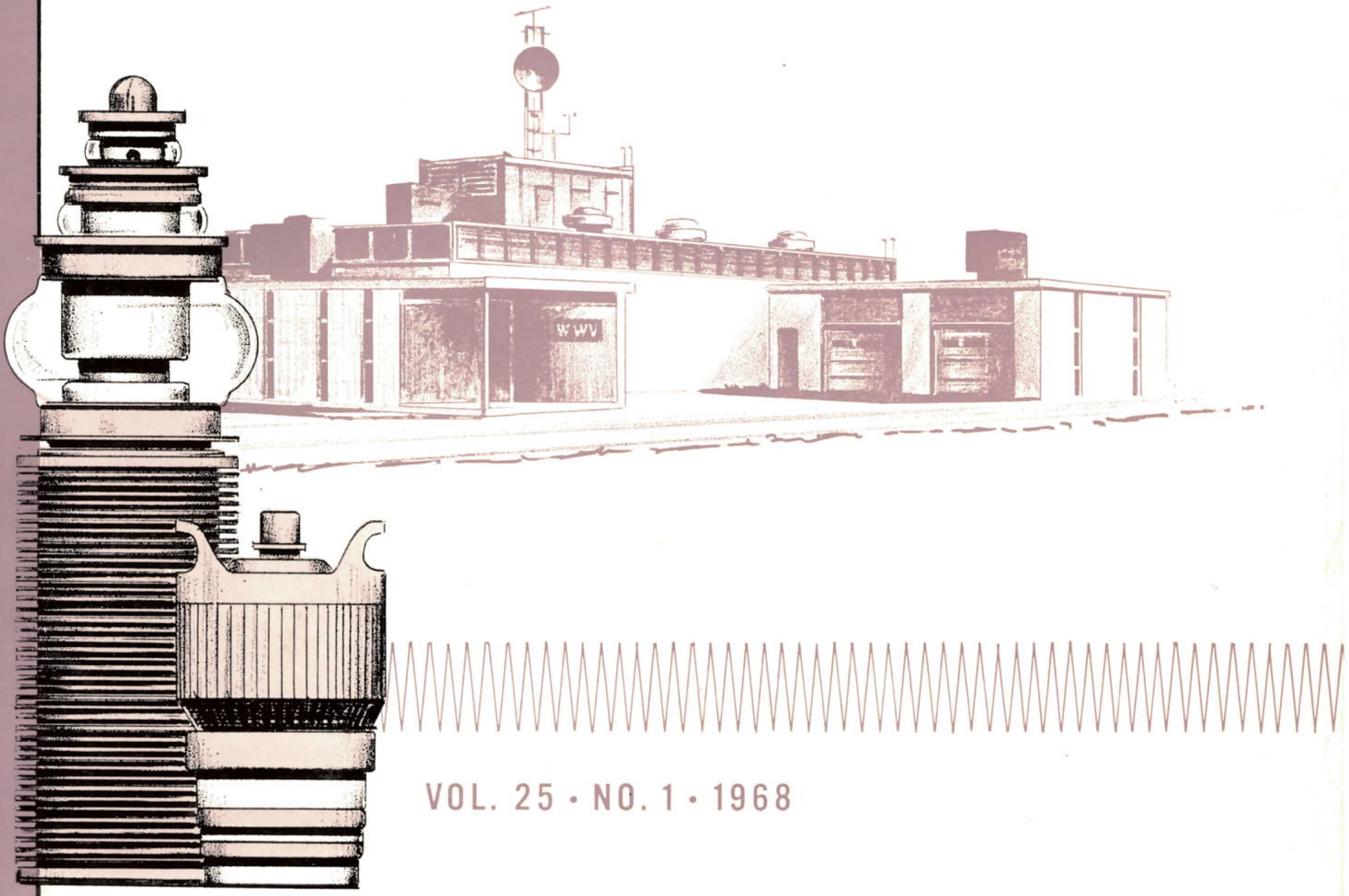
MACHLETT

CATHODE PRESS



VOL. 25 • NO. 1 • 1968

MACHLETT CATHODE PRESS

Volume 25 • No. 1 • 1968

Published by:
The Machlett Laboratories, Inc.
A Subsidiary of Raytheon Co.
Stamford, Connecticut 06907

Editor, *Richard N. Rose*

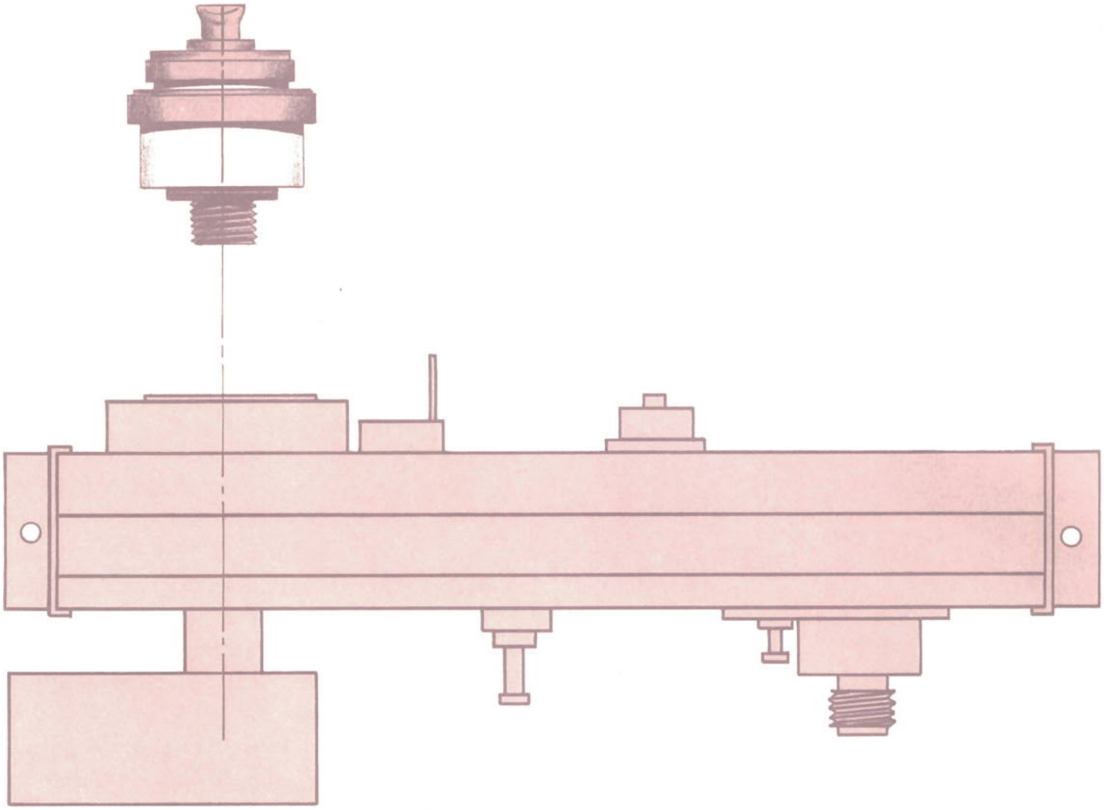
Art Director, *Edward J. Bulger*

IN THIS ISSUE

Cover
WWV's new transmitter building at Ft. Collins, Colorado, houses new transmitters, using Machlett tetrodes and triodes, operating at 5, 10 and 15 MHz.

March 1968

PRINTED IN U.S.A.



The Volume 23, Number 4, 1966 issue of Cathode Press contained an article describing two distributed feedback strip transmission line oscillators designed around the miniature 8600 series of triodes. This article will deal with further developments that have been made in the design and assembly of stripline oscillators, namely heat sinking of the triode to allow high duty factor operation, matching of the oscillator load to the triode to improve plate efficiency, and assembly techniques which give excellent frequency stability over temperature extremes without use of clamps or other holding devices.

Stripline Oscillator Heat Sinking Techniques

Stripline oscillators as they were originally designed were limited to duty factors of approximately 0.001 due to the poor heat transfer characteristics of the teflon impregnated glass fiber board from which these solid dielectric oscillators are constructed. The primary source of heat generated in a triode is the surface of the anode where the kinetic energy of the electrons which strike the anode is converted into heat. This unusable energy which is converted into heat is known as plate dissipation. Grid dissipation and filament heating are also sources of heat in the triode but in general these are of lesser magnitude than plate dissipation. Figure 1 shows a cross section drawing of an oscillator without any heat sinking other than the teflon glass boards. The etched striplines are only 0.0014 inch thick and thus provide little heat transfer away from the anode of the triode.

Some improvement in removing heat from the anode of the triode can be accomplished by using a 1/32 or 1/16 inch thick copper line as the anode line of the oscillator. This thick copper line provides a larger cross section area than the etched lines to transfer heat from the anode out into the oscillator package so that it can then be conducted through the teflon glass boards to a heat sink. Although this method offers some improvement the heat must still be conducted through the teflon glass which is a relatively poor thermal conductor.

By far the most efficient and direct approach is to remove the heat generated by plate dissipation by conducting the heat through a thermal conductive ceramic cylinder directly from the anode of the triode to a heat sink. This technique leaves only the heat generated due to grid dissipation and from the filaments to be conducted through the oscillator package to the heat sink. Boron nitride and beryllium oxide are heat conductive dielectric materials that are useful as the heat transfer material. The high dielectric constant of the ceramic material adds some additional plate to cathode (ground) capacitance but a slight readjustment of the plate cathode line length allows efficient operation with the ceramic attached to the anode. Because of the high dielectric constant of the ceramic cylinder, the heat sink or heat transfer block must be kept approximately one fourth inch away from the oscillator. The

Developments in Stripline Oscillator Design

by *MELVIN D. CLARK, President*
Terra Corporation

Model GLJ-3123 which has this technique is described in Figure 2. Model GLJ-3123 oscillators incorporating boron nitride cylinders have been operated continuously with 800 watts of output power and at a duty factor of 0.01. The heat transfer block naturally must be mounted to an adequate heat sink.

Figure 3 shows a proposed heat transfer block incorporated into a mounting plate which gives adequate heat removal without the large mounting surface area that is required for the oscillator heat transfer block layout of the Model GLJ-3123. The direct heat removal method of heat sinking the oscillator triode can be extended to allow mounting of the oscillator at considerable distance from the heat sink and transfer the heat to the sink through a heat pipe.[1] This technique is quite interesting in that the heat pipe can be constructed of flexible material and also that the temperature to which the anode is allowed to rise can be controlled by choice of heat conductive fluid with the proper vaporization temperature. Also with a heat pipe no heat is removed until the anode reaches the vaporization temperature of the fluid being used and the temperature of the anode is independent of the rate of heat generated by plate dissipation.

With these improved methods of heat sinking it is now possible to use the small and rugged stripline oscillators in high duty factor applications where heretofore only conventional coaxial oscillators could be used.

Matching of Load to Triode

Quite frequently in the design of microwave oscillators the efficiency is of secondary nature, i.e., the various oscillator parameters are chosen, the oscillator is built, and then the output coupling is adjusted to give maximum efficiency. This is especially true in conventional coaxial oscillators where line impedances are usually determined by tube diameters and available package size. In stripline oscillator design one has somewhat greater freedom since line impedance is determined by line width and also it is an easy task to change impedance at a point on the line and thereby obtain transformer action to better match the load to the triode.

The plate cathode line of a stripline oscillator using a Machlett Laboratories ML-8600 series of tube and the equivalent circuit are shown in Figure 4. Z_{o_1} and Z_{o_2} are the characteristic impedances of the plate cathode lines which may or may not be of the same value. R_L is the impedance seen looking into the matched line which couples power out of the oscillator and X_C is the capacitive reactance between the coupling probe and the plate cathode line. X_{L_p} is the inductive reactance of the plate supply contact[4] and X_{C_f} is the capacitive reactance of the plate filter capacitance. The total equivalent circuit for a distributed feedback stripline oscillator is shown in Figure 5. The impedance seen looking into the plate cathode line, R_L' in parallel with iX_{L_p}', is the load impedance

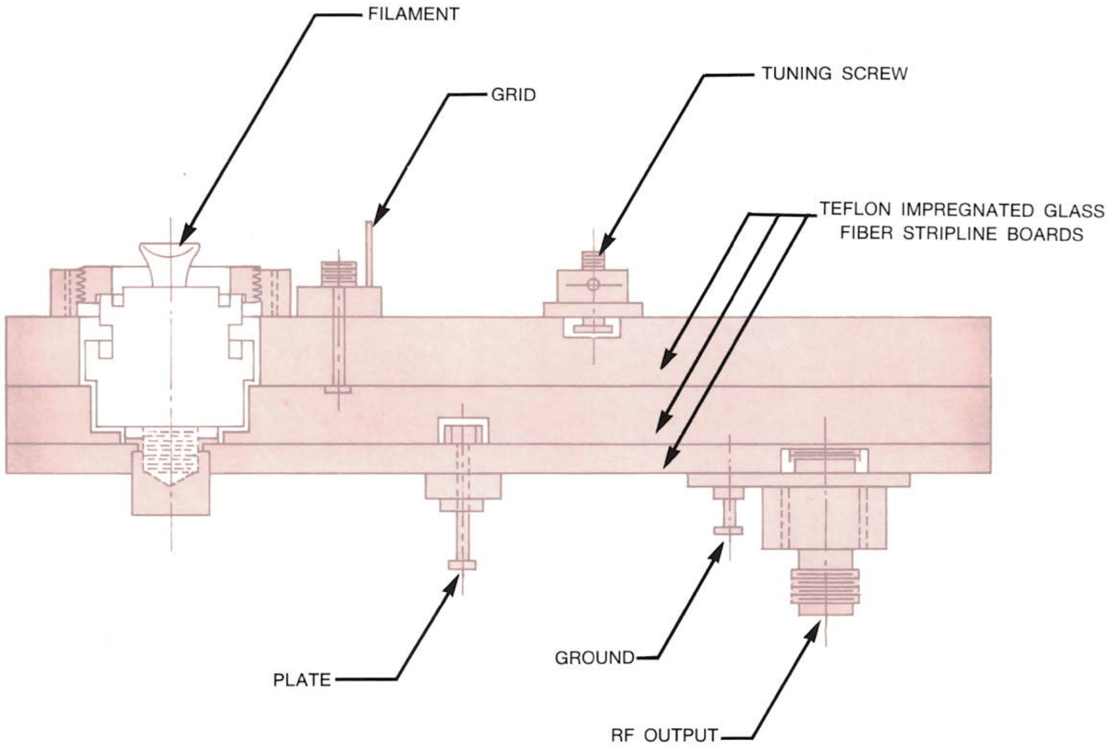


Figure 1—Stripline Oscillator Cross Section. Teflon Glass Boards Provide Heat Sinking.

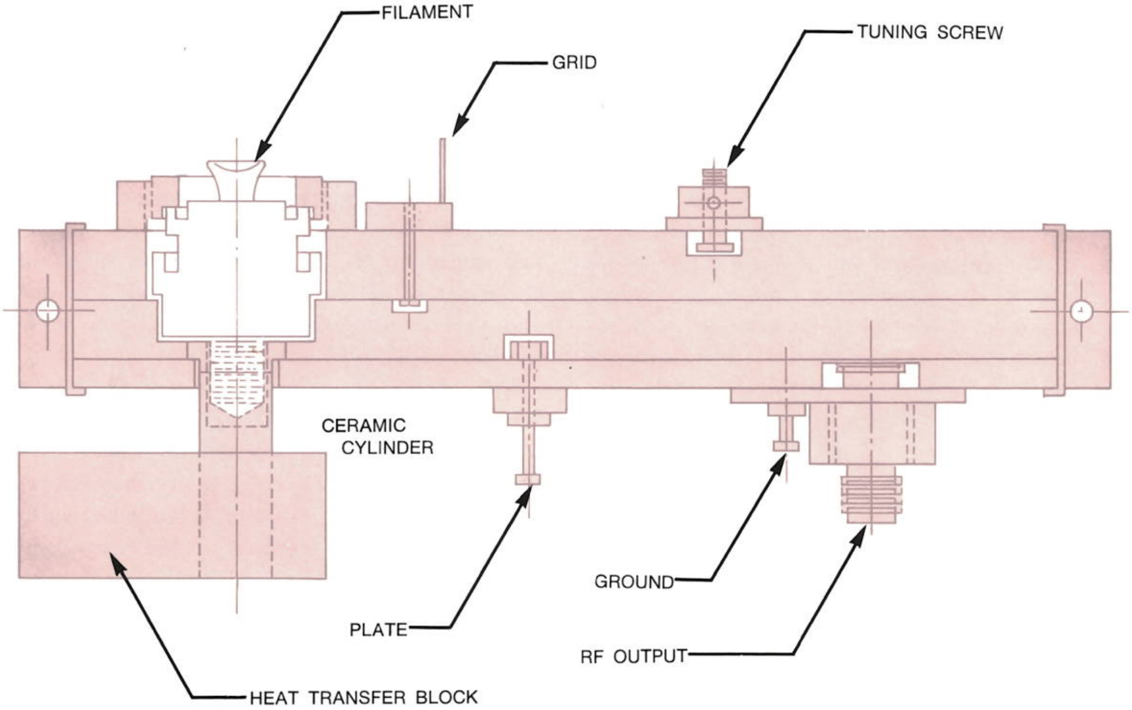


Figure 2—GLJ–3123 Oscillator Cross Section Showing Boron Nitride Heat Removal Cylinder Attached to Heat Transfer Block.

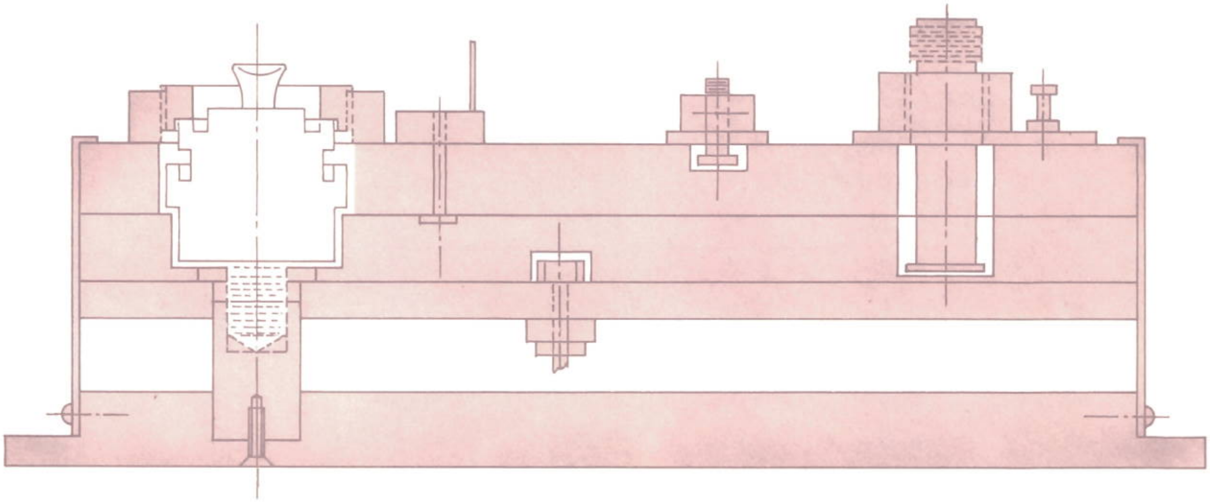


Figure 3—GLJ-3123 Oscillator Cross Section Showing Boron Nitride Heat Removal Cylinder Incorporated in a Mounting Plate.

$R_L - iX_C$ transformed down line one to Plane 2 (Figure 4) and at this point paralleled with $iX_{L_p} - iX_{C_f}$; and this combination of impedances transformed down line two to Plane 3 of the oscillator. At the resonant frequency of the oscillator the inductive reactance X_{L_p}' resonates with the tube and grid cathode line reactances ($X_{C_{pg}}$, $X_{C_{pk}}$, $X_{C_{gk}}$, and X_{L_g} in Figure 5); therefore the load on the tube is R_L'. The plate resistance r_p is much larger than R_L' and is neglected in this analysis. Conventional class C amplifier analysis can be used to compute the rf power that is available in the oscillator (normally called output power), the grid driving power, and the value of the load resistance which the tube would like to operate into for optimum efficiency. Thus for good efficiency the load resistance, R_L', seen looking into the plate cathode line should be equal to the desired load resistance computed by the class C amplifier analysis. While one does not have complete control over the value of R_L', through proper choice of Z_{o_1} and Z_{o_2} this load resistance can be optimized to a degree. The selection of the most optimum R_L' will assure one of maximum power available in the oscillator; the problem then is to remove this power from the oscillator so that it can be used.

The voltage reflection coefficient at Plane 1 of the equivalent circuit shown in Figure 4 is the ratio of the reflected voltage to the incident voltage

$$k = \frac{E_R}{E_I}.$$

And the power reflection coefficient is

$$k^2 = \frac{P_R}{P_I}.$$

Thus the output power, that power transmitted down the power output line is

$$P_T = P_I\,(1 - |k|^2)$$

where P_I, the incident power, is the rf power available in the oscillator less the grid driving power. Table I gives the values of $(1 - |k|^2)$ for various characteristic impedances of the plate cathode line at the location of the output probe.

TABLE I

EFFECT OF CHARACTERISTIC IMPEDANCE ON OUTPUT POWER

Z_0	Z_L	$(1 - \lvert k\rvert^2)$
30	50 – i75	0.497
40	50 – i75	0.584
50	50 – i75	0.640
60	50 – i75	0.678
75	50 – i75	0.707
80	50 – i75	0.709
90	70 – i75	0.711

Table I illustrates that only a slight improvement is obtained when the impedance of that portion of the plate cathode line in proximity to the output coupling probe is increased beyond 75 ohms. In practice it is seldom practical in distributed feedback stripline oscillator design to use impedances as high as 75 ohms for the plate cathode

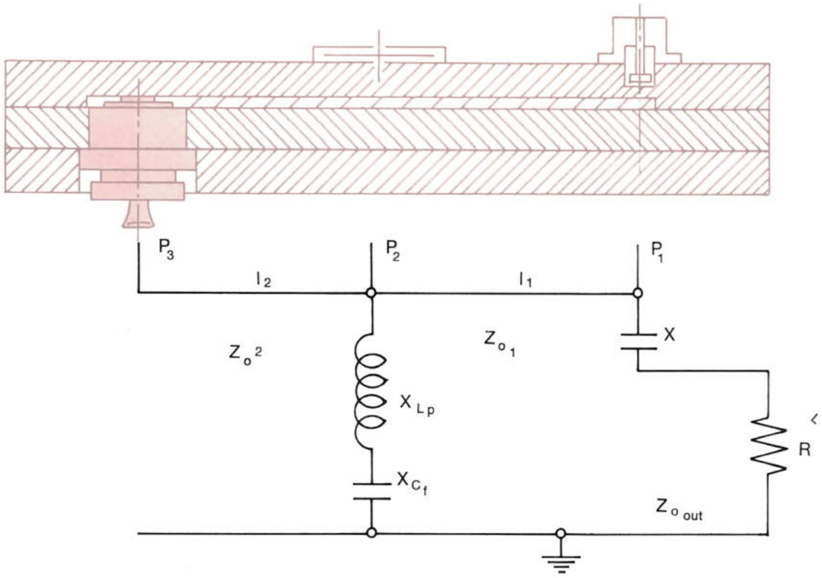


Figure 4—Plate-Cathode Line of the Distributed Feedback Stripline Oscillator and its Equivalent Circuit.

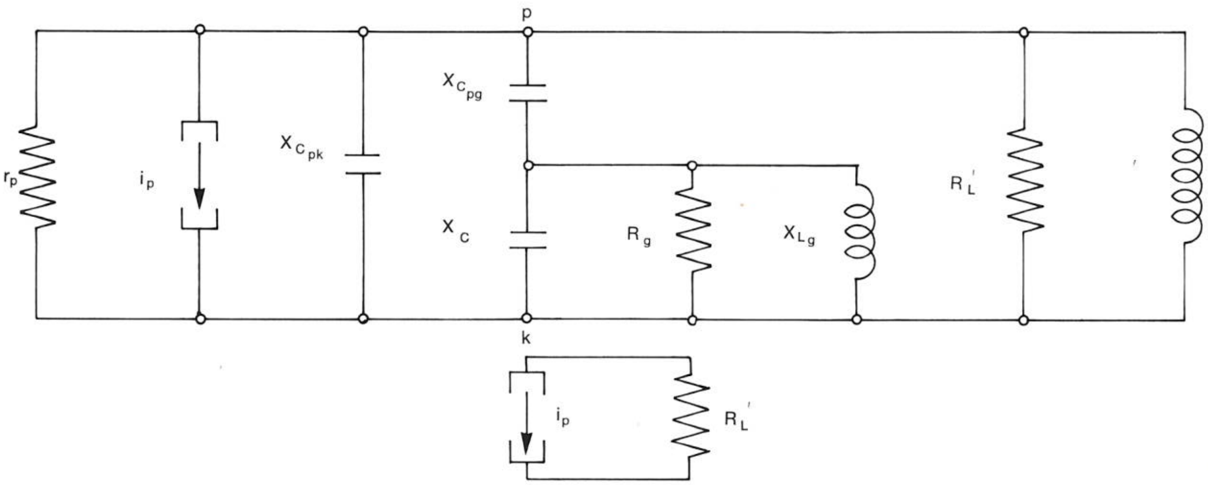


Figure 5—Equivalent Circuits for Stripline Oscillator.

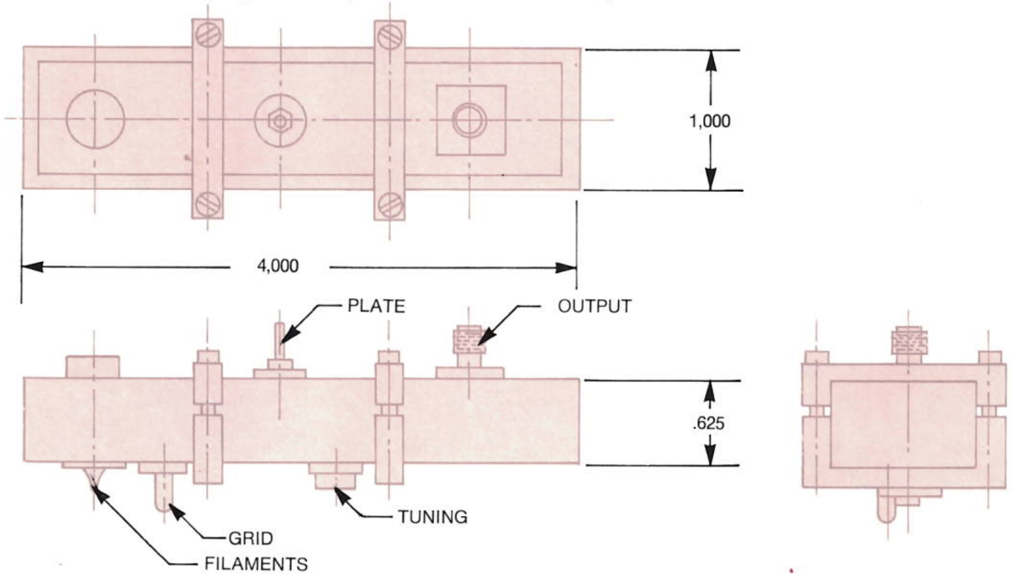


Figure 6—Model GLK-3214 Strip Transmission Line Oscillator.

TABLE II

MODEL GLJ–3123 MEASURED DATA

OSCILLATOR SERIAL NUMBER	OUTPUT POWER	PLATE VOLTAGE	PLATE CURRENT	PLATE EFFICIENCY	FREQUENCY STABILITY		
					+100°C	+25°C	−50°C
01615	1000 W	1.5 Kv	2.15 a	31.0%	−0.50 MHz	fo	0 MHz
01616	830	1.5 Kv	1.90	29.1	−1.50	fo	+2.50
01617	760	1.5 Kv	1.70	29.8	−2.25	fo	+0.50
01618	890	1.5 Kv	1.95	30.4	+1.25	fo	−2.25
01619	970	1.5 Kv	1.75	37.0	+3.50	fo	−1.25
01620	805	1.5 Kv	1.70	31.6	+0.25	fo	+0.75
01621	810	1.5 Kv	1.60	33.7	+0.50	fo	−0.75
01622	760	1.5 Kv	1.60	31.6	0	fo	−2.00
01623	790	1.5 Kv	1.70	31.0	−1.00	fo	+1.00
01624	820	1.5 Kv	1.80	30.4	0	fo	−0.50

line because of ground plane spacings required to be compatible with the ML-8600 series of tubes and line widths required for adequate feedback.

During the development of the Model GLJ-3123 the addition of a step in the characteristic impedance at a point on the plate cathode line near Plane 2 in Figure 4 increased the plate efficiency from approximately 20% to 30%. Measured data including plate efficiencies for a number of Model GLJ-3123 oscillators is given in Table II.

Based on the above analysis the value of the characteristic impedance of the plate cathode line at the plane of the output coupling probe and a step in the characteristic impedance of the plate cathode line at some point on the line, in addition to numerous other parameters, must be taken into consideration in the design of distributed feedback stripline oscillators if they are to operate efficiently.

Assembly of Stripline Oscillators

Another problem with stripline oscillators of early design was the frequency shift that was experienced with changes in the ambient temperature. Some very early models drifted as much as 10 MHz over the temperature range of −54°C to +80°C with no external fixtures to hold the stripline boards together. These early models were held together by eyelets at the four corners of the package. During temperature extremes the boards would flex slightly and a change in ground plane spacing would occur resulting in a change in characteristic impedance and thus a shift in the resonant frequency of the oscillator would occur. Dual registration of the striplines gave some improvement in stability and external clamps such as those shown in Figure 6 gave adequate results but were bulky and expensive to manufacture.

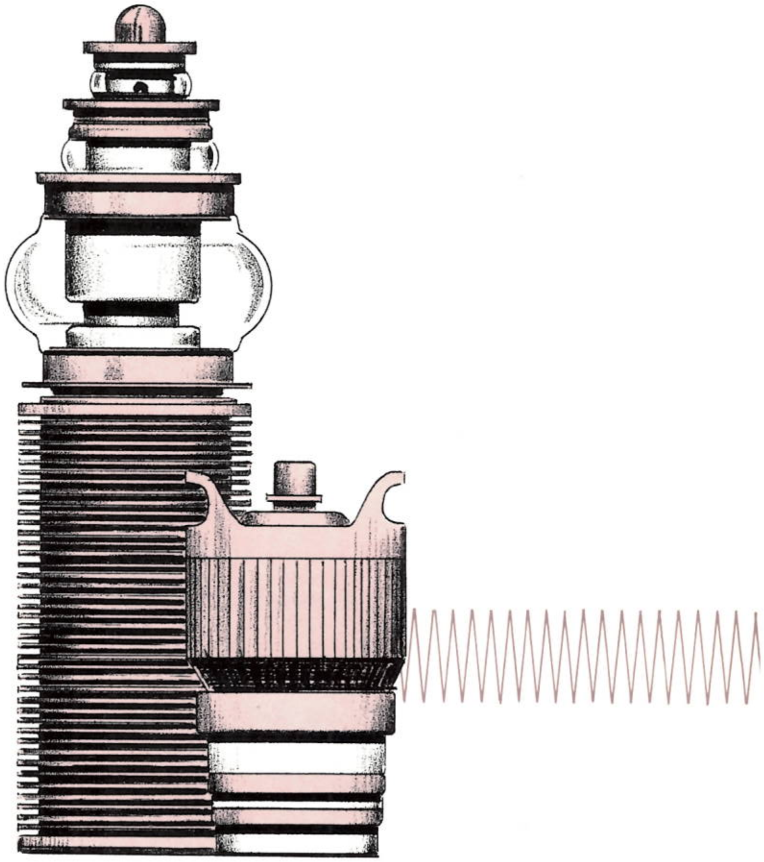
A technique that has been used for the past year with excellent results is to bond the three stripline boards together (one dual registered stripline is bonded to the other stripline). This process provides a very solid package wherein the three separate stripline boards become one piece. Oscillators constructed in this manner are very rugged mechanically and exhibit excellent frequency stability when subjected to temperature extremes. Measured frequency stability data for a number of Model GLJ-3123 oscillators is given in Table II.

Conclusions

Further developments in the stripline oscillators have overcome certain limitations that were inherent in the original design; specifically, the restriction to low duty factor operation and the frequency shift with respect to ambient temperature extremes. In addition, considerable improvement in optimization with respect to plate efficiency has been obtained. The improvements that have been discussed in this paper make these miniature, rugged, ideal form factor, stripline oscillators even more desirable than the conventional coaxial cavities.

Bibliography

1. Feldman, K. Thomas Jr., and Whiting, Glen H., "The Heat Pipe," *Mechanical Engineering*, (February 1967), 30–33.
2. Brownell, Arthur B. and Beam, Robert E., *Theory and Application of Microwave*, New York, McGraw-Hill Book Co., 1947, pp. 70–72.
3. Tube Performance Computer, Number 5, Eitel-McCullough, Inc., San Bruno, California.
4. CFRD Memo to File, J. C. Pacini, Division 1422, Sandia Corporation, Albuquerque, New Mexico, February 3, 1965.
5. Seely, Samuel, *Electron Tube Circuits*, New York, McGraw-Hill Book Co., 1958, pp. 832–392.



Fundamental developments in the concepts and techniques of measurement are directly associated with the extraordinary expansion of contemporary technology. Central to this growth has been the immediate availability of measurements[1]—time signals—of a new order of accuracy. As J. A. Barnes of the National Bureau of Standards, Boulder, Colorado has recently pointed out, ". . . it is possible to measure time with the smallest relative error of any quantity which man measures. This error is less than one-billionth of one percent."

Such was not the case in March, 1923, when WWV began transmitting standard radio frequencies—only to find that the "standard" shifted as the antenna swayed in the wind. As facilities improved and the transmissions[2] (controlled by quartz crystal oscillators) were no longer subject to the vagaries of the wind, accuracy reached a limit determined primarily by the astronomical observations on which the broadcast time signals were based. Atomic beam magnetic resonance techniques were developing in the '40's and early '50's; in 1948 the National Bureau of Standards first operated with an ammonia absorption cell clock. By 1958 the "atomic second" had become the tentative standard. Why "tentative"? Because the evolution of technique is so rapid as to require, almost, an opportunistic approach. (Figures 1 and 2) G. E. Schafer, Assistant to the Deputy Director for Radio Standards, IBS, has concisely stated the case[3]: ". . . standards and their uses are not static. Because of its dynamic nature and because of its central core status, the standard of time, the second, will be used as an example. (Each time an older unit is replaced with a new one of lesser indeterminacy, the new unit is of course defined within the zone of confusion of the old. As long as it is done this way, the results obtained by previous measurements will still be valid within the range of indeterminacy associated with the older unit.) Any periodic function can be used as a clock and the more stable its period the better clock it makes. Before 1956 the second was defined at 1/86,400 of a mean solar day. Thus its definition was based on the rotating earth as a clock. By 1956 it had become evident that the rotating earth was not sufficiently stable and the

---

[1] Should anyone doubt the need for accurate measurements it has recently been estimated that 20 x 10^9 measurements are made in the United States each day.

[2] Transmission of time signals on a continuous basis began in 1943 at the WWV transmitters in Beltsville, Maryland.

[3] Schafer, G. E., "A Systems Concept of Electromagnetic Measurements in the U. S. A.," *Proceedings of the IEEE*, Vol. 55, No. 6, June 1967.

Editor's Note

During the greater part of its many years as a manufacturer of high power transmitting tubes, Machlett has supplied WWV with its modulator and final amplifier tubes—more than a million hours worth. This is an association in which the company takes great pride. During these same years WWV's growth has been continuous, both in its global recognition and importance. For WWV, the future is as broad and promising now as the wide horizons around Boulder and Ft. Collins.

RF Metrology—New Concepts of Accuracy

second was redefined as a certain fraction of the tropical year. It is possible to obtain this second to about two parts in a billion after about five years of astronomical measurements. Work with the cesium-beam-controlled clocks had already far surpassed this precision, and hence a new definition was needed. In October, 1964, the Twelfth General Conference of Weights and Measure authorized a provisional atomic definition of the second. The International Committee on Weights and Measures, acting for the Conference and in expectation of a more exact definition in the future, temporarily based the definition on an invariant transition of the cesium-133 atom. A value of 9,192,631,770 Hz was assigned to the cesium transition selected. [The 13th General Conference on Weights and Measures formally adopted the atomic second based on cesium on October 13, 1967.] It now appears that the second can be compared in terms of this realization to one or two parts in 10^{13}. If a clock could run steadily with this accuracy, it would gain or lose only one second in 300 thousand years. These changes in the definition of the second are a good illustration of the way in which the definitions of our units are continually being refined so that we can better say what it is we are trying to measure. The hydrogen maser now under development may exceed the precision of this standard by a factor of 100. The question will then arise whether to redefine the second in terms of this more precise clock." For a glossary of terms describing time units and systems see "Time Table," pages 10 and 11.

Together with the more evident developments of modern technology (radar, rocketry, nuclear physics) rf metrology, a system of rf measurements to be used as standards references, has grown silently but in comparable importance. There can be little doubt as to the fundamental importance of this evolving system of disseminating standards units. A. V. Astin, Director of the National Bureau of Standards has recently noted[4] the scope and importance of "compatible measurement technology": "The accuracy with which radio frequency parameters can be measured is highly critical in large, complex, multi-component systems such as satellites, missiles, and large aircraft. Compatible measurement technology is fundamental to solving interface problems not only among the many subassemblies that make up a satellite, but between a satellite and supporting ground stations.

"The growing significance of international cooperation to exploit the potential of satellites for communication, weather observation, and other world-wide peaceful pur-

---

[4] Astin, A. V., "Measurement Accuracy at Radio Frequencies," *Proceedings of the IEEE*, Vol. 55, No. 6, June 1967.

Time

Second	Name for fundamental time interval unit at the base of the International System (SI) of units.
Epoch	An instant of time designated on *any* scale. It may mean a certain number of seconds beginning from an arbitrary instant: 0 hr 0 min 0 sec.
Frequency	Number of oscillations per second; rotation of the earth; orbit of the earth around sun; number of waves emitted or absorbed per second in an atomic transition (change of state); etc. (One cycle/second is called "one Hertz" (Hz) in the International System (SI) of Units.)
Scale	Allows determination of the order of occurrence of an event: past, present, or future.
ET	A scale called "Ephemeris Time" based on one hypothetical annual orbital movement of the earth around the sun and extended to the present by observations of the moon and gravitation theory—it is a scale approximately realized by the apparent annual motion of the sun around the earth. The ephemeris second is defined as $\frac{1}{31,556,925.9747}$ of the "tropical year" on 31 December 1899 at 12 hr 0 min 0 sec. Epoch determinations in terms of the Ephemeris Second can be made to a few parts in 10^9: to achieve this accuracy requires measurements made over a period of several years. One Ephemeris Day equals 86,400 Ephemeris Seconds; one Julian (Ephemeris) Year equals 365.25 Ephemeris Days exactly.
UT	Universal Time scale, an astronomical time scale, commonly known as Greenwich Mean Time (GMT). Based on the rotation of the earth on its polar axis (used when accuracy of the second to 0.1 seconds is acceptable). The "universal second" is obtained from interpolation between successive observations of periodic events (e.g., zenith transits of a star for Sideral Time and successive mean solar zenith transits for GMT). Successive observations are used to correct a clock driven by a free running oscillator so that, for GMT, the clock produces 86,400 intervals, each one universal second long, between successive transits of the "mean sun."
UTO, UT1	UTO. UT scales without application of periodic and observatory position corrections. Such scales are recorded at many astronomical laboratories. UT1. A single UT scale derived from UTO scales by applying a correction for polar motion and dependences on observatory latitudes and longitudes. UT1 is actually a record of the motion of the earth on its polar axis, and yields successive positions (to within a few ms) of the rotating earth.
UT2	UT2 is derived from UT1 by applying a periodic correction (max. about 0.03 second) for annual and semi-annual seasonal variations. The scale gives successive *mean* rotational positions of the earth (about its axis) within about 30 ms by applying corrections for known periodic variations (atmospheric and tidal effects—annual and semi-annual). UT2 is not a uniform time because of progressive changes in the rotational speed of the earth. This is a widely used scale.
UTC(NBS) **UTC(USNO)**	Clocks at National Bureau of Standards and the U.S. Naval Observatory which approximate UT2 within about 0.1 second according to a system known as UTC (Universal Time, coordinated). "Piecewise" adjustments are made to change the length of the UTC second

	to yield approximate UT2 seconds. This involves an offset in pulse rate from its nominal value of one per second—at present the UTC second is 300 parts in 10^{10} longer than the international second, and changes according to this system on the first of a year, when necessary, because the earth's rotation rate may have changed. This number is the magnitude of the offset (or difference in pulse rate) of UTC from atomic clock rates, themselves known to be more uniform than the earth's rotation rate. Steps are also made in pulse epoch, as needed, to bring pulse epochs into coincidence(within about 0.1 second) with UT2. UTC and UT2 now have diverged about 6 seconds from an atomic time (AT) scale whose epoch began January 1, 1958.
SAT(NBS)	A clock which is also maintained in coincidence with UT2 to within 100 ms, but its stepped pulse scale employs a second of constant length, as referred to the NBS Frequency Standard maintained by the Time and Frequency Division of NBS at Boulder, Colorado. This scale (or one easily obtained from it by eliminating the readily discernible steps of 0.2 sec. in epoch, which occur about every three months) can be used by those maintaining large numbers of electronic instruments or oscillators—(e.g., satellite tracking)—where frequency or time interval conversion problems, inherent in the use of UTC scale, might present serious difficulties. The uniform *atomic scale* which can be obtained from SAT (or UTC) scales by making the proper correction (or corrections) for epoch (and offset) differences is used by astronomers as a readily available extension of the ET scale—it is therefore useful as a reference scale for all physical phenomena. The SAT system, too, is coordinated internationally on an experimental basis by the BIH in Paris.
Universal Second	$\frac{1}{86,400}$ of the mean solar day, or any one of the basic time intervals on any of the Universal Scales.
Solar Day	The time between successive zenith transits of the sun.
Tropical Year	0.35 second shorter now than 1900; that is, it is shorter than the Julian Ephemeris Year by this amount. Variable period assumed to be produced by interplanetary matter, electromagnetic fields interacting with the earth's core, interplanetary gravitational anomalies and planetary attractions. A tropical year is the interval on the ephemeris scale related by a specific formula to an increase of 360° in the sun's geometric mean longitude (measured from the mean equinox of date).
SFTS	Standard Frequency and Time Signals made available by the National Bureau of Standards, Boulder, Colorado, by means of (a) broadcasts: HF, LF, and VLF (worldwide) (b) portable clocks (portable atomic clocks can be flown to remote locations for highly accurate synchronization) (c) rf cables and lines (local distribution) (d) satellites carrying clocks or transponders (experimental) (e) moon-bounce radar (experimental)
AT(NBS) or AT(USNO)	Independent atomic clocks controlled in rate by the National Bureau of Standards Frequency Standard (a cesium beam device) or by cesium frequency standards kept by the U.S. Naval Observatory. The atomic time scale (AT) readings of these clocks have been known as NBS-A or A.1, respectively.

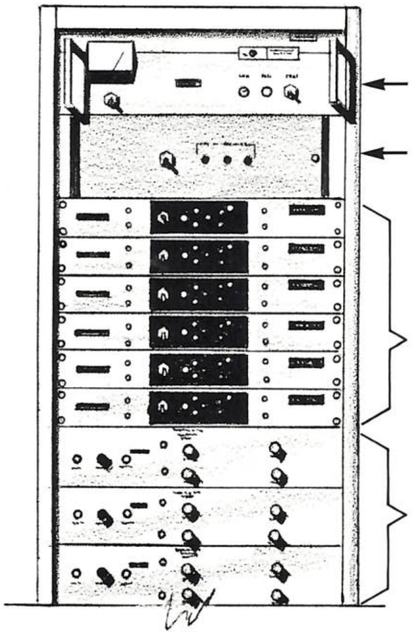
Time

AT

The Atomic Time scale. The Thirteenth General Conference of Weights and Measures designated an atomic or molecular frequency standard to be used for the physical measurement of time. The frequency of the transition of the cesium atom (9,192.63177 MHz) was chosen to be assigned (as an exact number) to cesium frequency standards. The uncertainty of such frequency standards can be 5 parts in 10^{12} (or 5 parts in one thousand billion); this accuracy is achievable within minutes (as compared to years for ET). Within the limits of present accuracies, the international (atomic) second is equal to the ephemeris second.

The A.1 reading of AT is registered on an atomic clock AT(USNO) at the U.S. Naval Observatory. Origin: Oh: Om: Os on the UT2 time scale, 1 January 1958. This scale reading is now derived from several atomic (cesium) frequency standards maintained at the Observatory, referred to a hydrogen maser "flywheel" maintained by the U.S. Naval Research Laboratory. There is presently being contemplated an official ATC(BIH)—a composite atomic clock maintained by the BIH in Paris—formed as an average of readings of various major atomic clocks over the world. Its readings of atomic time are presently known as A3.

TABLE



TIME ROOM

Voltage regulator

Code comparator
(takes pulses from 3 units; sounds alarm if more than 5 μsec difference between signals)

6 phase detectors to measure and compare outputs from standards

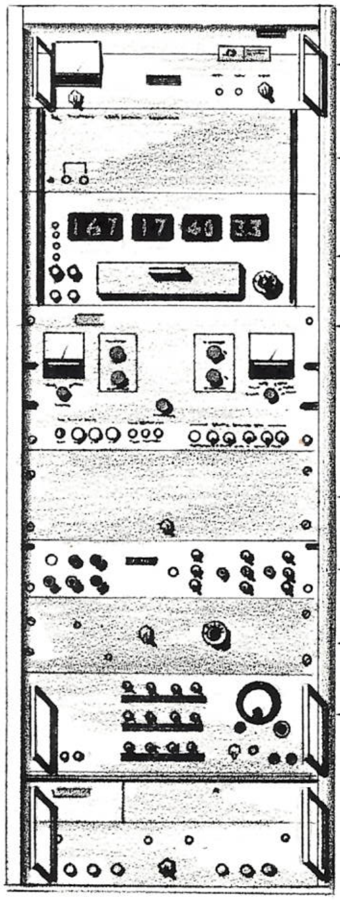
3 phase error multipliers to amplify the phase difference between two oscillators thus facilitating precise measurements.

Table (Continued)

The following terms are used to describe measures of performance of frequency standards.

Stability	Stability. A measure of the time varying deviations (magnitude and rate) of an oscillator from a standard oscillator. It should describe the degree to which the instrument in steady operation gives results constant in time.
Precision	Precision. The measure of reproducibility of measurements made using a single standard in measuring other frequency standards or sources of frequency.
Accuracy	Accuracy. A measure of the inherent certainty or quality (or, inversely, the uncertainty) of a specific standard in realizing the ideal definition of the standard of frequency (or time) defined in the International System (SI) of Units. When quoting "accuracy" it is customary to cite the inaccuracy, i.e., ± so many parts per million. The unit employed in the definition in this case is the "second" for time interval, or inversely, the "Hertz" for unit frequency.
BIH	The BIH is the International Bureau of Time located at the Paris Observatory in France.

II



Regulated power supply Sorensen ACR 1000

Standby power supply for time code generator/programmer

Time code generator/programmer . . . Provides all program control for WWV

AF/RF driver (for SSB or dual side band)

Accepts 1 MHz signal (from offset distribution panel) derives other frequencies to drive transmitter

AF/RF driver power supply

Distribution panel for all offset signals

Offset generator (motor driven resolver)

Cesium standard

Provides atomic frequency signals for offset generator and motor drive

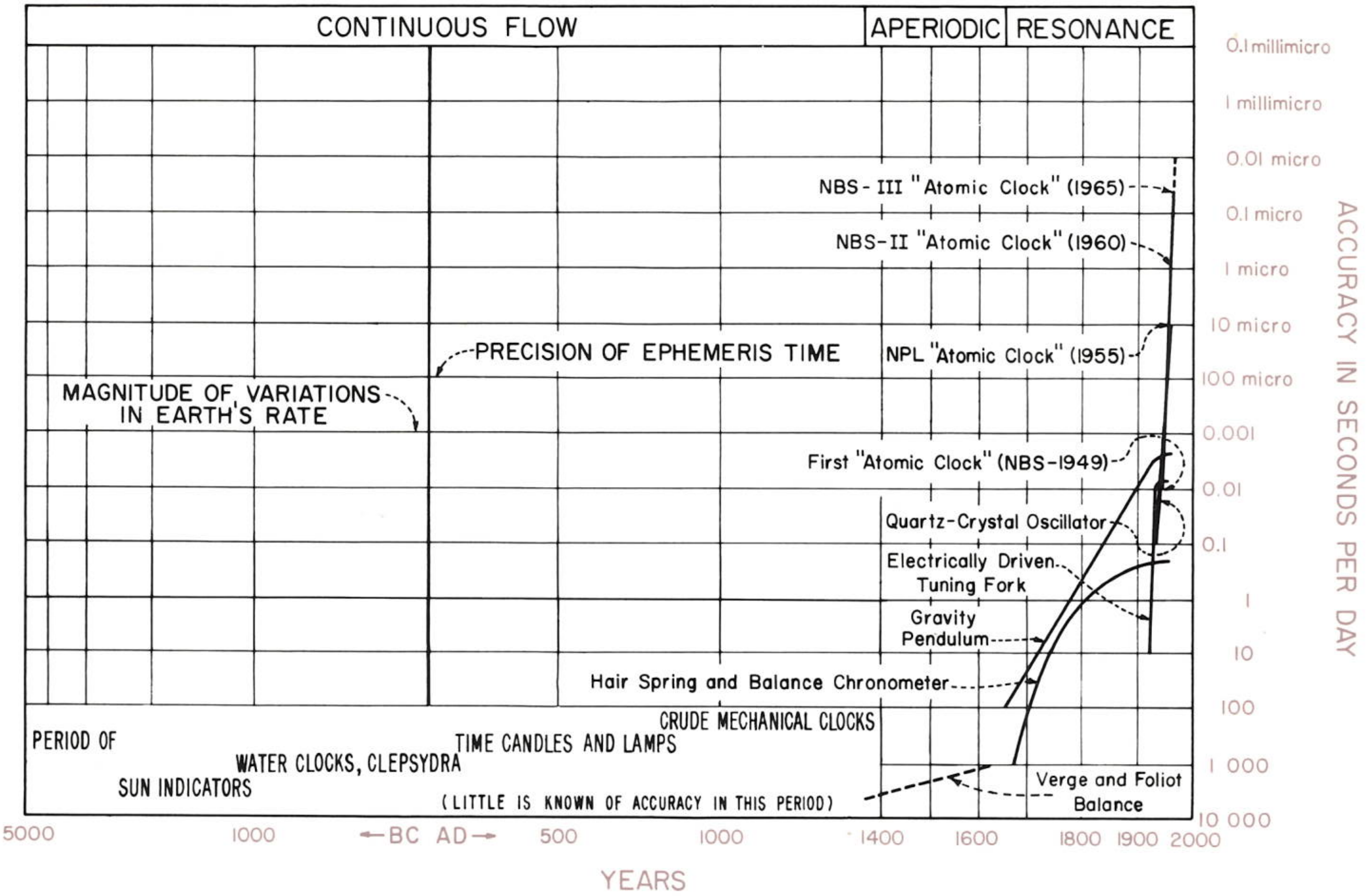


Figure 1—The Accuracy of Timing Through History.

poses has developed concern over the compatibility of radio frequency measurement among participating nations. The growing international commerce in radio frequency measuring instruments has added to the concern."

Generation of Standards Units

Although the generation of the time signals to be broadcast takes place at the Ft. Collins transmitting sites, the basic time signal against which these are compared is generated at Boulder, some fifty miles away. The Atomic Frequency and Time Standards section is responsible for the stability, precision and accuracy of this basic signal, from the atomic clock readings known as NBS-A. (Figures 3 and 4) Yardley Beers[5], NBS, Boulder, explains how: "The standard in use is a particular cesium atomic beam built by NBS and referred to as 'NBS III'. However, the cesium beam standard is a passive device, and the present one is not designed to operate continuously; but rather the Section operates continuously five very stable oscillators, some controlled by quartz crystals and the others stabilized by atomic resonances. The frequencies of these oscillators are periodically compared with NBS III and the data are recorded automatically. The output of one of the five oscillators is fed to a correction device consisting of a driven phase shifter. The rate of drive of the phase shifter is adjusted to (a) make output time correspond to the weighted average of the five oscillators (or, automatically, to four of them if the fifth one is in serious disagreement) and (b) to make the output frequency correspond to that of NBS III. The output of this correcting device is referred to as the Frequency Controlled Oscillator (FCO), and serves as the working output for the NBS atomic clocks and for the control of the radio stations. Connected to the FCO is also a device for producing the frequency offset for the UTC(NBS) clock. Connected to these oscillators and other circuits are a number of devices which count cycles and thus become clocks for telling time on both the atomic and UTC Time Scales."

---

[5] Beers, Yardley, Consultant, Radio Standards Physics Division, National Bureau of Standards, Boulder, Colorado; adapted from "WWV Moves to Colorado"—Part II, *QST*, February 1967.

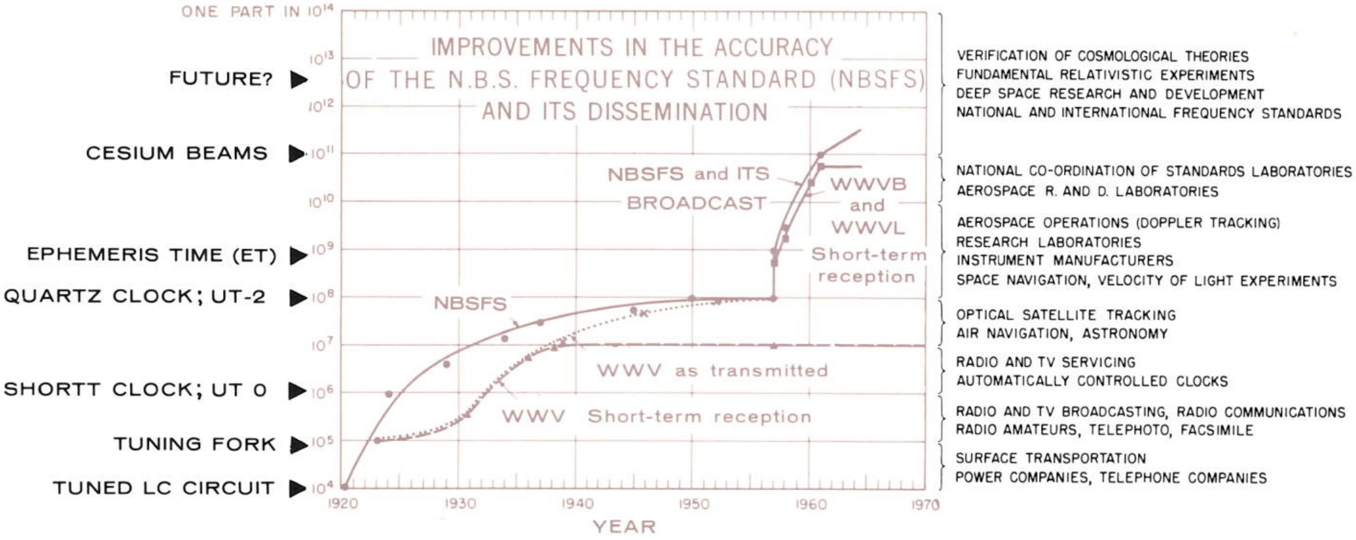


Figure 2—Improvements in the Accuracy of the NBS Frequency Standard (NBSFS) and its dissemination.

Dissemination of Standards Units

At present a phase-lock link controls the transmitted phase of the WWVB 60 kHz signals which are monitored at Boulder and phase compared with the reference signal derived from the NBSFS. A long-range servo system acts to correct any difference between the two signals. The 400 hertz FM reference signal is transmitted continuously on the carrier frequency of about 50 megahertz. The error signal is a 400 hertz amplitude modulation of a 10.5 kilohertz subcarrier used to frequency modulate the carrier. The out-of-phase error signal varies in amplitude and direction to correct the transmitted phase. The HF signals from WWV are referred to the atomic standard via phase-lock to WWVB.

Recently it was proposed to establish a microwave link between Boulder and Ft. Collins to replace the VHF signal used in the phase correction system which directly locks the LF and VLF signals from WWVB-VL to the NBS-A atomic time scale reading. Both the phase-lock system and the microwave link are of unusual electronic interest.

A microwave link would enable WWV and WWVB to transmit time signals to Boulder each day for accurate comparison with the master NBS clocks, UTC(NBS) and SAT(NBS). Significant deviations of 0.1 microsecond or greater could be reported by phone to the station operator so that minor adjustments might be made in the controlling oscillators.

However, at the present time, accurate time transmissions from WWV are insured by comparison (via coaxial cable) of the three cesium standards at WWV with the corrected standard at WWVB. Clocks at the stations are also periodically compared with NBS-A by means of portable clocks.

Signal generation of the transmitting sites is accomplished by use of oscillators located at each site (3 for WWVB-WWVL; 3 for WWVH and 3 new cesium controlled units at WWV). In practice these oscillators are referred to each other—on the assumption that error or failure would be associated with only one of the three, the other two being correct. Suitable interconnections exist so that one station could provide time from another in case of a major failure. A screened "Time Room" at the WWV building contains the "time rack" (see Table II, pages 12 and 13) and the Audichron, a precision recorder-repeater (Figure 5) which provides all voice signals at precise intervals.

When WWV moved from Greenbelt, Md., to Ft. Collins and went on the air from Colorado on December 1st, 1966, new transmitters had been installed. The old units at Greenbelt, which had served well for something like twenty years through modification and re-modification, had been ready for retirement. Machlett triodes had provided a total of more than one million hours operation in these transmitters with some of the thoriated-tungsten filament tubes operating as long as 90,000 hours[6]. A great many of these triodes (ML-5541, ML-6423-F) provided useful service into the 70,000 hour range. The new WWV transmitters, manufactured by the Technical Materiel Corporation, are Models GPT-10K (which uses the ML-8170/4CX5000A) (Figure 6) and GPT-40K, using the ML-6697 (Figure 7). The new WWV building, which houses the

---

[6] For background information, see *Cathode Press*, Vol. 22, No. 4, 1965; Vol. 20, No. 2, 1963; Vol. 18, No. 2, 1961; Vol. 13, No. 4, 1956.

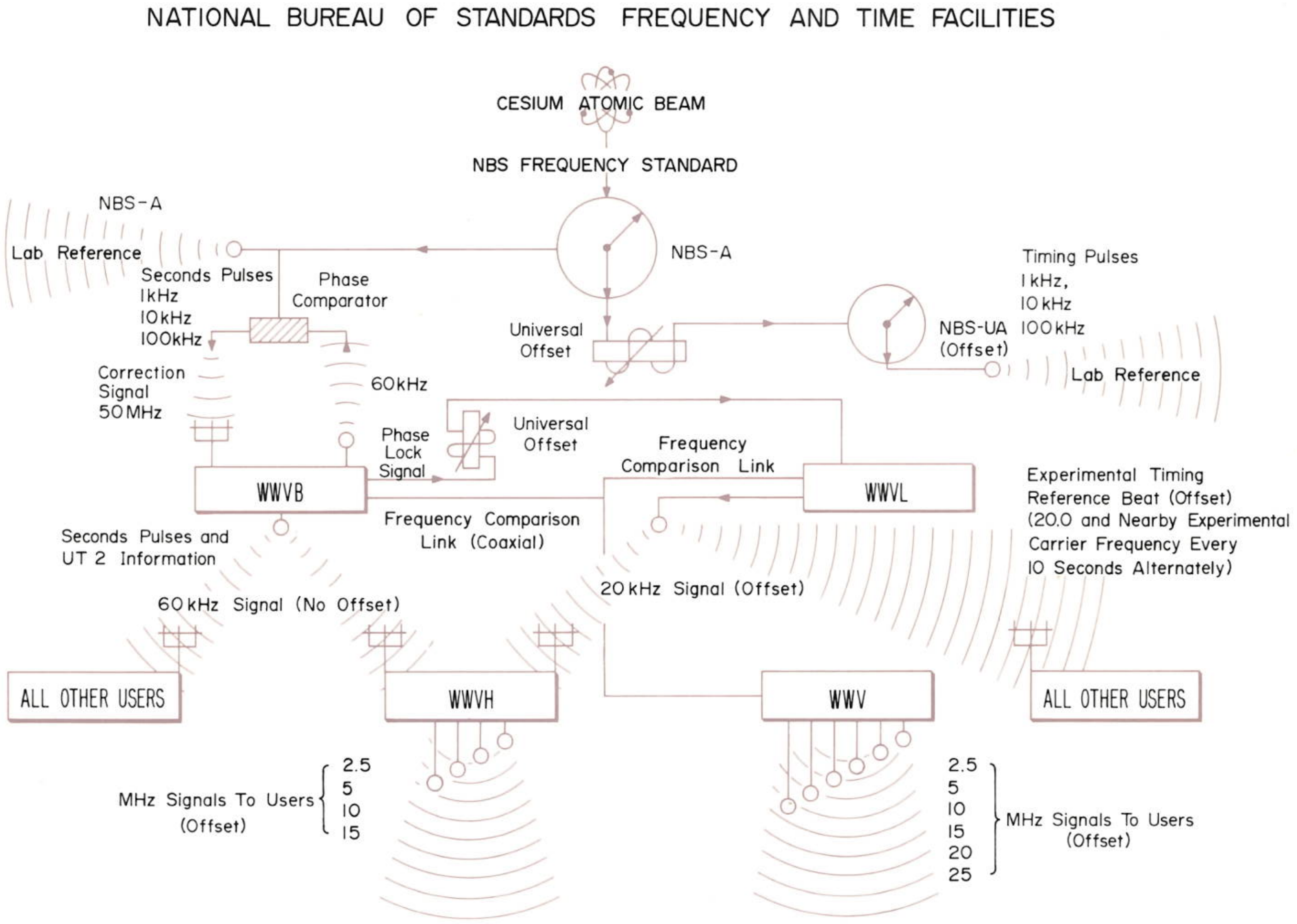


Figure 3—National Bureau of Standards Frequency and Time Facilities.

eight transmitters, has administrative and work space for a staff of 12 engineers and technicians. The building itself has been located so that it is notched into a small rise on the land so as to have the least possible effect on the radiation pattern of the radio transmissions from the antennas surrounding it.

Each one of the four new transmitters is designed to feed a vertical antenna with effective power of 20 kW; three transmitters are used for operation at 5, 10 and 15 MHz; and the fourth is used as a standby transmitter. High equipment reliability will be obtained by using the transmitters to provide only 10 kW on each of the three standard frequencies, a slight increase over the past power emissions. The other four transmitters are rated at 5 kW and are similarly used at half-power to transmit 2.5 kW at frequencies of 2.5, 20, and 25 MHz, with one transmitter being held as a standby.

The six single-frequency antennas (Figure 8) normally used are grouped around the transmitter building (Figure 9) in such a way that there is little "shadowing" of any antenna by the others. This makes possible an omnidirectional radiation pattern for each of the frequencies broadcast. The antennas used are vertical, modified sleeve-type, ½-wave dipoles. Only one tower is required for each antenna; the highest is 200 feet for 2.5 MHz transmissions and the lowest, 20 feet for 25 MHz.

Standby capability is provided by two identical monopole antennas on 88-foot towers; these general-purpose antennas are effective over the entire range of WWV frequencies from 2.5 to 25 MHz. They can be used for operation with only slightly reduced efficiency when any of the six regular transmitters or antennas is out of order or is being serviced. Each of the antennas is connected to its transmitter by coaxial line for maximum reliability, ease of matching without special networks, and to withstand wind and ice better.

Both the GPT-10K and the GPT-40K are equipped for several modes of operation including, of course, SSB.

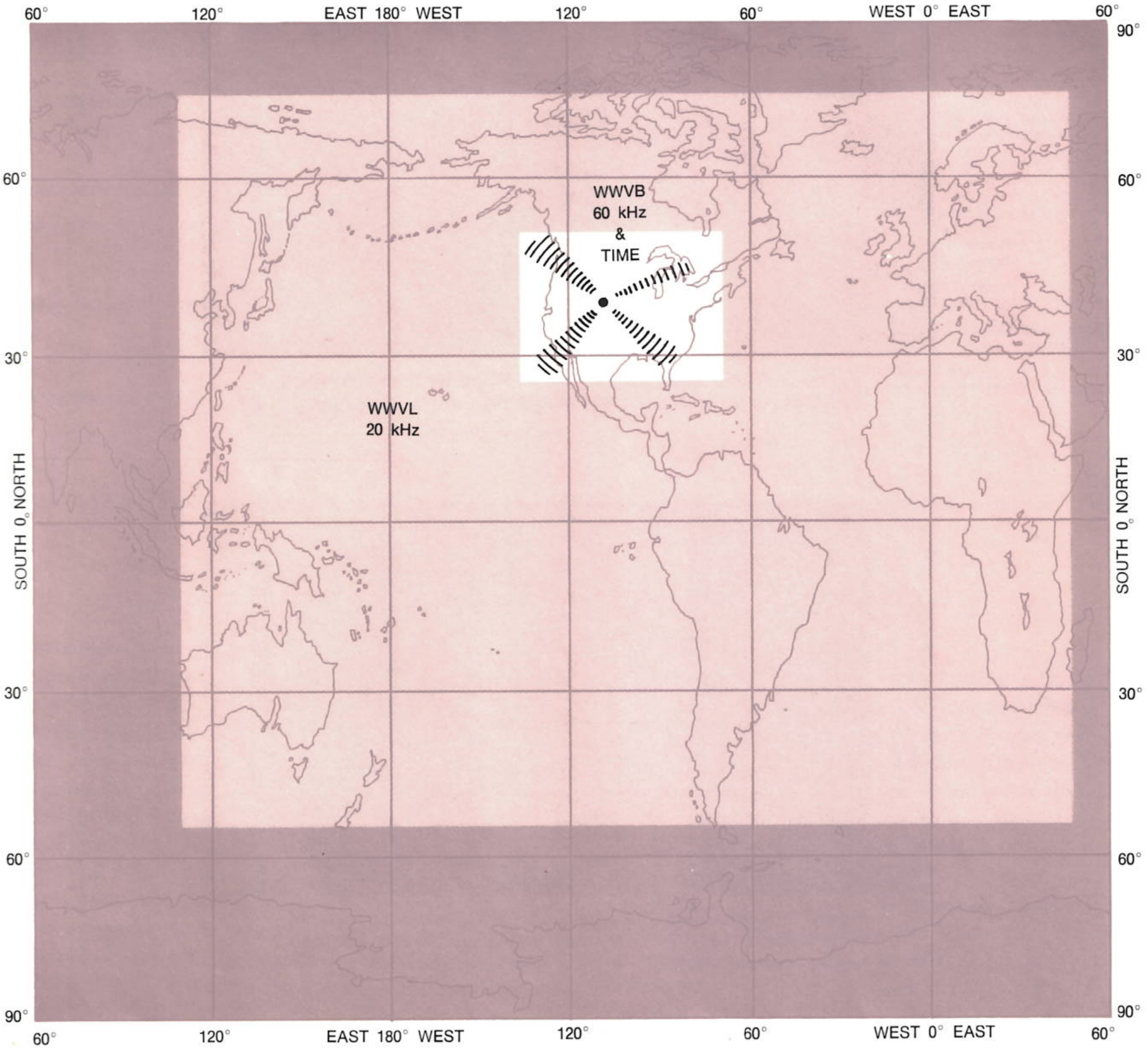


Figure 4—Global Coverage of WWV Transmitting Stations.

While operating now on AM it is possible that, sometime in the future, operation with modulation on either sideband may take place. Modulation is applied at low level to the transmitters and the following stages are linear. "In this way, there is available a wide choice of modulation types: a.m. or single sideband, with either sideband, and with any arbitrary degree of carrier suppression . . . The wide flexibility of modulation is particularly advantageous with respect to coordination with WWVH in Hawaii, which uses the same carrier frequencies. This station, [now obsolescent], is expected to be rebuilt a few years hence. In this event, similar features will be incorporated. Then the upper sideband can be used by one station and the lower by the other, and users who wish to distinguish between the two stations will be able to do so with suitable receivers."[7]

---

[7] Beers, Yardley, Consultant, Radio Standards Physics Division, National Bureau of Standards, Boulder, Colorado; adapted from "WWV Moves to Colorado"—Part II, *QST*, February 1967.

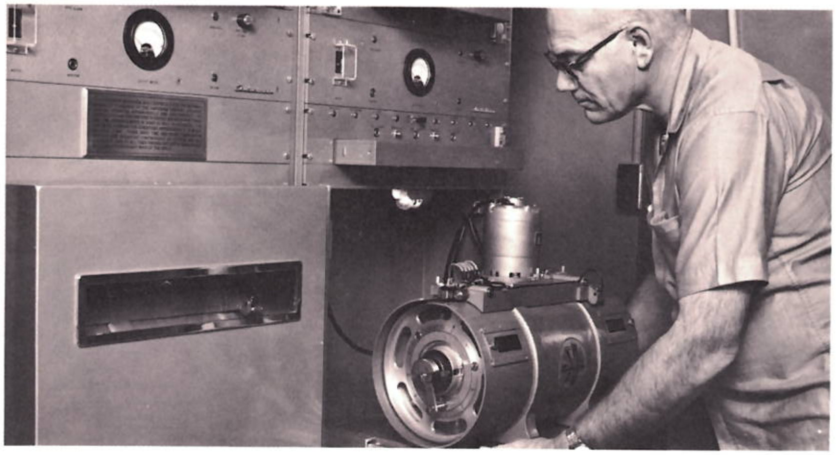


Figure 5—The Audichron, a Precision Recorder Repeater which Provides All Voice Signals at Precise Intervals, is Inspected.

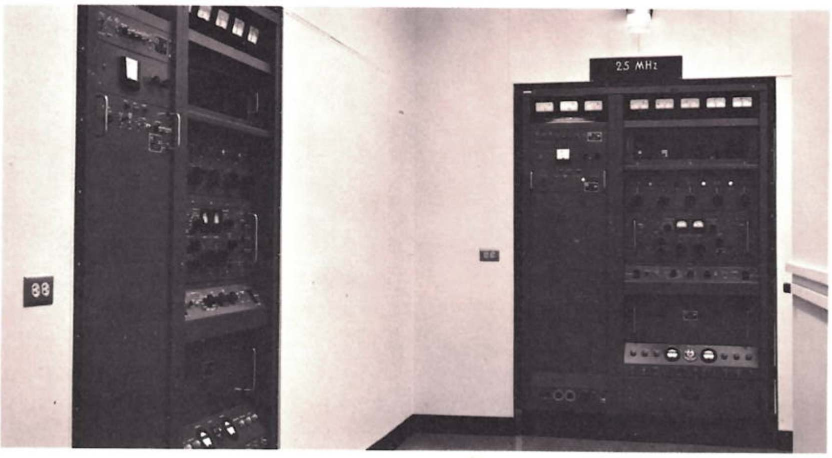


Figure 6—View of 20 MHz and 25 MHz Technical Materiel Corporation's GPT-10K Transmitter Using the Forced Air Cooling ML-8170/4CX5000A.

Figure 7—WWV's 15 MHz TMC Model GPT-40K, a Transmitter which Uses the Forced Air Cooled ML-6697 or ML-6697A.

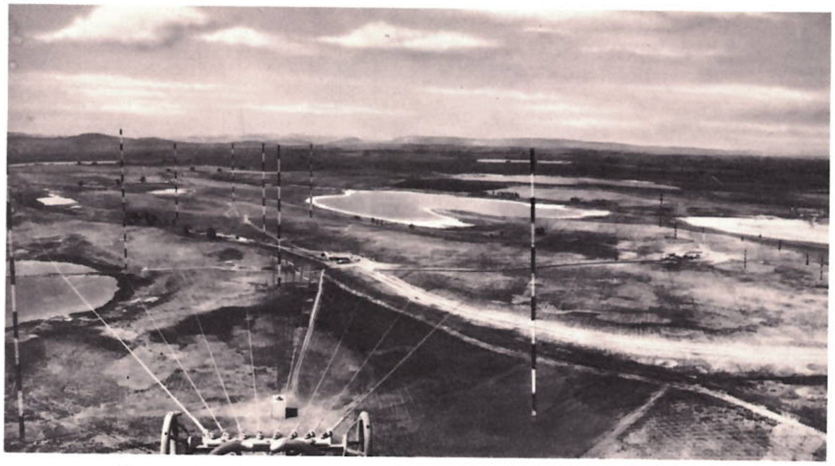


Figure 8—WWV Transmitter Field, Ft. Collins, Colorado.

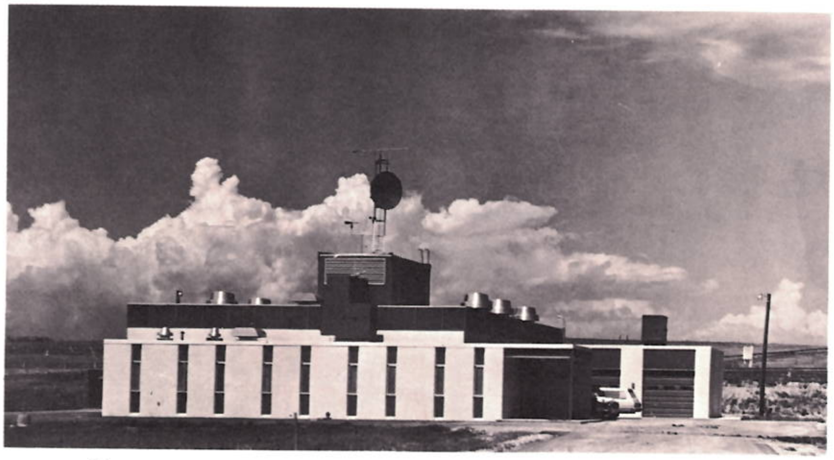
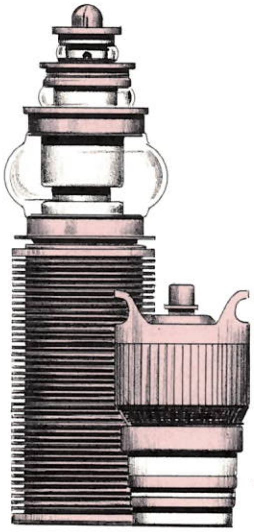
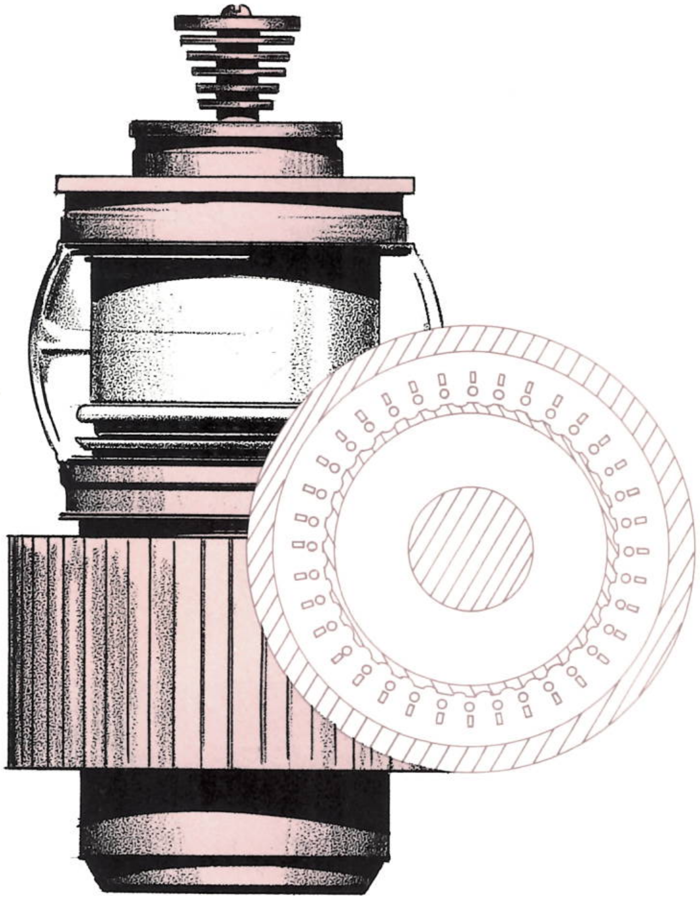


Figure 9—WWV Transmitter Building, Ft. Collins, Colorado.

Both the GPT-40K and GPT-10K are fundamentally similar units conservatively designed for 40 kW PEP and 10 kW PEP, respectively. As just noted, the transmitters are operated by WWV at ½ average power or 10 kW and 2.5 kW each. Each transmitter incorporates a signal limiting circuit (feedback from PA to IPA and exciter) to limit high drive peaks occurring during multiple signal transmission and suppress unwanted transmission of byproducts. Other auxiliary circuits include a "crowbar" protector for the 40 kW PA. By detecting sharp increases (such as might be caused by arcing) in PA grid current the crowbar acts to short the output of the high voltage rectifier and cause the main power breaker to trip, thus removing power from the rectifier. In the 10 kW unit current sensing relays in the IPA and PA screen and plate circuits actuate associated protective relays if current rises too high or voltage drops too low.





by HELMUT LANGER, Senior Development Engineer, The Machlett Laboratories, Inc.

Introduction

Over the last decade the use of hard tube modulators have found extensive use as a switching element in high power radar equipments. Tubes of the shielded grid triode type are an important contribution toward reliability especially when high power gain and excellent high voltage stability are required. In the following, variants of the ML-6544 tube of shielded grid tube design are discussed with emphasis on high peak cathode current capability, high power gain and high voltage operational capabilities.

High Cathode Current Shielded-Grid Triode Design

The design approach of the Machlett ML-6544 consists of a multiple radial beam structure as is shown in Figure 1, whereby each of the 42 segments represents an electrostatic lens system[1]. The cathode cylinder is grooved and is provided with an electron-emissive coating of Barium-Strontium Oxides. Opposite the band between each cathode groove, a round control grid rod is located and in line with it and beyond each grid wire is a narrow fin like second grid bar which is connected internally to the cathode.

Finally, the outer cylinder makes up the electron collector or anode of the tube.

This electrode arrangement results in high perveance, moderately high Mu and quite low feedback capacitance. Typical power gain of a shielded grid structure, as the ML-6544, is in the order of 100 at a plate efficiency of between 85 to 90%. Whereas the plate to grid current ratio at a plate efficiency of about 90% in conventional triodes is between 3 and 5, this typical current ratio in the ML-6544 comes to about 20. These figures assume conservative pulse cathode current densities of 2 to 3 amperes per square centimeter of emissive cathode area. However, it can be shown that when attempting to operate the electrode system at higher cathode current densities, the ratio between plate current and grid current degrades, beam spreading and an increasing amount of control grid current interception sets in, the device becomes less efficient as power gain rapidly decreases.

Several years ago, a study was conducted with the aim of providing a beaming geometry basically similar to that of the ML-6544, while attempting to achieve operational cathode current densities approaching 10 amps/cm^2 yet maintaining a power gain of about 100. The main objective, of course, being to obtain more power output from a relatively small tube envelope without overloading the

---

[1] H. D. Doolittle, H. Langer—"A One Megawatt Pulse Modulator Tube," *Cathode Press*, Vol. 16, No. 1, 1959.

High Current Switch Tubes of Shielded Grid Design

electron flow controlling element, i.e., the control grid. Furthermore, gains were to be achieved in the form of reduced interelectrode capacitances and tube stay capacitances in its operational environment. From the practical aspects, the interelectrode spacings and configurations had to maintain good high voltage operational stability.

In studying field distribution and electron trajectories in the electron discharge region, it follows that relatively high perveance is required to obtain large cathode currents. In other words, a potential maximum has to be established close to the cathode, which in an electrostatic beaming system is accomplished by a compromise in narrowing the grid cathode spacing and changing geometry of the control grid element and cathode focussing arrangement.

This allows high cathode current densities with moderately high grid drive voltages, however, grid current interception may be high as is shown in Figure 2, curve B.

Electron interception by the control grid is caused by direct electron trajectories from the cathode and by back streaming of electrons in the control grid-shield grid region. Figure 3 shows typical electron flow patterns as are present in the ML-6544 beaming structure and in Figure 2, curve A, the resulting current distribution is shown. If the second grid were to consist of round bars, instead of fin type wires, back streaming would be still larger[2]. Due to the fact that the second, or shield, grid is held at cathode potential while the control grid is driven positive, a more or less pronounced potential minimum exists in this region depending upon grid geometries and interelectrode spacings. This potential minimum could be reduced by increasing the anode voltage, however, this obviously lowers the plate efficiency of the tube and is impractical.

In order to reduce the effect of the shield grid to obtain a potential minimum in the control-shield grid region, a basic change in the electrode configurations is required. It is accomplished by constructing and locating the control grid such that it partly surrounds the shield grid, which in turn now becomes a round bar. A typical, improved, beaming structure and the approximate electron trajectories are illustrated in Figure 4. Cathode current density distribution up to 10 amps/cm^2 is presented in Figure 2, Curve C, which shows that the intercepted grid current at 10 amp/cm^2 equals .5 Amp or a ratio of 20:1 between plate and grid current. An improved electron beaming system as shown in Figure 4 still maintains all the advantages of a shielded grid triode and allows operation at cathode current densities of 5-10 amp/cm^2 with power gains equal to the 6544 at cathode current densities of 2-3 amp/cm^2. Also, the plate current characteristics approach tetrode linearity which becomes important when switch tubes are used to drive microwave tubes requiring little or no change in switch tube output current with varied plate voltage loadings, i.e., mainly crossed field devices.

Tube Characteristics and Tube Application

In Figure 5 and Figure 6, the constant grid drive characteristics of the ML-6544 and the improved high cathode current design (DP-22) are compared. Table I lists general characteristics, typical operation parameters and maximum ratings for pulse modulator service. While the ML-6544 is rather conservatively rated with a maximum cathode current of 75 amperes, which represents a cathode current density of 2.3 amps/cm^2, this is mainly done on account of excess drive power required for higher cathode current densities and a lack of sufficient tube life information at high cathode current densities a few years ago. The ever constant effort of improving tube and cathode processing and recent parallel life tests have shown compatible life expectancies at 5 amp/cm^2 to the 2.0 amp/cm^2 on the

---

[2] J. H. D. Harris et al, Patent 2,932,754 "Electron Tubes," Issued April 12, 1960.

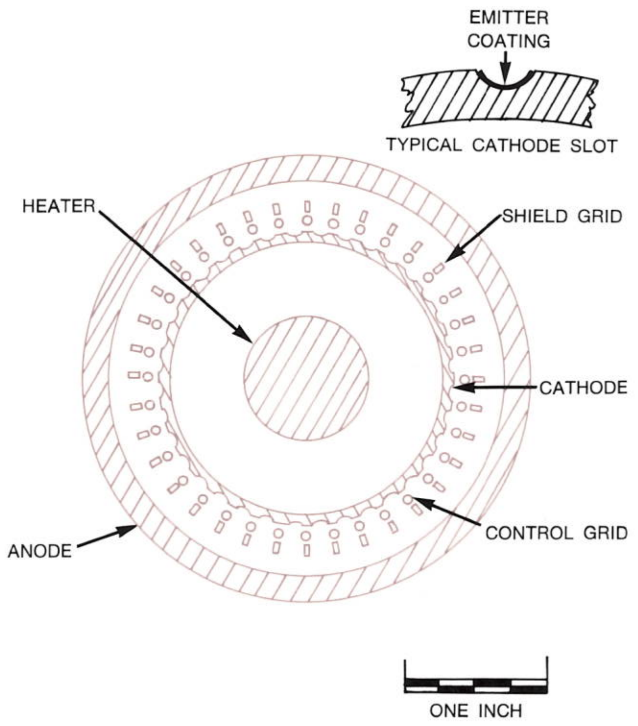


Figure 1—Right Section through Active Electrode Area of ML–6544. Insert shows cathode slot and coated area.

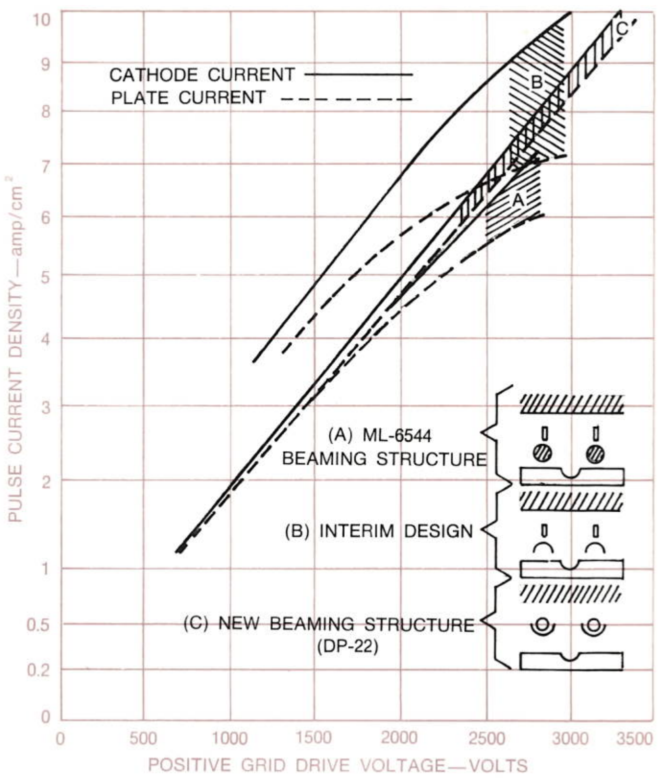


Figure 2—Cathode Current Density Distribution at $E_b = 3.0$ KV.

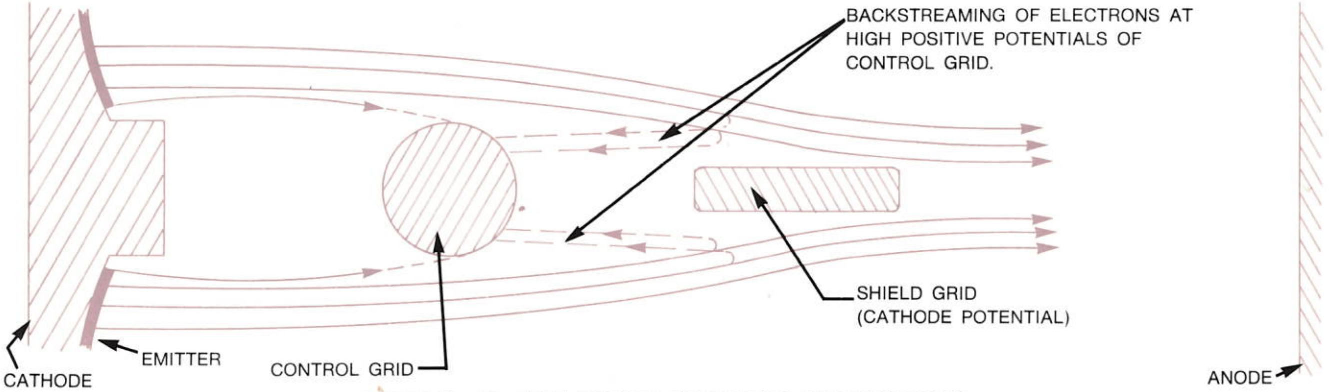


Figure 3—ML–6544 Electron Trajectories (Approximation).

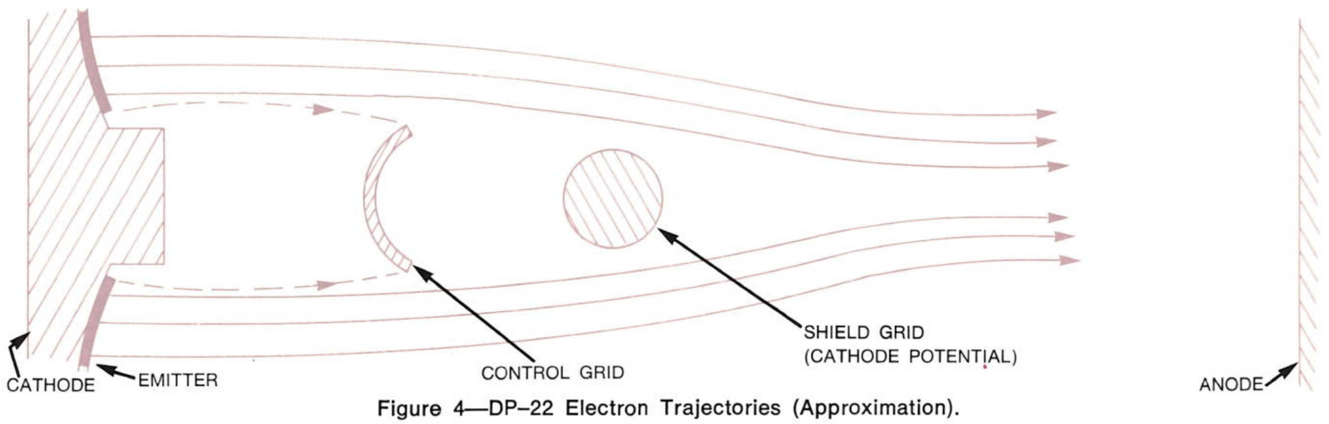


Figure 4—DP–22 Electron Trajectories (Approximation).

TABLE I
ML–6544 ELECTRICAL CHARACTERISTICS

	ML–6544	DP–22	
GENERAL			
Filament Voltage	6.0	6.0	Volts
Filament Current	60	60	Amps.
Amplification Factor	90	150	
Interelectrode Capacitances			
Grid-Plate	4	4	$\mu\mu$F
Grid-Filament	260	250	$\mu\mu$F
Plate-Filament	40	35	$\mu\mu$F
MAXIMUM RATINGS—PULSE MODULATOR OR PULSE AMPLIFIER			
DC Plate Voltage	20	20	KV
Peak Plate Voltage	25	25	KV
Pulse Cathode Current	75	160	Amps.
DC Plate Current	250	250	mA.
Grid Dissipation	75	75	Watts
Plate Dissipation	1000	1000	Watts
Pulse Duration*	6μsec.*	6μsec.*	
Duty Factor*	.03*	.003*	
TYPICAL OPERATION			
DC Plate Voltage	18	18	KV
DC Grid Voltage	–250	–200	Volt
Pulse Grid Voltage	1200	2300	Volts
Pulse Plate Current	65	150	Amps.
Pulse Grid Current	5	7.5	Amps.
Pulse Driving Power	8.7	18.7	Kw.
Pulse Power Output	1.0	2.3	Mw.
Plate Output Voltage	15.5	15.5	KV
Duty Factor*	.003	.0014	
Power Gain $= \frac{\text{Power Output}}{\text{Driving Power}}$	115	123	

*Longer pulse duration or higher duty factors may be realized, depending upon other related tube operation parameters.

6544 a few years ago[3]. Tubes have been operated in-plant at 5 amp/cm^2 for periods in excess of 2000 hrs. operational life with very little decay in pulse cathode emission. Tests are being continued at still higher cathode current densities, with a goal of 10 amp/cm^2 from a 30 cm^2 oxide coated cathode.

As such, it is of interest to tabulate typical application parameters for the DP-22 (improved beaming design) which are based on cathode current densities of $\geqq 5$ amps/cm^2, giving a power output of >2.5 Mw to typical 1 Mw output for the ML-6544 (Table I). If the DP-22 is used for short pulse applications with low duty factors peak cathode currents in excess of 300 amps. should be easily realized without getting into excessive grid drive power requirements. The strapped input resonance frequency of this

[3] C. V. Weden—"Design and Applications of Tubes for Hard Tube Modulator," *Cathode Press*, Vol. 18, No. 1, 1961.

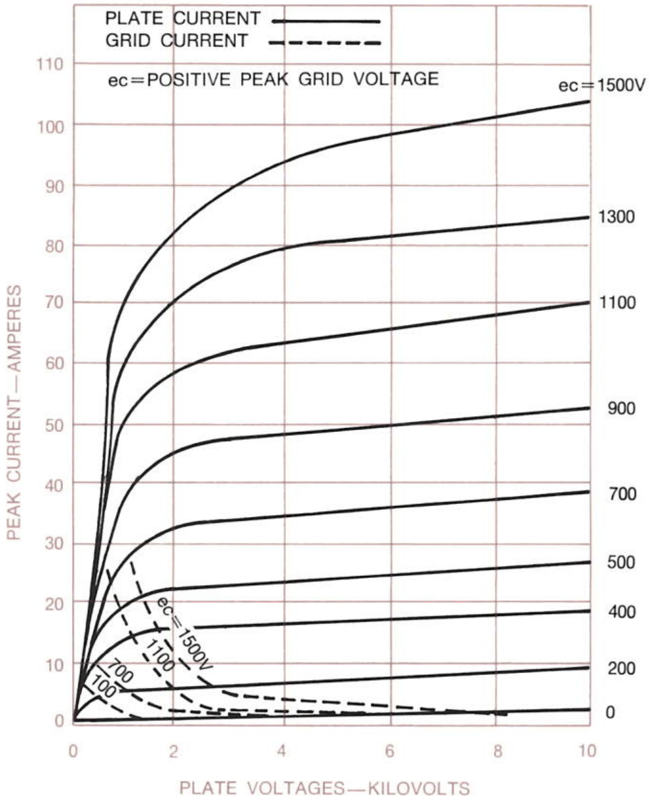
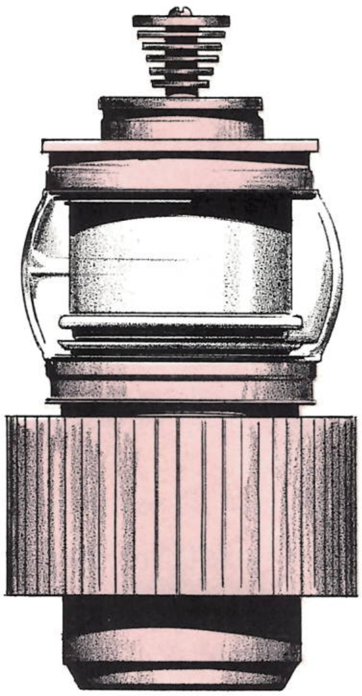


Figure 5—ML–6544 Constant Grid-Voltage Characteristics Ef = 6.0 Volts.



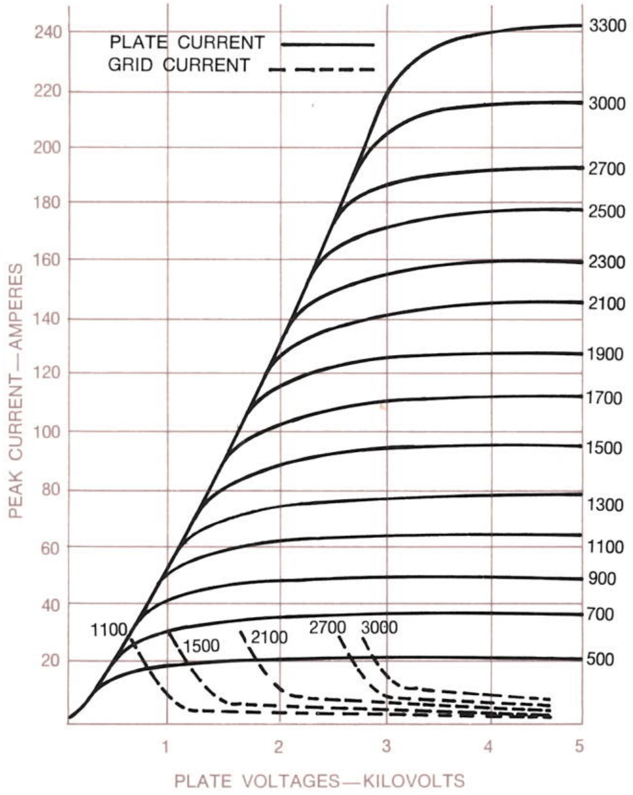


Figure 6—DP–22 Constant Grid-Voltage Characteristics Ef = 6.0 Volts.

tube is about 65Mc, however it could be increased several fold by modification of the ML-6544 support structure.

The improved beaming geometry as discussed lends itself also to other ML-6544 extension type tubes with higher voltage hold off capabilities, typical of which are the ML-7003-35KV; ML-7002/7715-60KV; and the ML-7845 which is rated for 75KV.

Conclusions

A high cathode current type shielded grid triode version of the basic Machlett ML-6544 tube type has been discussed, which is capable of operation at high cathode current densities with power gains of about 100.

In a subsequent article, ML-6544 tube operational capabilities in respect to pulse length duty factor and peak cathode currents under different loadings will be discussed, with emphasis on typical applications and operational life data.

Acknowledgments

This study was conducted under the guidance of Dr. H. D. Doolittle, Manager of Technology, The Machlett Laboratories, Inc. Acknowledgment is also given to Johannes Mueller, who contributed greatly in the design and evaluation of the many electrode geometries which were studied.

by A. R. BERNARDI, Senior Applications Engineer
The Machlett Laboratories, Inc.

Introduction

Your Machlett tube represents a major investment for both of us. You expect a reasonable service life of trouble free operation and we are anxious that the care and meticulous workmanship expended in its construction is justified by its field performance. Since we both, then, have the same objective, we are asking that you, the customer, observe a few simple rules to ensure the success of our joint venture.

The Life You Save May Be Your Own (Tube)

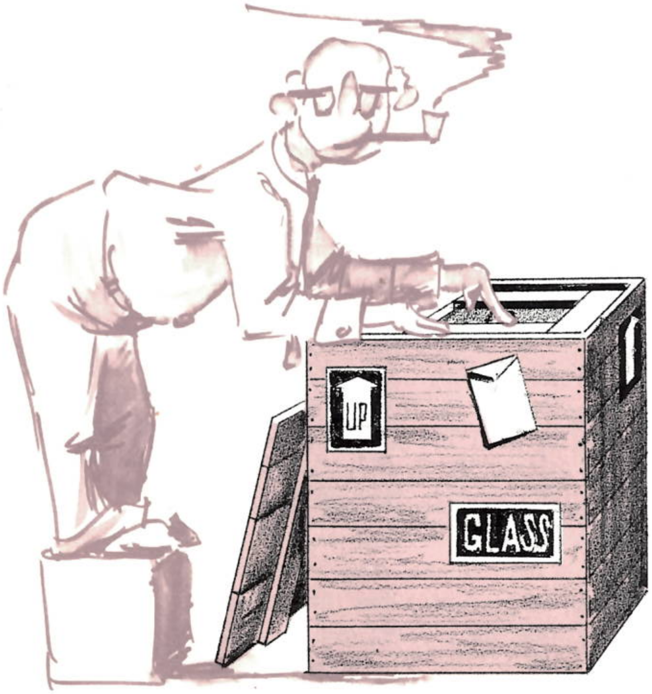
Initial Inspection

If a tube is safely installed in its socket it has probably weathered the most severe attempts against its life. It has not only made the journey, double packed, from Machlett to you, but has made the final trip, exposed to the elements, into the tube socket. Unfortunately this trip is sometimes not completed. Broken filaments have been found to be the greatest cause of "infant mortality" on record. This in spite of the extreme care used in packing and many "dry runs" of the container with built in accelerometers. While a large power tube may appear massive and rugged, in reality the grid and cathode structures are often composed of fine and brittle wires. Excessive shock or vibration may easily lead to irreparable damage.

Upon the receipt of a tube in its crate or packing case, examine the container for evidence of rough handling. If such evidence exists make a note to that effect on the carriers' receipt form before you sign it.

AS SOON AS POSSIBLE or not more than 10 days after receipt, the tube should be removed from its container and examined. Always handle the tube by its anode jacket to avoid straining the glass or ceramic to metal seals. If necessary use the control grid or screen grid flange. The tube should never be handled by its filament terminals. Visually inspect the tube for glass and ceramic cracks or other signs of unusual shock. An ohmmeter check between all elements should be made to detect shorted elements. The cold filament resistance should be measured with a suitable bridge, accurate in the milliohm range, and compared with readings taken on previous tubes. At the sign of any damage or broken filaments a "joint inspection report" should be filed with the carrier for possible transit damage claim. While the above inspection will detect obvious damage, the best test is to install the tube in the operating equipment where latent damage may be discovered. This practice will avoid putting a questionable tube into storage for later use.

In each container along with the tube you will find a POWER TUBE SERVICE REPORT. Take the time to read and understand the instructions printed on the reverse side, (see page 27). Immediately enter the tube type, serial number and date received on the form. Before stocking or trans-shipment enter a note on the margin that the tube was inspected and the cold filament resistance reading. This single piece of paper is very often the only written communication between you, the final user, and the Company. When finally completed, fill it out clearly so that we here at the factory can determine how it was used and why it is being returned. At the top of the form there is a sentence which reads "It is urged that it also be submitted for all tubes retired from service because of its statistical value to the user, the dealer, and to our company". Please take this statement seriously. It may be bothersome to fill out and mail a report on a tube that has gone 5 to 10 thousand hours but this information is vital to us as a quality control measure. In addition, you will be doing yourself a favor; there are always a few cases of tube failures which are "cliffhangers". You may not, for instance, remember having done anything wrong and we cannot justify a premature failure based on tube tests prior to shipment. A record of a good life history of tubes of the same type in your equipment would aid us greatly in deciding "unusual" cases.



Example

The ML-7560 is used as a modulator in a high power radar system. The tube is operated at 50 kv with pulse currents of 250 A. We have been fortunate in obtaining life figures, on this tube, in this application which revealed that the average life of 102 tubes operating for a total of 1,316,127 hours was 12,903 hours. With information of this kind, any significant shift of the life distribution curve, in this particular equipment, would trigger an immediate investigation.

When it is necessary to return a tube to the factory either directly or through a distributor always use the original packing and shipping container and insure for full value. In this way you will be protected against transit damage on the return trip. If the original container is not available, we will be glad to supply one for the return shipment.

Storage and Rotation

Most users of large power tubes have too much at stake to lead a "hand to mouth" existence. "Off the Air" broadcast stations or "down time" industrial equipments do not produce revenue. Therefore, it is usual to have at least one spare for each tube type and perhaps many for a multitube installation.

It is recommended that power tubes be stored upright, anode down, in their original shipping containers. The location should be dry and reasonably free of extreme temperature changes.

Those tubes being placed in storage upon rotation should be thoroughly cleaned. Bulbs of glass tubes should be wiped with a clean cloth moistened with alcohol. Ceramic envelopes can be cleaned with ordinary household cleanser to remove arc marks or accumulated dust and grime. The fins of air cooled tubes should be wire brushed

INITIAL INSPECTION

All tubes upon receipt should be given a thorough check for irregularities, and should be tested under normal operating conditions. This will assure that tubes damaged in transportation are not carried in stock.

TRANSIT DAMAGE

Upon receipt of any shipment and before signing the express receipt, containers should be carefully checked for visible signs of damage. These must be noted on the express receipt BEFORE signing.

ANY IRREGULARITY found during the initial inspection and test is an indication of mishandling during transportation. The Carrier must be notified at once and the item held for inspection by the Carrier's representative. It is important that the item and container be kept exactly as received until inspection has been made. After this Joint Inspection has been made, the item and a copy of the inspection report should be returned as indicated below, so that claim for damage may be filed.

PERIODIC TEST OF STOCKED TUBES

If spare tubes are held in stock for long periods, they should be tested approximately once every three months in the type of equipment in which they are to be used and under normal operating conditions.

PERMISSION FOR DISMANTLING

In returning a vacuum tube for warranty consideration, the owner gives permission to The Machlett Laboratories, Inc. to open the tube and dissect the elements where such procedure is considered necessary for a complete examination.

RETURN PROCEDURE

If it becomes necessary to return a vacuum tube to The Machlett Laboratories, Inc., the information requested on the opposite side of this sheet should be given and this report returned along with the tube to

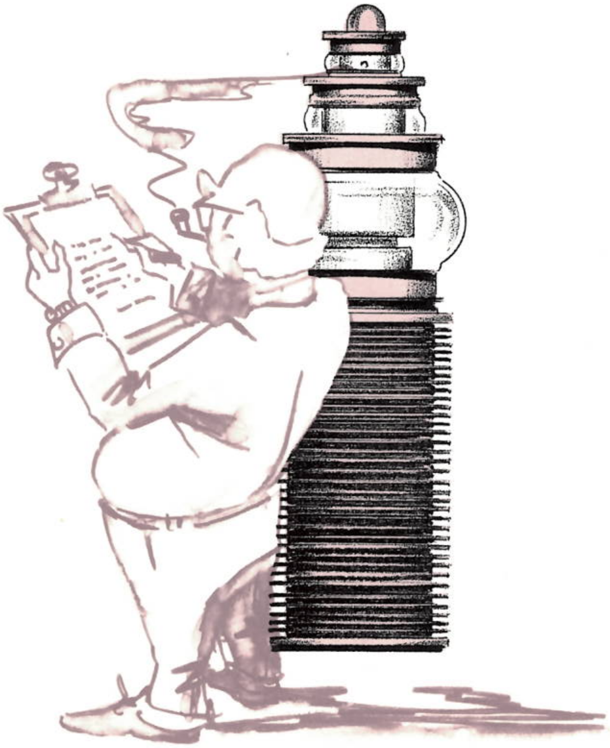
The Machlett Laboratories, Inc.
Attn. Service and Adjustment Dept.
1063 Hope Street
Stamford, Conn. 06907

It is important that tubes be carefully packed in original carton, so that there will be no further damage to the tube during return shipment. If the original carton is not available or is too badly damaged to be reused, a new carton of the proper size will be supplied upon request at no charge. DO NOT SHIP TUBES BY PARCEL POST.

to remove trapped dirt and insects. Water cooled tubes will invariably have a layer of black scale on the outer anode surface. The cleaning procedure we recommend is:

a. Prepare a cleaning solution of hot tap water (70°C) and 20% OAKITE-31. Extreme care should be taken to protect exposed parts of the body and clothing when handling OAKITE-31.
b. Soak anode of tube in OAKITE solution until all deposits are removed.
c. Thoroughly rinse anode in clean hot tap water for at least 5 minutes.

On the back of the Machlett POWER TUBE SERVICE REPORT you will find a recommendation to test tubes approximately once every three months in the type of equipment in which they are to be used. The three-month figure is a general one which applies to the average installation. Some users, mindful of the accidental damage to filaments which often occurs due to handling, prolong this period. Whether or not a particular tube type, in a particular application need be rotated every three months is a function of the operating parameters. It would be imprudent to extend this period for tubes being used near their maximum ratings. In installations where minimizing tube handling is absolutely essential, a complete record should be kept as the shelf period is extended, say, a month at a time. As data accumulates indicating that the tubes can tolerate the increased shelf life in the application, the period may then be increased accordingly. Decisions of this kind should not be based on the performance of a single tube. A minimum of three tubes should be sampled to test the feasibility of extending the period of rotation. Extensions beyond 6 months should be approached with extreme caution.



Installations considering, or already exercising, programs of this type are urged to report their results to The Machlett Laboratories since statistical information of this type, involving thousands of hours of use, is extremely valuable.

Break-in Procedure

Prior to operation upon initial receipt or upon rotation the filaments should be run for 1/2 hour at rated Filament Voltage. If convenient, operation at +5% or +10% Ef is preferable during this period.

Following this initial filament run operate the equipment at reduced plate voltages, as suggested below, in order to achieve some degree of conditioning. Restore filament voltage to rated value if initially elevated.

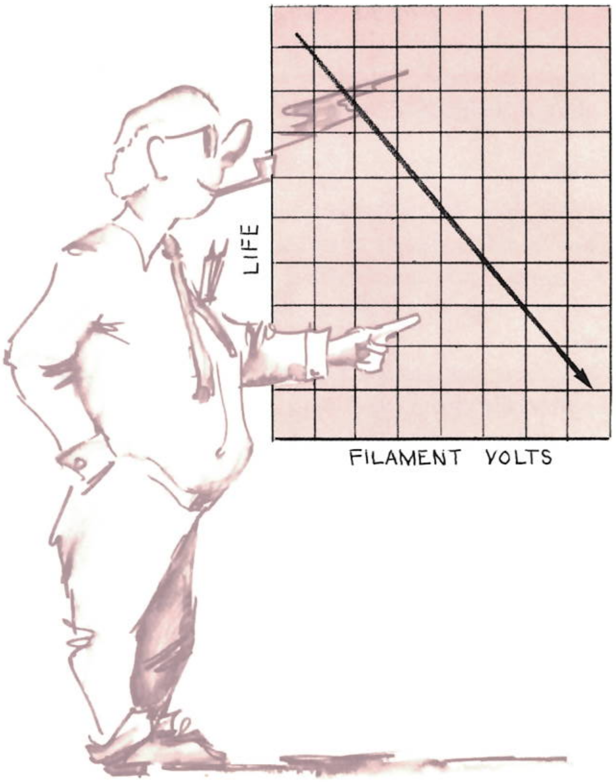
Amplifiers—plate voltage reductions are limited by the △-Y switch which reduce the plate voltage to approximately 57% of full voltage. Operate the amplifier (transmitter) for 1/2 hour at reduced plate voltage under rf conditions. At the end of this period restore operation to full plate voltage. In the event of a tube arc repeat the reduced plate voltage period.

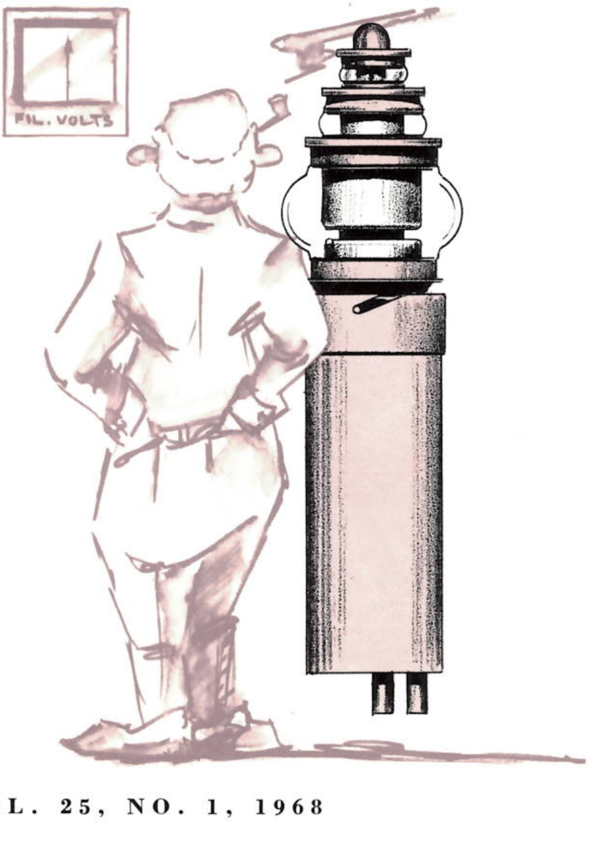
Oscillators—condition tube under normal oscillator conditions for 15 minute periods at 50%, 75%, 100% and 110% of normal maximum operating plate voltage. If a tube arc should occur during any one of these periods, return to the previous level for an additional 15 minute period before proceeding.

Conditioning tubes which have become gassy due to exceedingly long shelf life or overloading may present a special problem. A tube in this condition is apt to arc at relatively low plate voltages. During each arc, unless the tube is protected by a crow-bar circuit, the filter capacitor energy is "dumped" into the tube resulting in the liberation of additional gas. In this situation it is wise to install a 20–30 ohm resistor in the dc plate lead where the only capacity between it and the tube is the rf bypass capacitor. This resistor will limit the energy "dumped" into the tube to allow conditioning to proceed at a reasonable pace. The 20—30 ohm figure is given for normal oscillator/amplifier plate voltages of up to 15 kV. In pulse equipment where the plate voltage ranges to 50 kV an 80—100 ohm resistor should be employed.

Filament Care

The subject of filament care has received considerable attention[1, 2] in the literature; it will be sufficient here to repeat that pure tungsten tubes will tolerate considerable latitude in filament voltage providing the filament is operated at a temperature high enough to provide the required emission. Thoriated tungsten tubes are not as tolerant and should be operated, in most cases, within ±5% of ratings. Keep in mind that while 5% may sound like a small percentage, operating either type at +5% will reduce filament life by approximately 50% while operating at –5% will increase filament life by approximately 100%. Whether or not a particular equipment will tolerate operation at –5% (don't forget line voltage changes) depends on the equipment design. If the tube is being used at an adequate margin below its peak emission capability operation at –5% can be tolerated. This can be established by operating an amplifier or oscillator under its heaviest load at rated Ef. If the filament voltage can be dropped by 10% without any significant change in grid or plate current then operation at –5% is permissible. In applications where emission demands are such that a 10% drop produces a significant change in parameters, gradually lower the filament voltage until a change is detected, then advance the voltage 5% above this point. During this procedure make sure that the line voltage is not abnormally high or low which subsequently may change to affect the operation. After a period of operation, should the emission start to fall as the tube ages, the voltage should be advanced accordingly to restore the emission capacity.





---

[1] Industrial Users of Electron Tubes—Longer Tube Life Thru Proper Care and Operation by D. S. Frankel, *Cathode Press.*

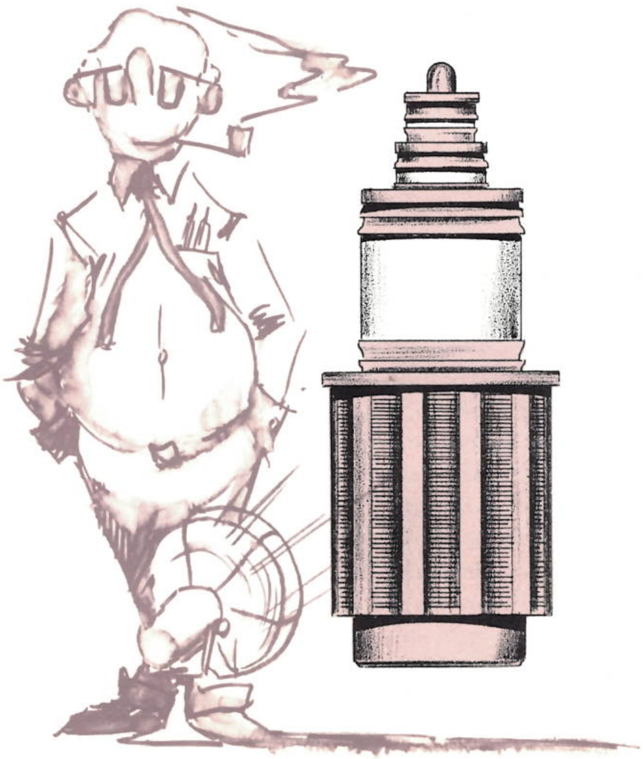
[2] Electron Tube Users can Increase Tube Life by Charles Singer, *Cathode Press,* Fall 1950.

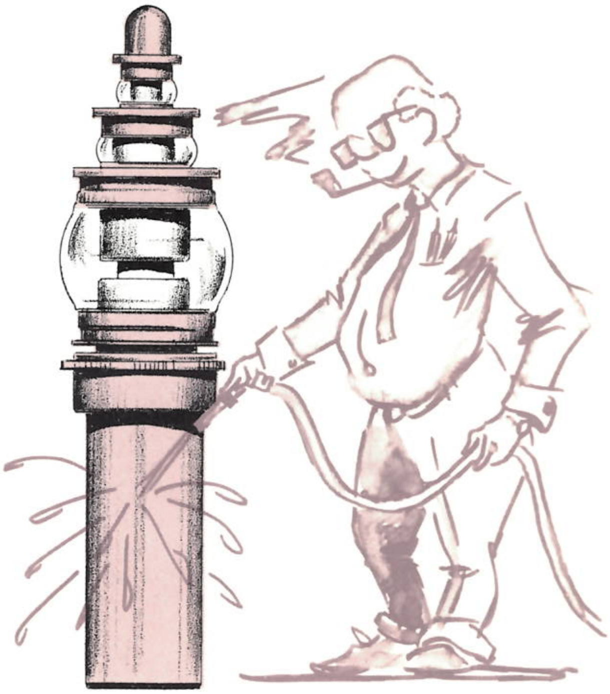
New tubes, on initial installation, should be run at rated Ef for approximately 100 hours before attempts are made to run at reduced filament voltage. During this period the tube will "harden" and make it less susceptible to filament poisoning which is an attendant danger when operating at reduced filament voltage.

Cooling

Once a tube has withstood transportation and installation and is safely nested in its socket, its next most serious threat comes from temperature. In one way or another, this factor takes the highest toll of premature operating failures.

While most equipments have adequate safety interlocks to monitor air flow, water flow, water pressure, etc., invariably some combination of factors occur to defeat their purpose. A regular maintenance program to check these devices should be instituted to ensure that the grid and plate current relays are properly set and operating and that the air flow and water flow protection devices really open the plate circuit when the coolant drops to an unsafe level. The cooling of the filament, grid and plate terminals is no less important in maintaining the vacuum seal integrity and to prevent internal, unequal, expansions which may result in structure shifts and shorting of tube elements.





While the application of temperature sensitive paints[3] or similar devices to the seals is to be recommended, this technique is probably most helpful during de-bugging or initial equipment installation. During normal operation where not only is the tube not in view but often running unattended this technique, while providing information after the fact is not very helpful in alerting operators that a problem has arisen before fatal tube damage occurs.

A simple, yet effective, method of dealing with this problem has been observed[4]. A strip of fuse material is attached to a suitable spot on the anode. The free end of the strip is fastened to a nylon string which in turn is led to a spring loaded interlock. When the anode temperature exceeds the melting point of the fuse, the material parts actuating the interlock thus removing plate voltage and actuating a visible or audible alarm.

Troubles

At some point during the operation of any equipment, whether oscillator, amplifier or modulator unsatisfactory operation leads one to question either the tube or the equipment. Since "tube checkers" for large power tubes are economically impractical most users resort to tube substitution methods to separate the problem area. When this approach is undesirable there are a few simple tests which can be accomplished in the operational equipment to isolate tube problems.

---

[3] Similar to that manufactured by Tempil Corporation, 132 W. 22nd Street, New York, New York 10011.

[4] For specific recommendation, inform The Machlett Laboratories, Inc. of tube type and normal operating parameters.

A. Blue Glow

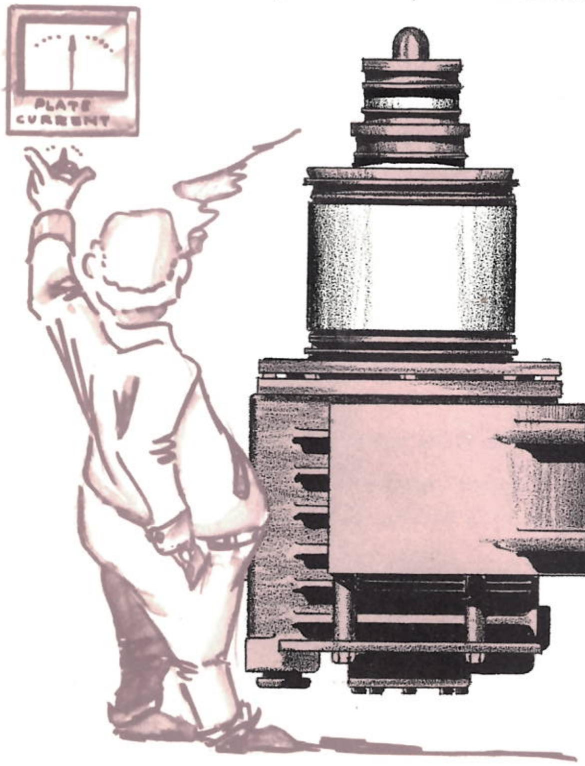
Users sometimes become alarmed when a new tube is installed and a "blue glow" is observed. The alarm may or may not be justified depending on whether the glow is the result of fluorescence or gas.

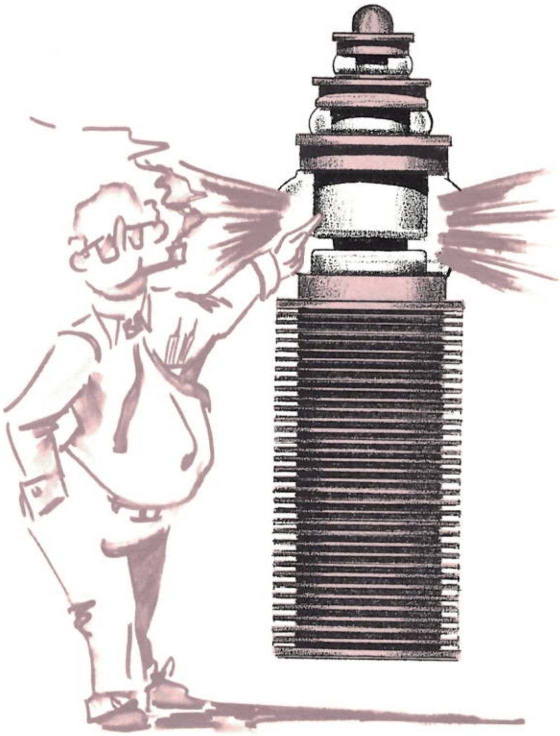
Fluorescence is usually violet in color and appears to be originating at the inside surface of the glass in a well defined ring. It is most pronounced while operating a tube at voltages near maximum ratings under conditions of light loading. This type of glow often disappears as the amplifier or oscillator is loaded heavier. Fluorescence is generally attributable to stray electron bombardment of the glass within the tube and is not detrimental.

"Blue Glow" as a result of gas usually takes the form of a blue haze which appears to fill the entire internal volume being most pronounced near the internal structure. This type of glow, resulting from gas, is undesirable and will shortly lead to filament poisoning and tube arc-overs at relatively low voltages. It is doubtful that a tube this far gone can be saved, although an attempt should be made by running the filaments at +10% Ef for a 24 hour period and then following the previously described "Break-in Procedure."

B. Emission

Emission problems usually first manifest themselves in amplifiers by a loss of power output along with dropping plate current. In oscillators, the signs are falling grid current and increasing plate current. Static dc measurements of peak emission are impossible due to plate dissipation limits. Emission problems can be ascertained by operating the amplifier or oscillator near maximum power output conditions and noting the grid and/or plate current. There should be no significant change in these parameters as the filament voltage is dropped by 5%. Conversely, if a tube operating at nominal filament voltage is suspect of falling emission, filament operation at +5% of nominal will usually restore normal conditions signifying a falling emission condition.

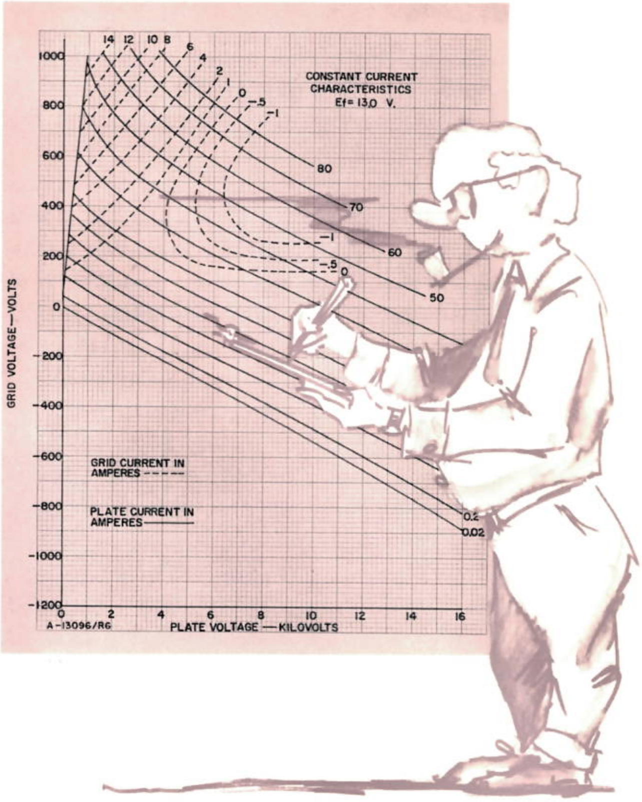


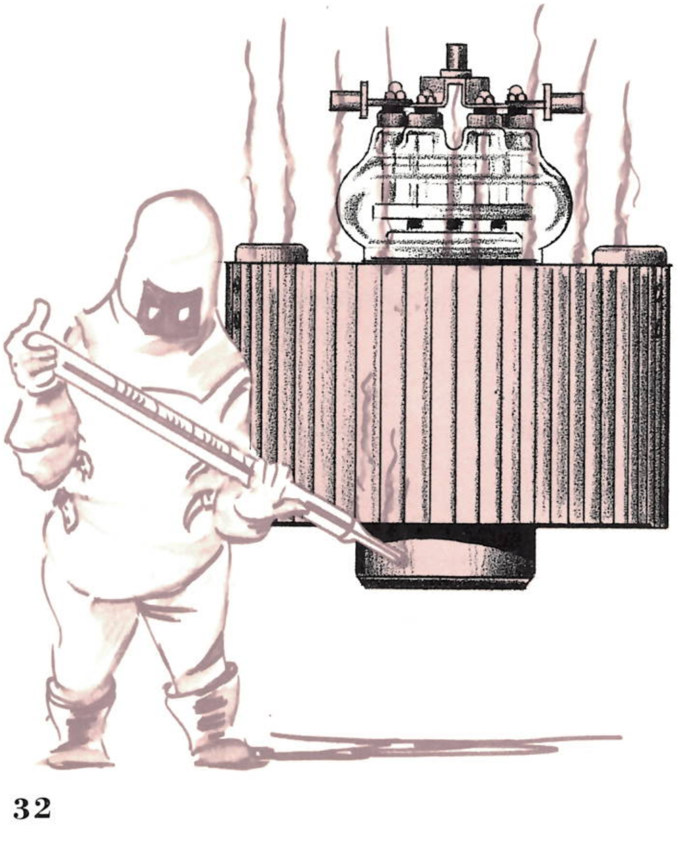


The question is often raised as to whether filaments may be operated at lower than nominal voltages to increase life. A general answer is yes but is contingent on the design of the equipment. Transmitting tubes are provided with an emission capability to accommodate operation at –5% Ef. The equipment manufacturer often designs to utilize but one-half the rated emission capability, thus there usually is a double safety margin in actual operation. In practice, operation at lowered filament voltage can be determined by operating the amplifier or oscillator at its maximum power output and then noting where the power output or grid and/or plate current changes occur as the filament voltage is decreased. Allow a 5 minute interval at each increment drop to permit the filament temperature to stabilize. Operation at voltages below –5% Ef is not recommended unless closely regulated since the tube will still have to accommodate normal line voltage fluctuations. During operation, as the tube ages, and the emission drops the filament voltage may be raised accordingly. Always operate the filaments 5% above the voltage where changes are noted in the operating parameters since one would want to make this adjustment only at significant intervals.

Thoriated tungsten filaments lose emission for one of two reasons. De-carburization or poisoning. De-carburization is a normal aging process which reduces the tungsten carbide shell around the filament wire and is manifested by an increasing filament current at rated filament voltage. Early tube emission failures of this type is usually the result of operating the filaments at voltages in excess of nominal voltage and in some cases by the additional heating produced by large rf currents. Such degradation is a normal end of life phenomena. Poisoning is the result of ion bombardment of ionized gas liberated by excess grid or anode temperatures or overloads. The filaments may often be restored by flashing at +40% Ef for a few minutes. If this voltage is not available operate at +10% Ef for 1—2 hours or +5% for 12—24 hours.

Air cooled tubes "react" more quickly to falling emission. During this time the plate current is no longer space charge limited but is temperature limited leading to larger plate drops, hence increased plate dissipation. Since the radiators of many tube types are soldered to the anode, the anode temperature may exceed the melting point of the solder. Voids are created which lead to even higher temperature, more liberated gas, etc., until more of the solder melts and the anode is punctured by the failure of the anode copper wall.





C. Oscillator Zero Bias Test

Occasionally a situation arises where for an unknown reason the unit does not perform properly and a spare tube is not at hand for substitution. The question arises is it the tube or equipment? A simple test, easy to perform, which, while not absolute, will give some indication of tube malfunction, is the zero grid bias test.

Strap the oscillator grid to ground or the filament C.T. As the plate voltage is brought up from some low value, the circuit will not oscillate but will draw a plate current which varies with plate voltage. The relationship ib vs Eb should agree closely with the values taken along the horizontal 0 grid voltage line on the published constant current characteristics. The test can be carried up to the rated plate dissipation, provided sufficient cooling is provided by equipment design.

Example: ML-6696, rated plate dissipation 60 kW.

On the constant current characteristics along the 0 grid voltage horizontal line we find

Eb (kV)	ib (A)	
2	2	
3.2	5	
4.7	10	(plate dissipation 47 kW)

If the observed values are within 10% of the published curves, the tube can be assumed to be acting normally.

Biographies

MELVIN D. CLARK

Melvin D. Clark received his BSEE degree from the University of Missouri in 1959 and his MSEE degree from the University of New Mexico in 1962. He is president of Terra Corporation, a company which he helped found in 1965 to design and manufacture microwave oscillators. Prior to the establishment of Terra Corporation, Mr. Clark was a Staff Member of the Sandia Corporation where he did the initial development work on distributed feedback strip transmission line oscillators.

HELMUT LANGER

Helmut Langer, who received his EE degree from the Ingeneurschule Barth, Berlin, in 1949 and who attended the Technical University there, worked as an engineer for the Telefunken Company prior to coming to Machlett in 1954. Now a Senior Development Engineer, Mr. Langer has developed high voltage, high power radar and transmitting tubes, both oxide cathode and thoriated-tungsten cathode types. Other important work includes: vapor cooling systems, magnetic beam tubes, and tubes for severe mechanical environments. He holds electron tube patents both here and in Germany.

ANTHONY R. BERNARDI

Anthony Bernardi received his B.S. in Electrical Engineering from the Cooper Union. Before joining Machlett in 1965, as Senior Applications Engineer, he had been associated with the communications industry for 16 years. His experience includes the development of high powered SSB transmitters.

The ML-EE64Y is the smallest 10 kv (peak) switch tube—and the smallest 10 kv (peak) regulator tube you can buy. ML-EE64Y gives you up to 36 free cubic inches per tube, and doesn't require a socket. It offers you a 12 amp peak current, high signal sensitivity, and a simple BeO heat sink with no other cooling required. The ML-EE64Y provides tabs for simple, low-cost connection.

For complete data, write to Machlett—the tube specialist most responsive to customer needs—today. The Machlett Laboratories, Inc., 1063 Hope Street, Stamford, Connecticut 06907.

Why use this tube...for high voltage switching or voltage regulation...when this one is better?

ML-EE64Y
Actual size.

THE MACHLETT LABORATORIES, INC.

A SUBSIDIARY OF RAYTHEON COMPANY