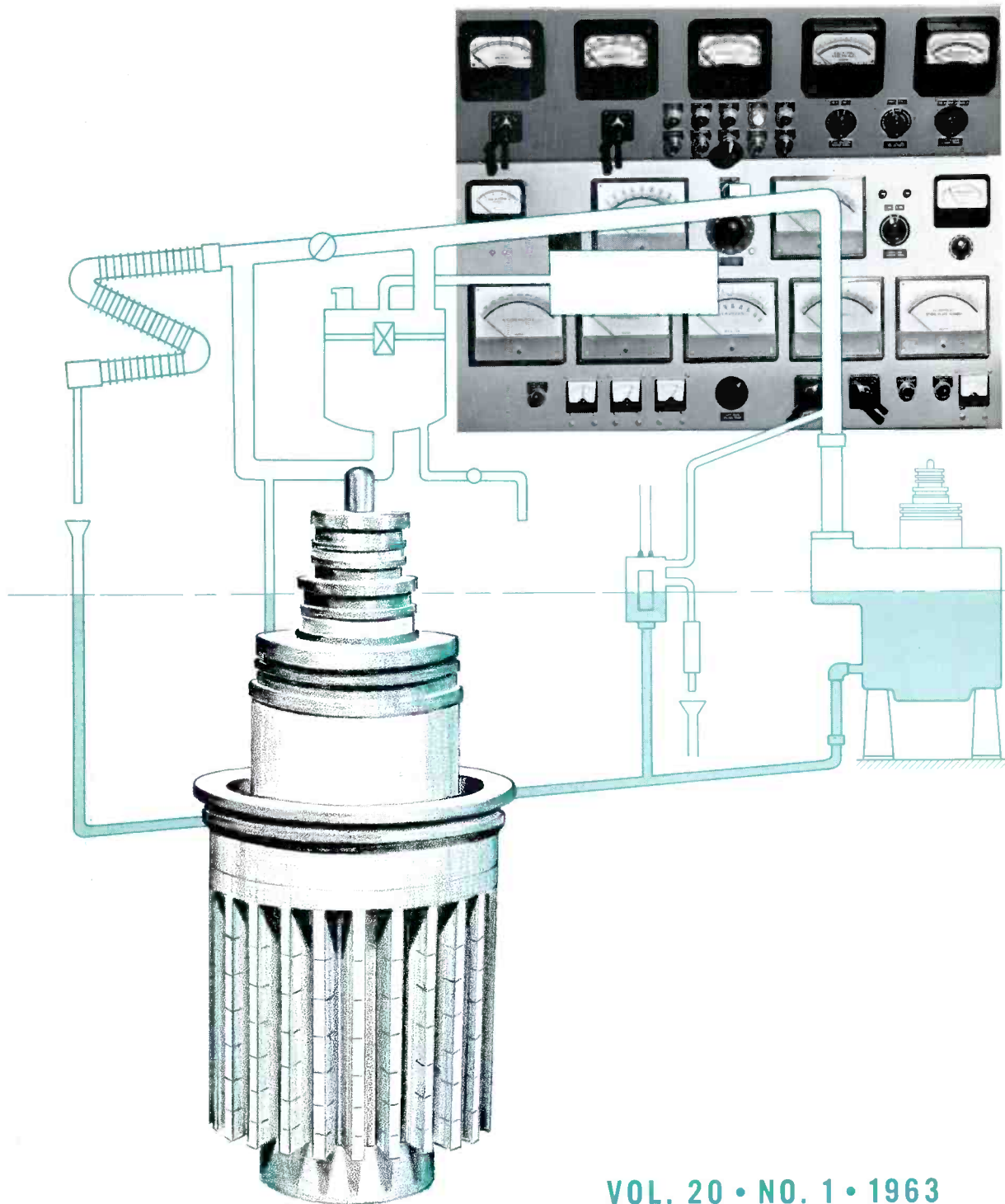


MACHLETT

CATHODE PRESS



VOL. 20 • NO. 1 • 1963



ML-7351A

High Sensitivity Tipless Vidicon

Highest sensitivity—less than 0.05 Ft. C. faceplate illumination required.

The Machlett ML-7351A tipless vidicon offers the highest sensitivity of any commercially available vidicon. High sensitivity permits use of tube with less than 0.05 foot candles illumination incident on faceplate. This corresponds to an average scene illumination of less than 2.5 foot candles when using an f/2.0 lens.

Lower dark current—for slow scan television

Operating at sensitivity equivalent to that of other high sensitivity vidicons, the ML-7351A requires a lower dark current. In slow scan systems, therefore, the lower dark current pedestal permits greater signal current accommodation by the amplifier. For example, at ASA 1200, the ML-7351A requires a dark current of only 0.05 ua, approximately $\frac{1}{4}$ that of comparable tubes.

High radiant sensitivity in the red region

High sensitivity in the extreme red region permits advantageous use of the ML-7351A in viewing incandescent materials, jet exhausts and other extreme temperature phenomena.

Resolution...

500 lines to 800 lines depending on focus electrode potential.

Signal decay rate...

About half that of standard light sensitive vidicons.

Write today for the complete data on the ML-7351A tipless vidicon.

THE MACHLETT LABORATORIES, INC.

SPRINGDALE, CONNECTICUT



An Affiliate of Raytheon Company

CATHODE PRESS

Vol. 20, No. 1, 1963

Editor, *Richard N. Rose*

Art Director, *Edward J. Bulger*

IN THIS ISSUE

- Design, Engineering and Construction of the
"Thermex" High Frequency Tube Tester 2
- Supplementary Advantages of Vapor Cooling:
Space Heating and Distilled Water
Production 12
- Radar Beacon . . . The First C-Band Pulsed
1 kW Oscillator 16
- Nimbus Weather Satellite 20
- Atlantic Pipeline Company:
Microwave User Since 1949 24
- SPANDAR: NASA's Long Range Tracking
Radar Transmitter — Its Design and
Performance 30

ANNOUNCING A NEW SECTION IN CATHODE PRESS

- New Developments 40

Product Lines represented in this issue:

- Large Power Tubes
- Small Power Tubes
- Photosensitive, Storage & Display Tubes

COVER . . . is a representation of the subject of the initial article in this issue: the 1.2 MW Test Unit, emphasizing one of its test capabilities — vapor cooling.

Published by:
The Machlett Laboratories, Inc.
An Affiliate of Raytheon Co.
Springdale, Connecticut

Editor's Note:

With the acquisition of its new 1.2MW power tube test unit, The Machlett Laboratories has consolidated the testing of its largest power triodes (forced-air-cooled, water-cooled, and vapor-cooled) in a single, highly efficient device. In addition Machlett has established the means for future development into even higher power tubes than are now offered (600kW input) and can take new developmental steps with the full assurance that these tubes-to-be will be qualified for performance at their highest ratings. Other large test sets now in operation include a 100kV-100mA pulse tube test set and a 200kV-200mA unit (Cathode Press Vol. 19, No. 1, 1962, "Hard Pulse Modulator Test Facility: 200kV-200mA Capability") in addition to its already extensive power tube test equipment, place Machlett in a uniquely strong position to evaluate and rate its tubes.

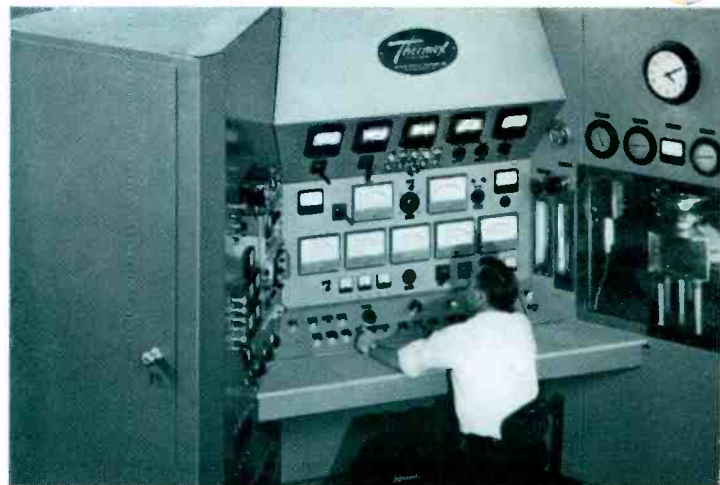
• • •

Design, Engineering and Construction of the

In the following article, Mr. T. L. Wilson, Chief Engineer, Electronics, Votator Division, Chemetron Corporation, describes the Machlett 1.2 MW test set as seen from the point of view of the designer translating the customer's instructions into fact. Mr. Wilson discusses the need for one man operation, the consequent simplification of controls and the considerable attention given to proper layout and instrumentation of the control panel. The electronic/electrical fundamentals of the unit, as outlined, reflect the need for easily controlled, continuously variable drive and the use of an infinitely variable load impedance system. Physical provisions for tube installation and test, with resulting considerations given for maintenance of proper electrical conditions (terminal connections, provision for maximum decoupling between driver and neutralizing circuit among others) are developed in addition to matters relating to tube water load, tube cooling, power supply requirements and fault protection.

The basic statistics of the 1.2MW unit reflect its considerable magnitude.

• Plate Supply Volts	0-30 kVdc	Amps 0 —40a
• RF Bias Supply Volts	0-4 kVdc	Amps 10a
• Bias Supply (peak emission & static test) Volts	0.5 kVdc	Amps 20 ma
• Frequency	13.56 Mc	



Mr. T. L. WILSON

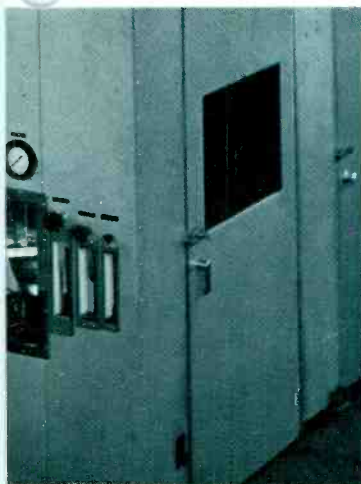
Mr. T. L. Wilson is a native of Salt Lake City and an electrical engineering graduate of the University of Utah. He was with RCA in Camden, N. J. and Federal Telephone and Radio Company, Newark, N. J. before joining Thermex, now a Department of the Votator Division.

Votator, a division and major affiliate of the Chemetron Corporation is basically a manufacturer of process equipment. Through its pioneering line of "Thermex" dielectric heating equipment, Thermex and Machlett have been jointly associated for many years.*

*Registered Trademark of Chemetron Corporation

'Thermex' High Frequency Tube Tester

*By T. L. WILSON, Chief Engineer, Electronics,
Votator Division, Chemetron Corporation*



I ntroduction

"We need a high-frequency test set sufficiently stable to handle a wide variety of tubes under various load conditions, to make all the necessary production tests plus special engineering tests for the 'odd-ball' job, to handle powers from 50 kilowatts to 1.2 megawatts, to use ordinary city water directly in the cooling system, to put no unusual burdens of short circuits on the power lines, although it is expected to operate a crowbar as much as 2,000 times per week, and to do all this without any danger of radio interference or X-radiation."

This in essence was the assignment given to the Votator Division of Chemetron Corporation by The Machlett Laboratories, an affiliate of the Raytheon Company. After many months of detailed planning, building and testing in Louisville, Ky., plus installation and more testing at Springdale, Conn., a test set that meets these exacting requirements and more is a reality and is in daily use to ensure the production of increasingly reliable tubes for a large variety of uses.

The compact new unit, which covers a floor area of 255 square feet, is designated a Thermex High Frequency Tube Tester. "Thermex" is Chemetron's trade-mark for the Votator Division's line of high-frequency dielectric heating equipment and related

electronic products. It is an amplifier type unit that can test the most powerful modern tubes in a circuit very similar to that in which they will actually be used; it also provides absolute stability of frequency for greater control of test conditions than more common oscillator-type test systems.

At 1.2 megawatts input, the new unit is believed to be

the most powerful high-frequency tube test set in operation at this time. A companion article in a subsequent issue of the CATHODE PRESS by Machlett's Mr. Raymond C. Black describes the uses of the equipment and reasons for the exacting specifications. This article deals with the design, engineering, and construction of the test set.

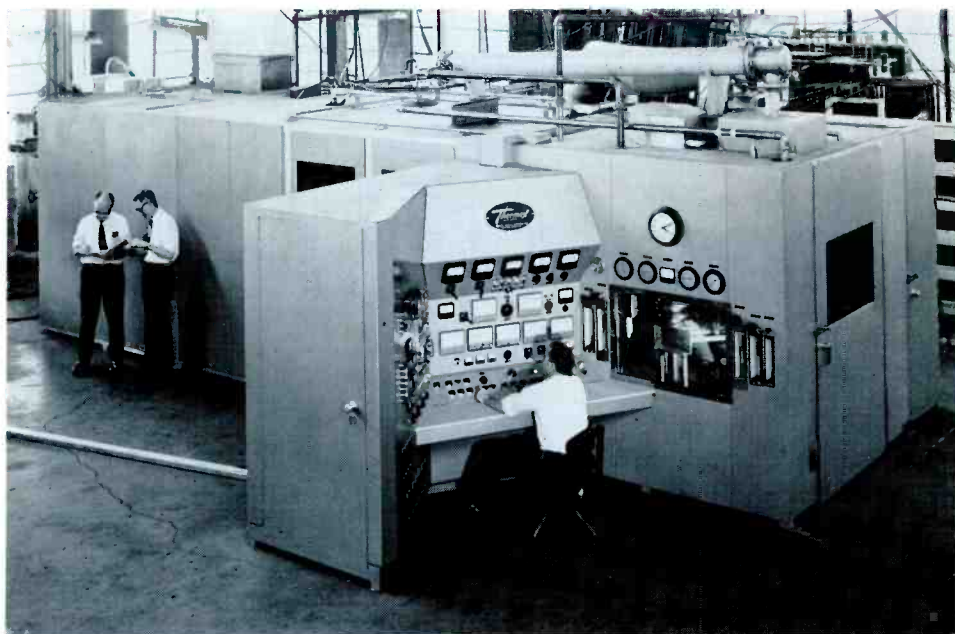


Figure 1 — Overall view of the 1.2 MW high frequency tube tester designed and constructed by the Votator Division of the Chemetron Corporation for The Machlett Laboratories, Inc.

Size and Shape

Machlett's specifications were written in such a manner that the over-all layout of the test set was left to the Votator Division's Thermex engineers who presented drawings and other data outlining their plan of attack. Among other early steps, a life-size mock-up of the main control panel was constructed for approval by Machlett.

The drawing of Figure 2 shows a plan view outlining the general shape of the equipment and the photograph of Figure 1, made at the Votator plant in Louisville, gives an over-all concept of the test set. As indicated in these figures the general shape is similar to a letter T, with the distances being 17'6" across the top and 29' from end to end.

The entire equipment was constructed to be broken down into a minimum number of sections, and all but the fragile and very heavy components were shipped from Louisville in

place in their cabinets. Scheduling arrivals at the plant site in proper order to permit logical unloading and movement into the building without the necessity of moving one section past another greatly simplified the installation of the equipment.

One Man Operation

Operator convenience and ease of accessibility to all components were two of the major considerations that dominated the layout discussions. For economy in normal production work it was essential that only one operator be required to accomplish all of the necessary operations of vacuum tube production test work. Yet the equipment had to be built with the knowledge that at many times the performance of special tests on developmental models of tubes would make it desirable to have space for several observers

near the operating position. Furthermore, although the testing of tubes is a task which requires skill and judgment on the part of the operator, the fewer control adjustments necessary for a given test, the fewer the costly mistakes. Therefore simplicity was an additional important consideration. It may seem contradictory to call a unit as large and complex as this test set a simple device. Yet when it is broken down into separate components and functions, it is not really

one wing of an "organ console" type control panel (Figure 4). Thus the operator, positioned at an angle to the front of the unit, merely turns his head to view either the metering equipment or the tube itself. Meters which had to be located above convenient eye level for space reasons are tilted to let him look directly at the scales. Switches for changing the ranges of the instruments are usually located near the instruments themselves. A few of the less used control

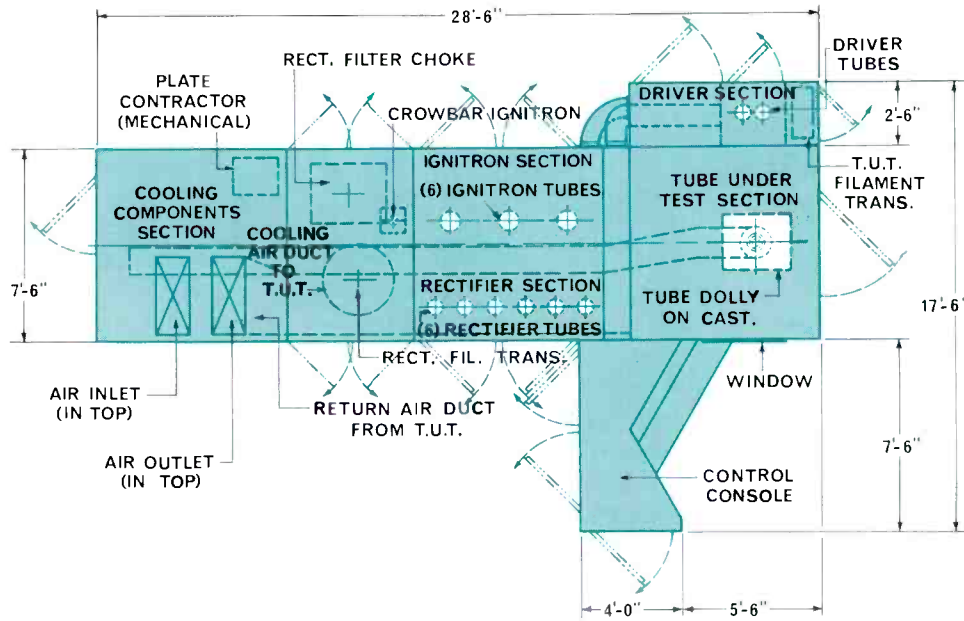


Figure 2 — Plan view of 1.2 MW test unit outlining general shape.

very complicated. Reference to Figure 2 during the reading of the next few paragraphs will help in understanding the description and comments.

Control Panel

During early design stages the control panel received a great deal of attention. The full scale mock-up enabled the designers to visualize the various operations the test man would have to perform and to place the controls and meters at a convenient location for him. For example, it was essential that the tube under test and the supervisory metering equipment be readily observed almost simultaneously. For this reason Machlett wisely specified large meters with mirror scales in many instances. Also, the final layout (Figure 3) located a large 30" x 36" viewing window for the tube under test to the right of the operator and made it part of

switches are also located on the upper portion of the panel.

Having one wing of the control console also serve as the wall of the tube under test compartment made it logical to have the water and air metering equipment located on this same wing of the console. This greatly simplified the piping problems and shortened the capillary tubes to the various thermometers. The temperature of incoming air and water and the temperature of the water leaving the load and the tube are measured by separate instruments. The incoming air pressure is also measured. Water flow in the anode circuit of the water cooled tubes and in the water load is measured by rotameters, two in each circuit, so that an accurate range of rotameters is available for the full size range of tubes and powers being handled. A fifth rotameter measures the water flow in a load that can be connected to the driver section of the test set.

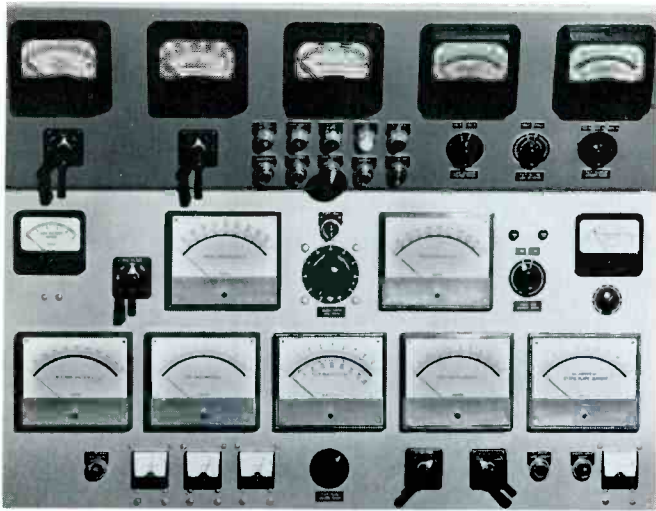


Figure 3 — Control panel showing large face meters easily viewed by operator.



Figure 4 — Control panel area showing ease with which test operator can view both tube under test and control panel metering.

The main controls required by the operator are located on a lower tilted panel that is just above a desk space on which he may place his test sheets and other reference material. This places most of the required switches and controls for the final amplifier at his finger tips, with no need to raise his elbows from the desk top. The main tuning controls and drive control for the equipment are handled by the left hand while the filament and plate voltage controls, on-off switches and other necessary switches are on the right. Major meters indicating plate and grid voltages and currents are directly in front of the operator.

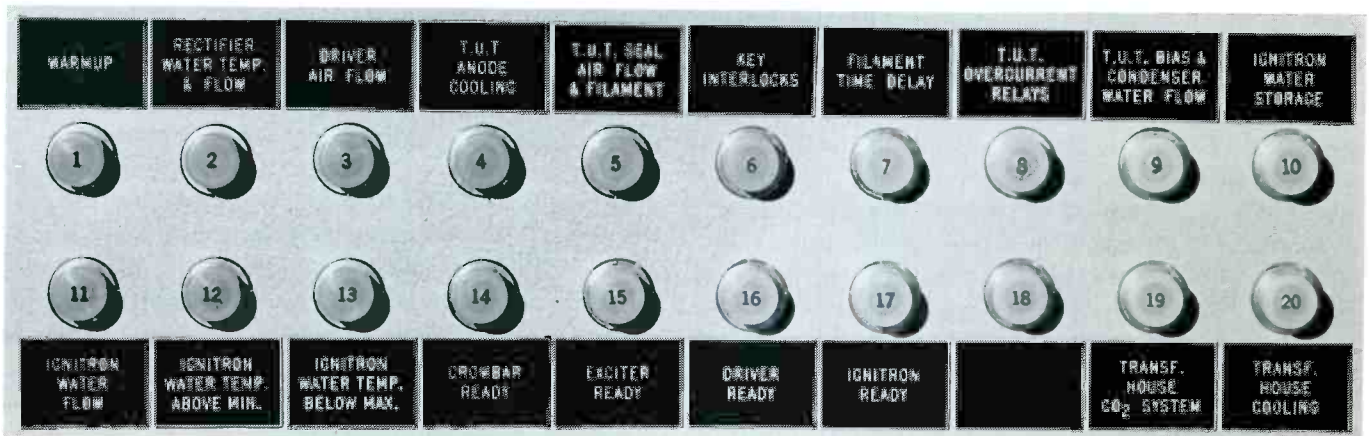
Controls for the low powered rf stages from the crystal oscillator through the driver stage are located on the left wing of the console. Some of these are manually operated while others are motor driven. All motor-driven controls in

the test set have position indicators. The left wing of the control console also has the "home" or "storage" position for all the door keys, an oscilloscope for noting wave shapes and measuring peak emission of the tubes, an rf voltmeter used in checking the rf potentials of certain circuits and in neutralizing procedures, and a rather comprehensive system of lights which indicate the conditions of various portions of the circuit (Figure 5). These lights are very useful in analyzing the status of the control circuit and have saved many hours of trouble-shooting in design testing and early stages of tube testing.

Block Diagram

Figure 6 shows an electrical block schematic diagram of the equipment. An assigned frequency band for industrial,

Figure 5 — Control circuit status lights for analysis of conditions in various portions of the circuit.



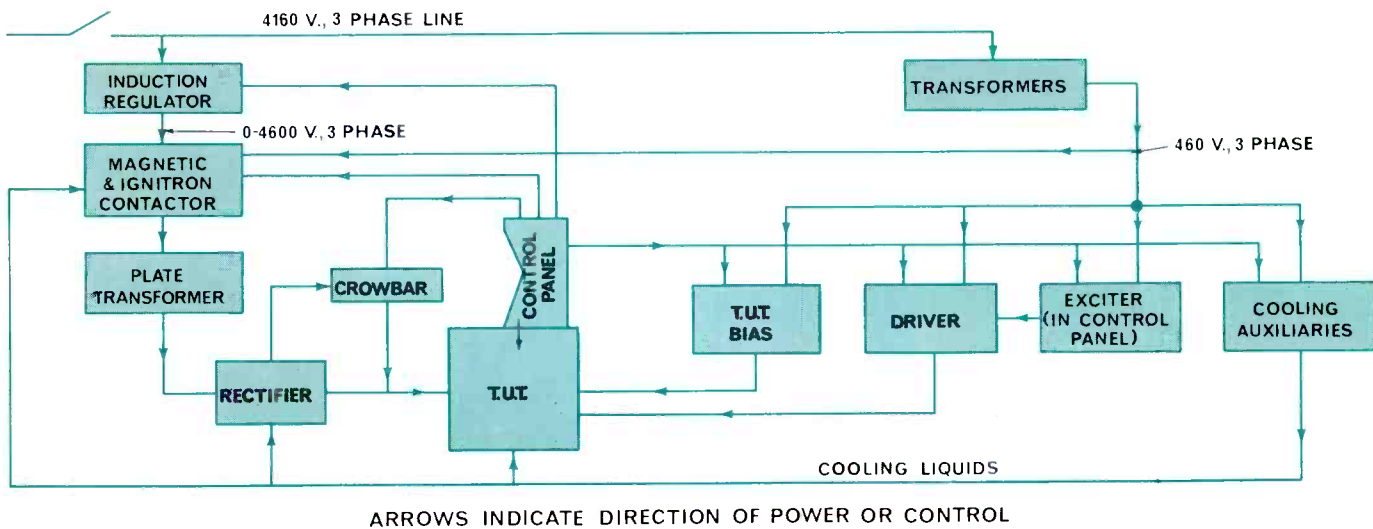


Figure 6 — Electrical block diagram of 1.2 MW test unit.

scientific and medical equipment, 13.56 megacycles, was selected as the frequency for this unit. However, as is well known, some of the harmonics of this frequency do not lie in the frequency bands assigned for the ISM services and even though the equipment was to be well shielded, it was possible that a harmonic could be troublesome. Therefore, a narrow bank on either side of this frequency was also specified so that slight shifts of frequency could be made if desired.

A crystal oscillator operating at half frequency feeds a tetrode buffer amplifier which also acts as a frequency doubler. This in turn supplies drive to an intermediate power amplifier utilizing a tetrode tube. The screen voltage of the buffer-doubler amplifier was made variable so that the drive power to the tube under test could be readily controlled by a single knob on the control operator's panel. This also required operating the subsequent stages in a Class A-B type operation during some of the low powered tests. However, no great attempt at linearity was felt necessary.

The actual equipment for the low powered stages is located directly behind the left wing of the control panel. A coaxial line is used to transmit the rf power to the driver stage which is located on the opposite side of the tube under test compartment from the control panel. This stage, using a pair of Machlett 7007 tubes in parallel, supplies the main driving power for all the tubes under test (Figure 7). The tuning of the driver is motor-driven from controls on the left wing of the console. Metering circuits for all of the low powered rf stages including the driver are also on this panel.

The driver is enclosed in its own cabinet, access to which is gained through three full height doors so that each component is within easy reach for maintenance.

The driver cabinet, in addition to containing the neces-

sary power supplies for its own operation, also contains the bias power supply and the filament transformer for the adjacent tube-under-test compartment.

Tube-Under-Test Compartment

Most designs of power amplifiers require the use of only one type of tube and one value of load impedance although several frequencies of operation are usually required. In Machlett's Thermex test set there is only one narrow band of frequency operation, but the set must handle at least five basic tube designs and a large number of load impedances so that the load on the five types of tubes can be varied from near zero load to considerably overloaded conditions. The variation in load impedance is an "infinitely variable" type system.

Inasmuch as the five basic tube designs also required three types of cooling, namely water, air, and vapor, considerable mechanical as well as electrical flexibility, was required of the design. In addition to the normal amplifying tests, during which the power handling abilities of the tube are determined, several static type tests are also performed with the test set. These include measurement of peak emission, gas current, amplification factor, filament characteristics, and others.

For ease of mechanical handling, as well as flexibility to adapt to the various types of tubes, wheeled carriages or dollies were constructed (Figure 8). Three of these were made, one for each of the three types of cooling to be employed. Each dolly has a basic insulated stand to which the various tube sockets and their adapters are mounted. The adapters for the various tubes, of course, include the connectors for the filament and grid terminals in addition to the cooling socket. The dollies are easily placed in position to receive the various connections required for the tests. A

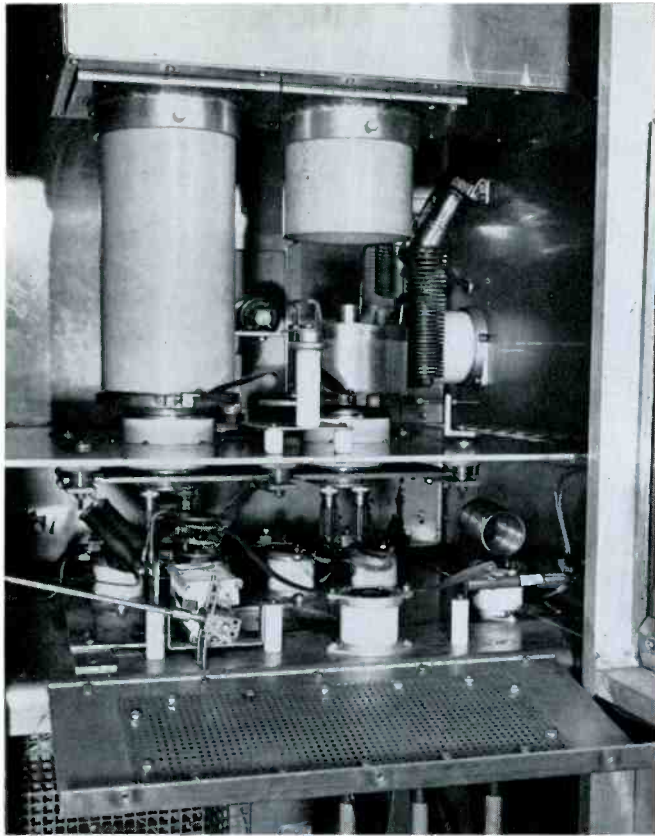


Figure 7 — ML-7007 tetrodes supply main driving power for all tubes under test.

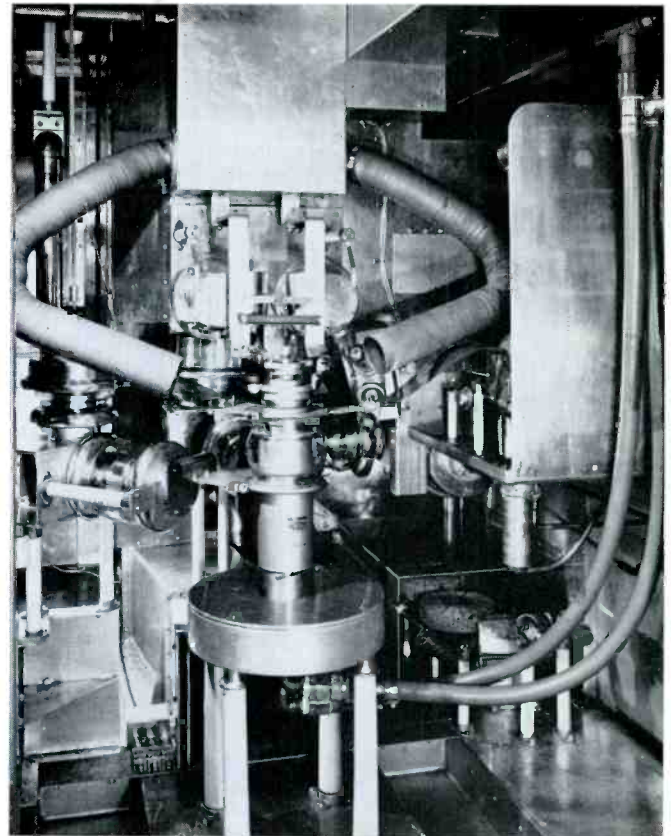


Figure 8 — Test bay showing tube under test on dolly and its simplified cooling connections.

portion of the tube-under-test compartment floor was lowered to the building floor level to facilitate moving the dollies in and out.

Cooling connections are easily made. The air cooled tube dolly is merely pushed against the main incoming air duct in the amplifier to complete the air connection. For water cooled tubes quick connecting fittings on flexible hoses are used so that only a few seconds are required for making the water connections. Water spillage is kept to a minimum and a floor drain carries away any water that does escape. Connections for the vapor cooled tubes are somewhat more complicated by the need to attach the steam outlet chimney that conducts the vapor from the boiler upward to the condensing system mounted on top of the compartment. From this point the condensed vapors drain back into the tube socket where they may again be vaporized.

Accessibility vs. Stability

Although dollies were provided for moving the tubes to be tested into the test position, it is desirable in many instances to be able to change the tube without removing the dolly from its test position. This limited the amount of equipment that could be placed directly above the tube under test. Furthermore, for stability reasons, certain por-

tions of the circuit had to be shielded from other portions. Thus, it was desirable to have a rear access door, reached by way of the ignitron contactor compartment, as well as a front access door to the tube-under-test compartment. For mechanical flexibility in handling the various sizes and types of tubes, the otherwise desirable short leads usually found in high frequency, high powered equipment were somewhat compromised. For example, a coaxial arrangement of filament and grid circuits was considered but abandoned due to the difficulties in changing tubes as well as adapting to various types of tubes. The various leads connecting the tubes to the circuits were made as wide as possible in order to reduce the difficulties inherent with this compromise. To permit rolling the dollies in and out, 180 degrees of the horizontal space around the tubes had to be left clear and was not available for circuitry. The side closest to the control panel also had to be kept relatively free of large circuit components in order to provide an unobstructed view of the tube from the operator's position.

To provide maximum decoupling between the driver circuit and the neutralizing circuit, in addition to the mechanical considerations mentioned above, the driver circuit was placed on the far side of the tube-under-test compartment from the control console. This placed the neutralizing

circuit, inherently smaller than the driver, near the operator's viewing window, but to the operator's left, i.e. to the rear of the tube-under-test compartment (see Figure 4). The main tank and load circuits were placed between the neutralizing circuit and the driver circuit and to the rear of the tube under test. Necessary shields were included to isolate the circuits from each other.

A coil type neutralizing circuit was chosen because of its simplicity as well as its relatively lower voltage requirements for the tank capacitor components. This places a parallel resonant circuit between the plate and grid of the tube so that there is a high resistive impedance between these two elements rather than the usual low capacitive impedance. It was found that this choice was adequate inasmuch as it is possible to reduce the drive voltage to zero, once the circuit is properly neutralized and under Class C conditions for many tube types and plate voltages.

The tank circuit utilizes a water-cooled inductance and a variable vacuum condenser which is also water-cooled. Another water-cooled variable vacuum condenser is used in the load circuit. The coupling capacity between the two circuits is not directly water-cooled (its mounting connectors are) nor adjustable under power, although it is a variable vacuum condenser.

Water Load

In achieving the specified capability of dissipating 800 kilowatts continuously, two loads were constructed. These were the same type as have been used for many years for calorimetrically measuring the power output of dielectric heaters. These loads are simple devices wherein the water itself conducts the rf current. Each load consists of a metal tank through which water is circulated, and these tanks are connected in series. Inasmuch as the tanks are near ground potential only short hose connections and metal pipes are required. The water load includes an electrode which is immersed in the tank water and is insulated from the tank itself. The inner electrode is connected to the hot terminal of the generator and conducts the current to the water. The flow rate and temperature rise of the water as it passes through the load are measured and calculations made to indicate the power output. It is usual to run the water flow at a convenient rate so that a full integral number of kilowatts per degree temperature rise is obtained. Then multiplying the temperature rise by the integral number gives the power output without the need of slide rule calculations.

The water load is made part of a parallel resonant circuit which is capacitively coupled to the main amplifier tank circuit. The load circuit is not normally tuned to exact resonance and the tuning adjustment is used to determine the amount of load placed on the amplifier. This does not unduly detune the amplifier, although it is necessary to maintain surveillance on the amplifier tuning as the load adjustment is made. The tuning and the load control switches

are located close enough to each other so that the operator needs only one hand to make both adjustments. Using this load circuit arrangement it has been possible to adjust the load from that required by the largest tube operating at high current and low voltage to that needed by the smallest tube at a fraction of its normal capabilities.

Cooling

For proper measurement of air flow to the air cooled tubes, and particularly for calibration of these measurements, it was desirable to have a long air duct between the blower and the tube under test so that the air flow would be laminar and stable at the point of measurement. This made it logical to have the cooling section as the rearmost compartment of the entire equipment. The cooling section, in addition to the large blower for air cooled versions of the tubes, contains another blower for moving air through the various cabinets for general cooling. Filters and a dampening system automatically filter and mix outdoor air with the returning air from the equipment to keep the interior at the desired temperature at all seasons of the year.

The cooling compartment also contains 3 water pumps, one for the tube under test and rectifier tubes, one for the water load, and one for the ignitron contactor. The ignitron contactor has its own cooling system to maintain the ignitron cathodes at the proper temperature under all conditions, independent of the load on the rest of the cooling system. Ordinary city water is used for cooling the tubes directly. No distilled water is used in the water cooling systems. City water is recirculated throughout the equipment with enough cool water being taken into the system to keep the average temperature of the water at a safe value. Automatic temperature control valves are used for this purpose.

The load resistor for the main rf bias supply, which also acts as the grid leak for the tube under test, is located in the return air duct just above the main cabinet cooling blower. This eliminates considerable heat from the rest of the equipment inasmuch as the air is discharged over the grid leak resistors. The mechanical magnetic contactor, included in the circuit in addition to the ignitron contactor, is also located in the cooling section compartment.

In both the rectifier and the tube-under-test cooling system, electrolytic targets were placed at strategic points to avoid electrolysis of the metal portions of tube sockets. In the case of the tube under test, the electrolytic target is at the dc potential of the anode of the tube under test, but a silicone flexible hose was placed between the electrolytic target and the actual tube under test. This flexible hose handles the major portion of the rf voltage drop so that only a small portion of the high frequency anode voltage is placed on the plastic piping.

Rectifier and Ignitron Compartment

The intervening space between the cooling compartment and the tube-under-test compartment is used for the main

high voltage rectifier and its associated filter, the ignitron contactor, and crowbar (Figure 9). Access to these sections is through full height doors on either side of the unit, with large glass windows for permitting visual inspection of the interiors during operation. The rectifier circuit utilizes six high vacuum type rectifiers in a three phase series type of circuit. Other than the use of rigid plastic piping in the cooling hose reels, the use of high vacuum rectifier tubes, and the necessity of increasing the size of the plate transformers for reasons described below, this circuit is quite standard. A small filter is included to smooth the ripple inherent in rectified dc to a sufficiently low value for test purposes.

The other power supplies for the entire equipment are rather straight-forward. All amplifier tubes have fixed bias supplies so that the entire equipment can be keyed as in a telegraph transmitter. This was actually done at low power levels as a test of equipment stability. The high voltage which, as previously mentioned, uses high-vacuum tubes necessitated by the high voltages which were called for, also includes an ignitron contactor, the reasons for which are described below.

Outdoor Components

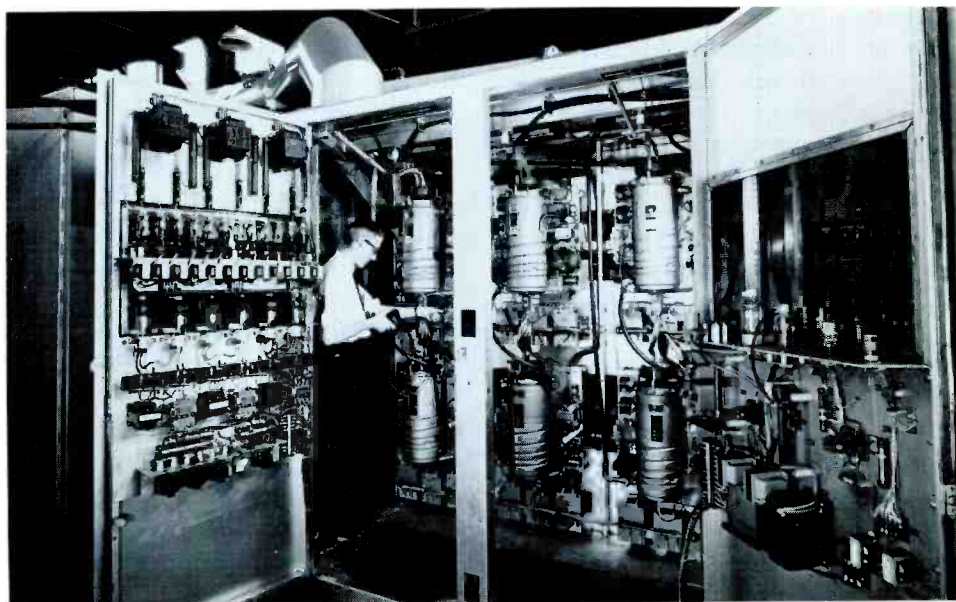
The very heavy components such as the main plate transformers, the induction regulator, the series line chokes, etc., were specified so they could be placed in an unheated building. The transformers and line chokes have been placed in a specially constructed steel house to provide shielding which

prevents radio frequency interference. The induction regulator for controlling the plate voltage from zero to 30,000 was placed out of doors. These items were located some 300 feet away from the main test set where space was available.

X-Ray Protection

In general, the equipment has a steel framework covered with $\frac{1}{8}$ " steel panels. Where radio frequency interference problems required good conductivity between sheets of metal, an aluminum liner was used. The steel, in addition to providing necessary structural strength and mechanical protection, also provided very adequate protection against X-radiation which comes from vacuum tubes when operated at voltages in excess of 20,000 volts. At 30 kilovolts, the highest required voltage, X-rays are of the soft variety that do not have great penetrating power. However, they are dangerous if allowed to escape into the areas containing personnel. Where windows in the steel cabinet structure were required, leaded glass was installed to complete the X-radiation protection. These precautions reduced the X-radiation to an almost immeasurable level when the doors were closed (very much less than 0.1 milliroentgen per hour). However, with the doors open the radiation was measured to be 115 milliroentgens per hour with the tube operating at 30 kVdc. The radio frequency shielding was also checked and was found to be good while the equipment was at the Votator plant. Preliminary checks made at the final installation site indicate the radio frequency radiation is well within the requirements of the Federal Communications Commission.

Figure 9 — Ignition compartment. Carl Ellsworth, Votator Division, is shown making an electrical check.



Interesting Problems

In addition to the interesting problems connected with the design of the tube-under-test compartment there were other unusual problems encountered. These were largely due to the high power requirements of the equipment and are generally electrical in nature.

Power Line Protection

For example, the utility company that was to supply power for operating this equipment was concerned about the high number of short circuits that could be experienced by the power line. In the development of new tube types it is essential that a reliable maximum voltage rating be determined. In making such an evaluation it is necessary to check tube arcing vs. dc plate voltage and power output on a number of tubes. To make a satisfactory analysis, the tubes must be run considerably in excess of the ratings that are ultimately given on the technical data sheet for the tube type. During such experimental work the tube will be subjected to many internal flash arcs. During the routine "seasoning" portion of production tube testing, plate voltages are also higher than those given in the published ratings, and the tubes will be subjected to internal arcs. These arcs place a short circuit across the high voltage dc power supply and permit a large amount of energy to be discharged into the tube under test. To limit the amount of energy a crowbar device was included. It places a second and lower impedance short circuit on the output terminals of the dc supply, thus short circuiting the currents which may flow in the internal arc of the tube under test. In order to limit the amount of damage to the tube under test, Machlett requested that the crowbar device operate in approximately 10 microseconds and not damage a small thin section of aluminum foil placed between the high voltage dc bus and ground. Such a crowbar device was successfully constructed.

When the utility company learned that such a device would be installed they questioned their ability to allow this equipment to be connected to their power lines. As originally conceived, with normal reactance in the magnetic components of the power supply it would not be unusual for a 12,000 kVA fault to be applied to the incoming power lines, and under some conditions, it could be even higher. This much of a suddenly applied (or suddenly removed) load on the incoming system would cause a serious voltage dip each time the short circuit was applied. These voltage dips would cause flickering lights and television picture difficulties in nearby residential areas and possible drop-out of contactors and circuit breakers with the associated equipment or plant shut-downs in nearby industrial plants. Any power system is subject to currents of this magnitude once in a while, but 2,000 of them per week were considered unbearable. The utility company requested that the suddenly applied or removed load be no more than the full load kVA of the equipment. This permitted no increase in load current

under many short circuit conditions. Of course this request was technically unfeasible.

Three steps obviated this problem. First, negotiation with the utility company produced a tentative agreement which raised the limit of suddenly applied or dropped load to 5,000 kVA. Second, sufficient reactance was included in the various transformers and line reactors in the incoming line so that the short circuit kVA would be limited to the 5,000 value. The line reactors were located alongside the high voltage transformers in the outdoor shielded enclosure. Third, a high speed contactor was included that removes the short circuit from the utility line in about one-half cycle. This was accomplished through use of an ignitron contactor system which was triggered to operate or open the circuit at the same time the crowbar was triggered to place a short circuit across the high voltage bus. Thus the crowbar removes the voltage from the tube under test in approximately 10 microseconds and the ignitron contactor removes the short circuit from the power lines in less than 10 milliseconds (about one-half cycle). This high speed removal of the short from the power line is too fast for visual observation of flicker even in fluorescent lights and is much faster than magnetic devices such as contactors and relays. In the several weeks of operation of the equipment during initial tests and operation no complaints have been received although it is known that the crowbar and ignitron contactor have both functioned several thousand times.

High Voltage Transformers

The inclusion of the high reactance in the power system feeding the equipment caused unexpected difficulty in specifying the size of the high voltage transformer. In normal power supply design, even in those for as large as 300 kilowatts output, the reactance of the supply line is usually found to be sufficiently low that an increase of 5% in transformer voltage and kVA above the dc requirements is sufficient. However, in the power supply for the 1.2 megawatt tube tester, where the large amount of current limitation had to be included for the reasons described above, the kVA rating of the plate transformer had to be increased from 1.2 to 1.7 MVA, an increase of 42% instead of the usual 5% commonly allowed. Resulting voltage regulation problems were easily taken care of by an induction regulator already specified for the equipment.

The increase in kVA of the plate transformer bank was required by the fact that inductance tends to cause current to flow even after the voltage which originally caused the current has reached zero. This creates an overlap of current conduction between the various tubes in the rectifier such that for short intervals of time two phases are "short circuited" during each cycle. The result is an increase in voltage drop in the reactance of the line feeding the rectifier bank, called the commutation reactance, and requires a higher voltage from the high voltage transformer to com-

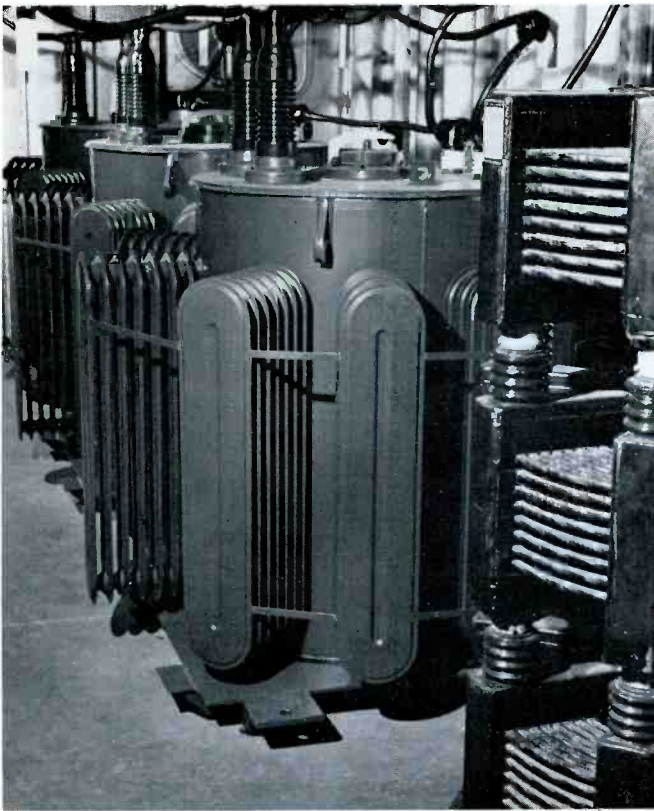


Figure 10 — Power supply transformers and line chokes, shown here, for 1.2 MW test unit are located in a steel house to prevent rf interference.

compensate for the additional drop. The current rating of the transformer remains constant although the kVA rating is raised by the additional voltage requirement.

Credits

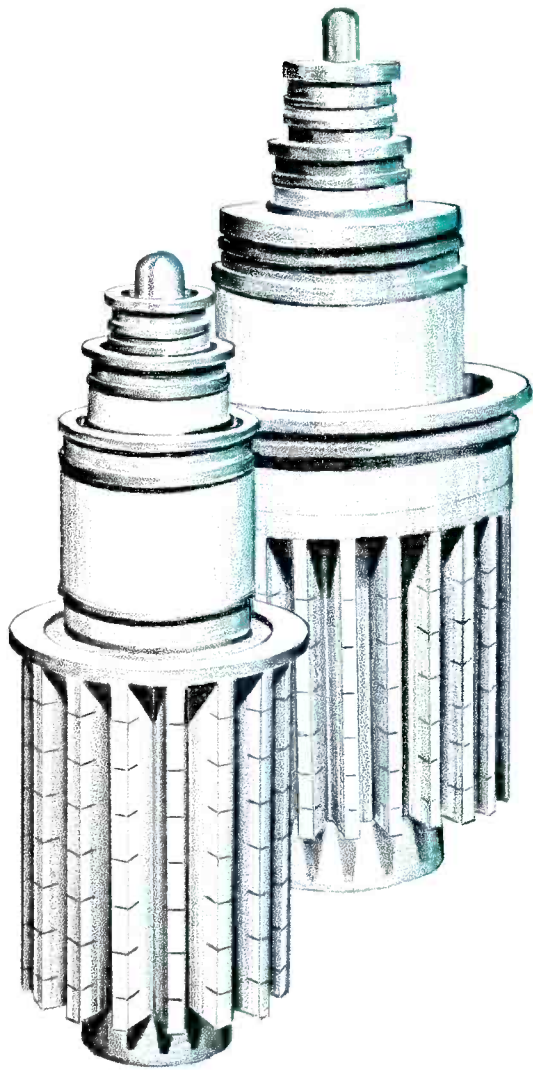
As in any project of this nature, the successful conclusion has been the result of cooperative effort not only between Machlett and Votator but also between the individual engineers immediately involved. During the construction phases, where engineering information was not complete, close cooperation of the manufacturing facility with the designing facility was required. Such cooperation was given by all concerned with this project. Some of the people carrying the largest share of the burden include R. C. Black of Machlett Laboratories who was advised by Dan Kudola and C. V. Weden (now Project Engineer, Power Grid Tube Laboratory at Eitel-McCullough) of the Machlett engineering staff. For the Votator Division Carl E. Ellsworth was assigned the job as his major effort and followed the job from start to finish. He was assisted in various stages by Richard R. Moore and Willard H. Hickok of the Votator engineering staff, plus Rufus E. Smith and James E. Marshall of the Votator manufacturing staff. To these men goes a lion's share of the credit for the success of the project.

• • •

Supplementary Advantages of Vapor Cooling:

Recovery of Heat

About half of the input power into a broadcast transmitter of high efficiency has to be removed as heat from the anodes of the power tubes in the final stages. In air cooled and also in water cooled tubes this power is lost. In water cooled tubes, for example, the temperature of the outgoing water is too low to be of any use. In vapor cooled tubes the same amount of heat has to be removed; however it is in the form of steam, which is directed into a heat exchanger. It now becomes feasible and rather simple, using a water cooled heat-exchanger, to bring the water in a secondary circuit to about 95°C, and use the water for central heating of the broadcast station and adjoining staff homes. Very hot water lends itself well to heat storage; thus, in many installations a hot water storage tank is provided, and at nighttime, when the transmitter might be shut down, central heating may be



Introduction

Cooling of high power electron tubes by the vapor cooling process has been in existence for more than 10 years in Europe, and has during the last few years found interest and application in this country also. The first major installation in America using this highly efficient method was the 250kW Voice of America transmitter, constructed in Greenville, N. C. by the General Electric Company¹. Each transmitter employs five Machlett ML-7482 vapor cooled tubes (Figure 1), two in the final amplifier, one in the intermediate power amplifier and two in the modulator. All tubes operate into one common cooling system.

Efficient cooling of high power tubes by ebullition of water or other liquids (with subsequent high anode dissipation levels) was developed in France by the Compagnie Française Thomson-Houston. The first commercial application was constructed and put in operation in 1950. Since then more than 100 broadcasting stations and more than 300 installations for industrial purposes, including rf heating, have been put into operation in Europe, Africa and America. Other European tube and equipment manufacturers have followed the lead of CFT-H and now almost all transmitters above 100 kilowatts output are being designed for vapor cooling of the modulator and power output stages.

The theory of operation has been discussed in several papers, as noted in Reference 1. Here we are interested in discussing the supplementary advantages vapor cooling can provide, which are:

- Hot water near the boiling point (95°C).
- Distilled water.

Space Heating and Distilled Water Production

By *HELMUT LANGER, Development Engineer, The Machlett Laboratories, Inc.*

accomplished utilizing the stored hot water from the daytime operation.

When heat recovery is desired, the vapor cooling installation requires a water cooled heat exchanger ahead of the air cooled heat exchanger, see Figure 2. It is furthermore necessary to provide a thermostat, which controls the water flow to the cooling circuit of the heat exchanger in order to obtain a constant water outlet temperature of approximately 95°C, independent of changes in the rate of plate dissipation of the power tubes. In a 100kW broadcast transmitter, with water entering the system at 20°C and leaving the heat exchanger at 95°C, about 180 gallons of hot water per hour will be obtained at no cost to the user. The heat obtained from the power tube is, therefore, about 800 Kilo Calories per kilowatt-hour. Reference 2, (Figure 3), describes hot water volume vs. anode dissipation for different

output water temperatures in the secondary circuit.

If the available steam is not completely condensed in the water heater exchanger, then a portion will go to the air-heat exchanger; this heat is then dissipated in the air. It must be determined in each instance whether the heat exchanger should be convection or forced-air-cooled. Of course, when no heat recovery is needed, an air-heat exchanger only will be required and the heat dissipated may be released into the outside air.

Heat recovery and subsequent use for space heating and local hot water needs is certainly not limited to broadcasting installations, but will also be of value in the field of industrial rf-heating where high power levels are involved, e.g. induction melting of steel, tin re-flow, rayon drying, and many more. When planning a new installation using the vapor cooling process or changing to it from another cooling

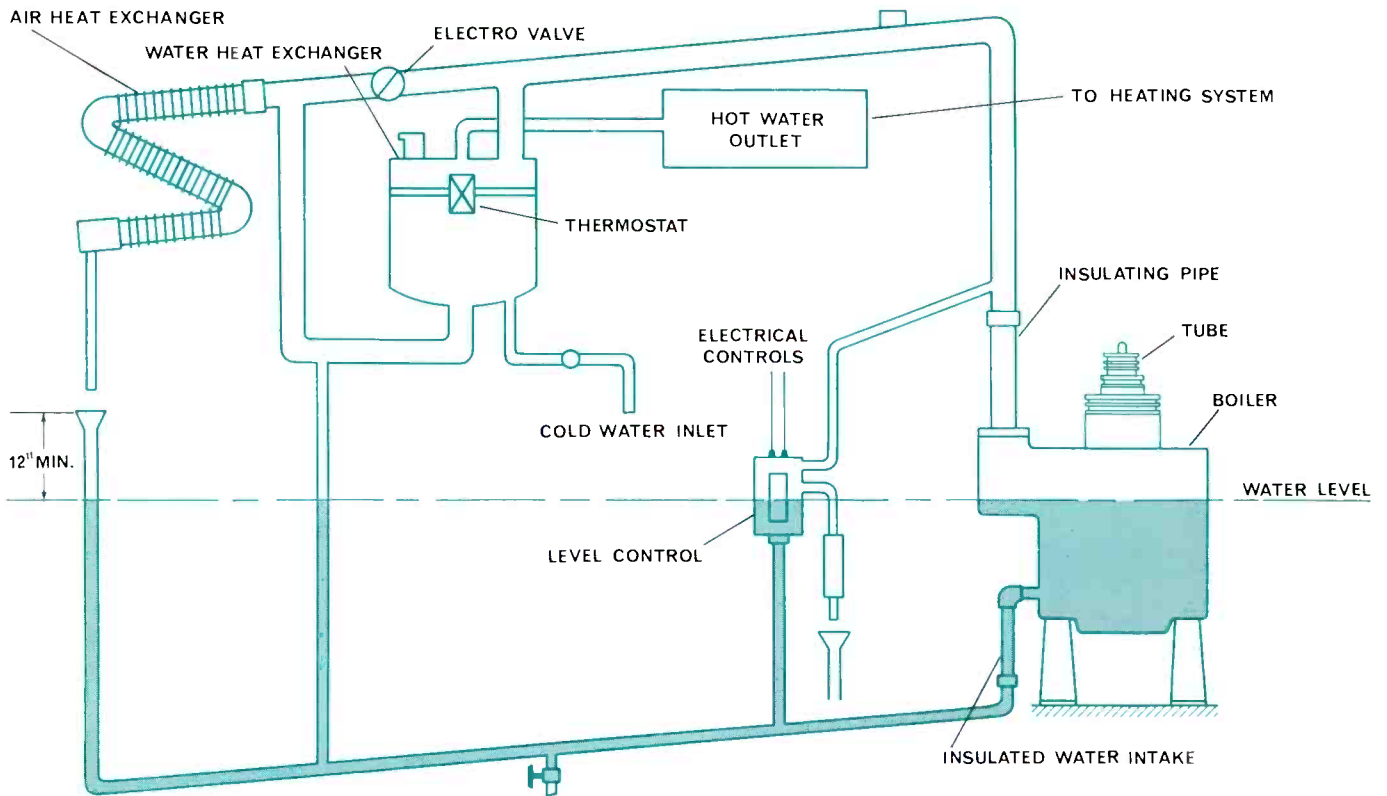


Figure 2 (above) — Diagram illustrates use of vapor cooling to provide hot water for heating of buildings and domestic purposes.

Figure 1 (below) — ML-7482 Vapor-Cooled Ceramic Triode. Note anode ribs or protrusions which promote efficient vaporization of water in boiler.



method, the advantages noted should be considered. It is certainly rather simple to utilize heat recovery and direct the available hot water into an existing heating system. If, for example, an oil-fired hot water system is used in the building, the oil-fired furnace may be treated as a supplementary device, only to be used when the vapor-cooled tubes are not in operation.

Production of Distilled Water

By tapping the outlet of a heat exchanger, a large fraction of the distilled water may be drawn off and utilized for industrial purposes. Compensation for water removal must then be made by feeding raw water into the vapor cooling boiler. A typical installation diagram is shown in Figure 4. The basic vapor cooling system remains unchanged; however, the boiler is equipped with an additional, insulated, raw water intake and a lower outlet for draining silt. Raw water has to be softened before it enters the boiler, and the raw water flow regulated in order to maintain a constant water level in the complete system. The distilled water may be stored in a water storage tank, (at time of removal from the heat exchanger the water will be very near the boiling point).

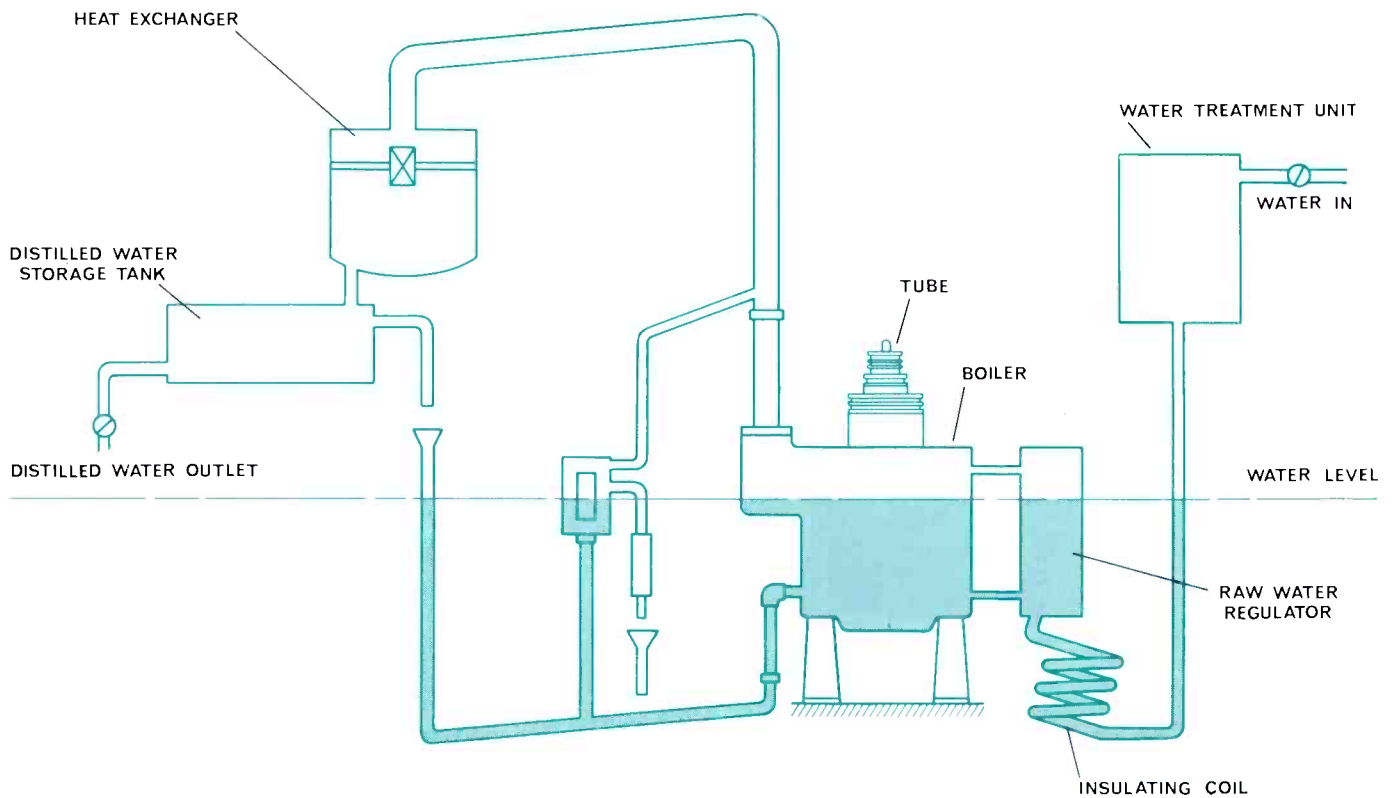


Figure 3 (above) — Diagram illustrates use of vapor cooling in production of distilled water.

Figure 4 (below) — Chart showing recovery of heat in form of hot water from Heat Exchanger.
 $(\Delta t = t_2 - t_1)$ t_1 = incoming water temp.;
 t_2 = outgoing water temp.)

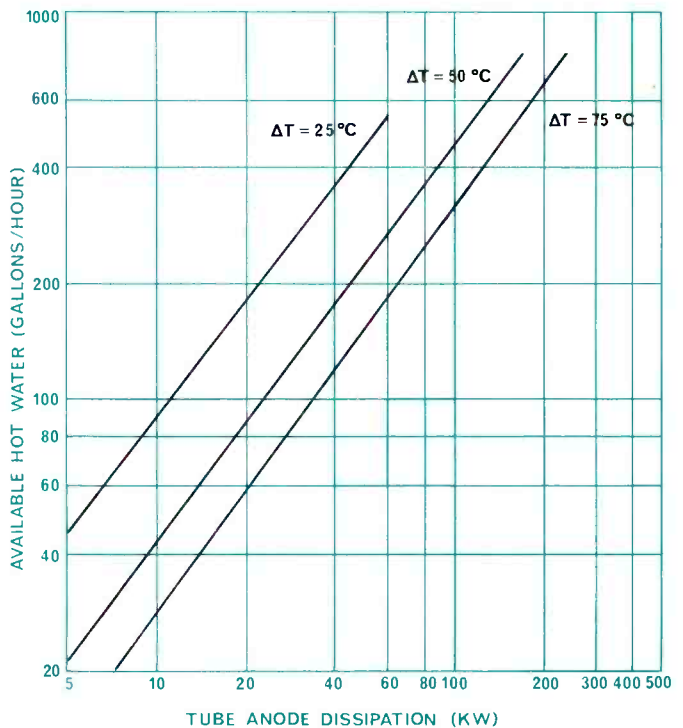
Production of distilled water can be regulated rather simply by use of a water level control in the storage tank, which would act to stop entry of distilled water into the tank when a certain water level is reached. An efficient, safely operating, distilled water supply system, and one which will not interrupt a basic vapor cooling system, may be readily designed by any competent heating engineer.

Conclusion

It has been shown that the vapor cooling process of large power tubes in broadcasting and in industrial heating application may, without much extra cost, supply hot water for heating and local uses and also make available large quantities of distilled water, which may be of advantage in certain industrial operations. (Several hundred liters of distilled water may be obtained daily from a tube of medium power output.)

REFERENCES

- 1"Vapor Cooling: Its First Major American Installation in the New 250kW Voice of America Transmitter." Cathode Press Volume 19, No. 1, 1962.
- 2"Note on the Vapotron" publication by the Compagnie Française Thomson-Houston, France.





Mercury capsule employing ACF radar beacons in which Machlett planar triodes were used.

Editor's Note:

ACF radar beacons utilizing Machlett planar triodes have been incorporated in spacecraft used in the NASA Project Mercury. The ACF beacons, themselves, are part of a communications sub-system supplied by Collins Radio Company to the McDonnell Aircraft Corporation.

Machlett planar triodes, extensively used in radar beacon equipment used by commercial airlines and others, have been chosen for their long term reliability and for the excellent electron emission density provided by the tube's cathodes. A radar beacon is primarily a radar "responder" being actuated by a coded radar beam sending to ground units an identifying signal. These signals are monitored and tracked on the radar screen. It has been through the use of these beacons that the Mercury capsules have been tracked in orbit and pinpointed after descent.

Two beacons, for example, were aboard the Sigma 7 capsule.

Radar Beacon ..



Mercury capsule showing location of radar beacons.

The First C-Band Pulsed 1kW Oscillator

Introduction

The recent marketing of a Radar Beacon, employing a C-Band pulsed 1 kW oscillator, by The ACF Electronics Division, Paramus, New Jersey, is of particular interest. For the first time a planar triode, ML-6771, has been used in this service and in this frequency range.

Planar Tube Experience in S-Band

ACF Electronics Division, Paramus (one of three plants of the Division) is principally involved in production and development of light-weight equipment for aircraft, missile or submarine use for information, detection, transmission processing or display. As an important part of this activity, ACF has developed long-range radar beacons for missile and space application. These beacons provide pulsed output signals used for missile or space vehicle tracking, identification or pulse-coded signaling. Radar beacons must be light, fault-free in performance and capable of prolonged periods of operation in environmental extremes.

In their development and application of the Type 149-S S-Band beacon (1.5 kW pulsed power) ACF has employed the ML-471. Through the use of this tube, and because of

reliable, long-life performance, ACF became interested in the possibility of using a Machlett triode as a magnetron replacement in their C-Band equipment, used in almost every major missile program.

Highest Reliability Required

Highly important space application, including the Mercury program, dictated the need for the utmost equipment reliability, especially with regard to transmitter and oscillator tube performance. By establishing special test criteria (developed in conjunction with Machlett engineering personnel) to match the tube to the cavity (Figure 3) it was found that the required performance standards could be obtained. Out of this arrangement the ML-471 was developed. Shock tests, to 100g for 5 milliseconds, have further demonstrated the ruggedness of the tube-cavity combination.

Of convincing interest was the long life experience provided by ML-471. Because of the excellent cathode emission, filament heater power was safely and satisfactorily reduced. An operating filament voltage of $5.9 \pm .2$ is now employed by the S-Band Radar Beacons (C-Band Beacons also use

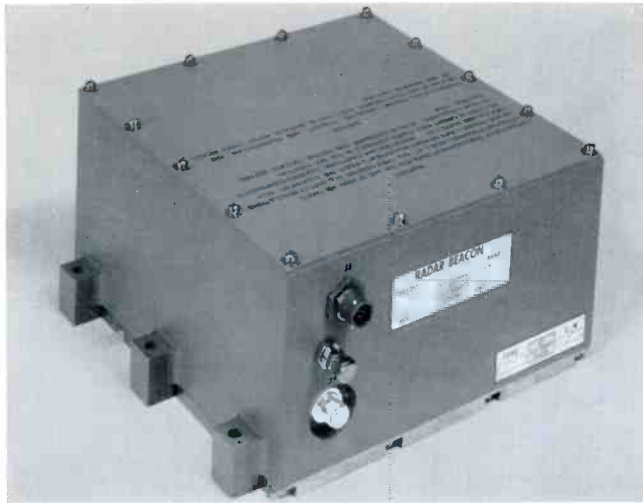


Figure 1 — Radar Beacon, Type 149, manufactured by ACF Electronics Division. This beacon used in S- (Type 149-S) or C-Band (Type 149-C) is employed in almost every major missile program. Transmitting tubes in all S-Band and some C-Band beacons are Machlett planar triodes.

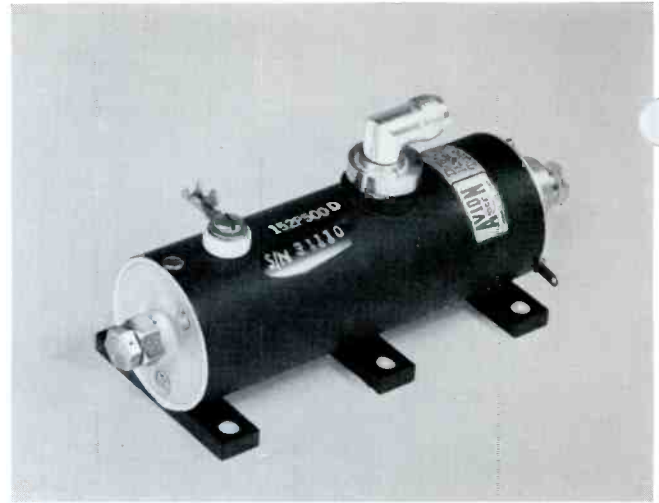


Figure 3 — ACF Cavity, Model Number 331, S-Band Triode Pulsed Oscillator Cavity:

Frequency Range	2800 - 3000 mc
Peak Power Output	1.5 kw min.
Pulse Drive	2.4 kv @ 2.2 amps nominal
Filament	6.3 v @ 0.9 amps nominal
Duty	0.001 max.
Pulse Width	2 #sec max.
Size	Approx. 5½" Long, 1½" Dia. excluding connectors

Figure 2 — Machlett ML-471, planar triode, achieves life increase of 50%, or more, operating at an E_f of $5.9 \pm .2$ volts in Type 149-S Beacon employing the ACF Model 331 cavity. Excellent cathode activity permits pulsed power emission of 11 amps cm^2 .



5.9 \pm .2 volts). This filament voltage reduction has effected a life increase of approximately 50% or more.

Life/power tests performed at ACF and at Machlett have shown a consistent power level range (1.2 to 1.5 kW pulsed output) over the period of the test, 700 hours and 500 hours, respectively. In both instances the tube was operating satisfactorily at the conclusion of the test period. It is of interest to note that the ACF test was made with 6.3 v on the filament, the Machlett test with 6.0 v E_f , a comparison which provides good evidence of the tube's ability to operate under varied conditions: Field experience, over fifty flights in orbited satellites, has amply re-inforced test conclusions, and has conclusively demonstrated that the tube can perform well and long at lowered E_f .

Planar Triode in C-Band Beacons

The use of a planar triode in pulsed C-Band beacon equipment by ACF marks a positive advance in this field. Severe environmental conditions, associated with the use of the beacon, favor the use of planar triodes. There are, for

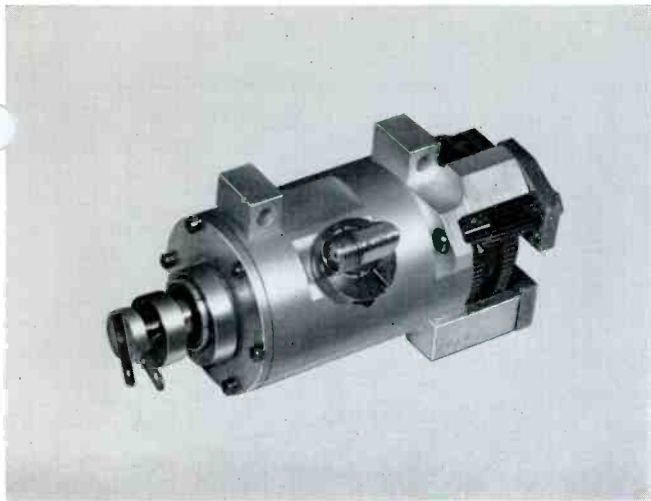


Figure 4 — ACF Cavity, Model Number 350, C-Band Triode Pulsed Oscillator Cavity:

Frequency	5400 - 5900 mc
Peak Power Output	1.0 kw (500 mc tuning range)
Duty Cycle	0.002 max.
Pulse Width	0.4 to 1.20 microsec.
Peak Anode Voltage	2.5 kv
Peak Anode Current	2.5 amp (nom.)
Vibration	10 g 20 - 2000 cps
Size	3 ³ / ₄ " Long x 1 ¹ / ₂ " Dia.



Figure 5 — Machlett ML-6771 — First Triode used in C-Band equipment. ML-6771 and its associated cavity, ACF Model 350, have successfully operated under tests to 30 g from 20 to 2000 cps.

example, no parts external to the tube which could be displaced to affect tuning. Further, the planar triode is less sensitive to voltage fluctuations and offers an economic advantage measured by a factor of four or more. Regarding comparison of sizes, the tube plus cavity is only a very slight amount larger than a magnetron of equivalent frequency range. All that was needed for the beacon was the right tube. Since the adoption of the ML-6771 by ACF for their C-Band Beacon, these desirable performance and economic parameters have been successfully incorporated in their equipments.

Employing a plate-pulsed oscillator, ACF's C-Band long range radar beacon is tunable throughout a 500 megacycle range from 5400 to 5900 mc. Nominal peak power of the transmitter is 1.5 kW (200 mc tuning range), available at a 0.001 duty, .4 to 1.0 μ sec pulse width. (For lightness and compactness ancillary circuitry of the beacon is transistorized.) High reliability — in addition to that inherent in the tube — and sustained peak power performance is achieved by ACF by an exact mating of the tube to the cavity (Fig-

ure 4). Unusual structural reliability, for a tube of the 6771 type, is evidenced by the successful shock and vibration test, wherein the ML-6771 and its associated cavity, operated without detriment to performance at 30 g, from 20 to 2000 cps, on six different planes. The ability of the ML-6771 to operate under these conditions, hitherto prohibitively difficult, results from the tube's excellent mechanical structure and precise assembly as well as its high cathode activity and stability. Even under high voltage, high altitude conditions, the ML-6771 cathode (as well as that of the ML-471) shows no tendency to deposit cathode oxides on the grid assembly. Further evidence of cathode performance is found in the ability of the tube to operate at reduced Ef.

• • •

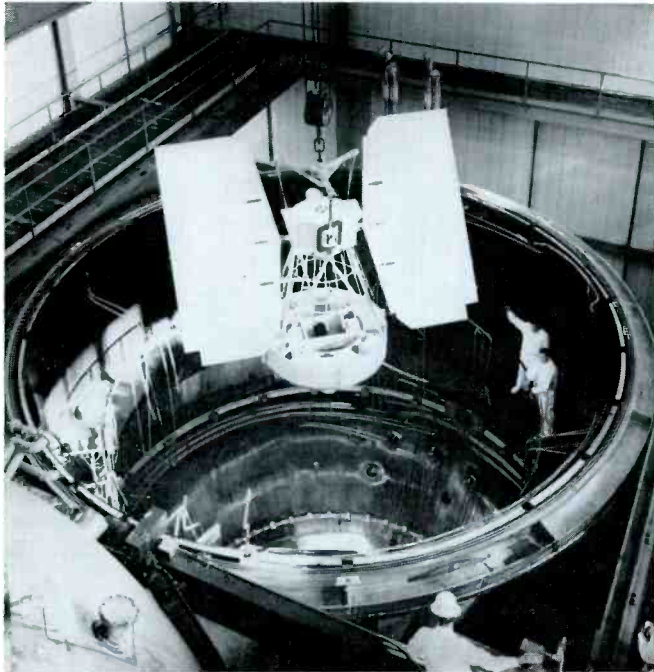
Reliability under critical conditions is a mark of Machlett products. With the assignment of the ML-6771 and ML-471 to ACF radar beacon equipment, demonstration of this fact is once again provided.

Editor's Note:

Machlett planar triodes have been chosen for many exacting assignments in the nation's space programs. One of the most important of these has been the use of specially adapted ML-6771 tubes in Mariner II, the Venus spaceprobe. These were the only electron tubes in the Mariner rf circuitry. Other interesting space usage of Machlett planar triodes is described elsewhere in this issue in an article on ACF radar beacons.

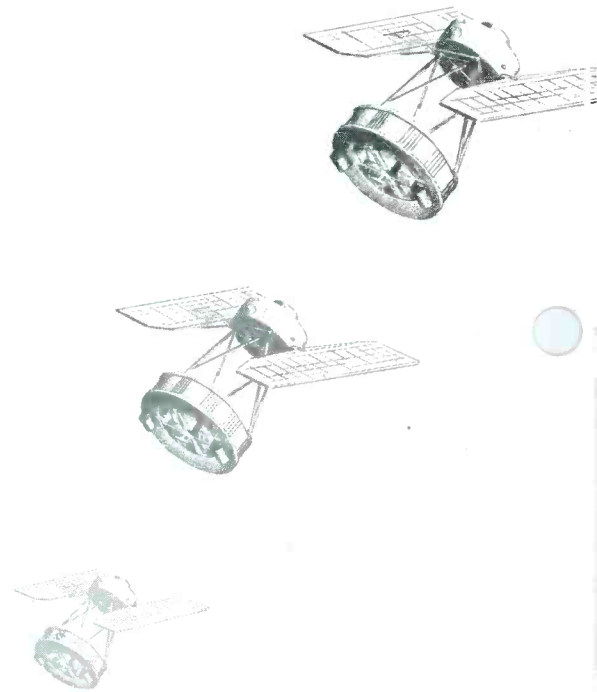
In the S-Band transmitters of the Nimbus weather satellite a frequency stable triode, ML-518 is employed for use during the brief transmission periods made by the satellite. The fact that the ML-518 can be brought to frequency stable operation within an extremely short period of time eliminates the need for long warm-up periods and thereby reduces power consumption requirements. Nimbus will transmit fourteen times each twenty-four hours as it passes near Fairbanks, Alaska on its near polar orbit; only ten of these transmissions, however, will be within the range of the Fairbanks' ground station. A satellite design life of six months, minimum, is expected. During this period over two hundred and thirty thousand photographs of the earth's surface (including, of course, its cloud cover) will have been transmitted to Fairbanks.

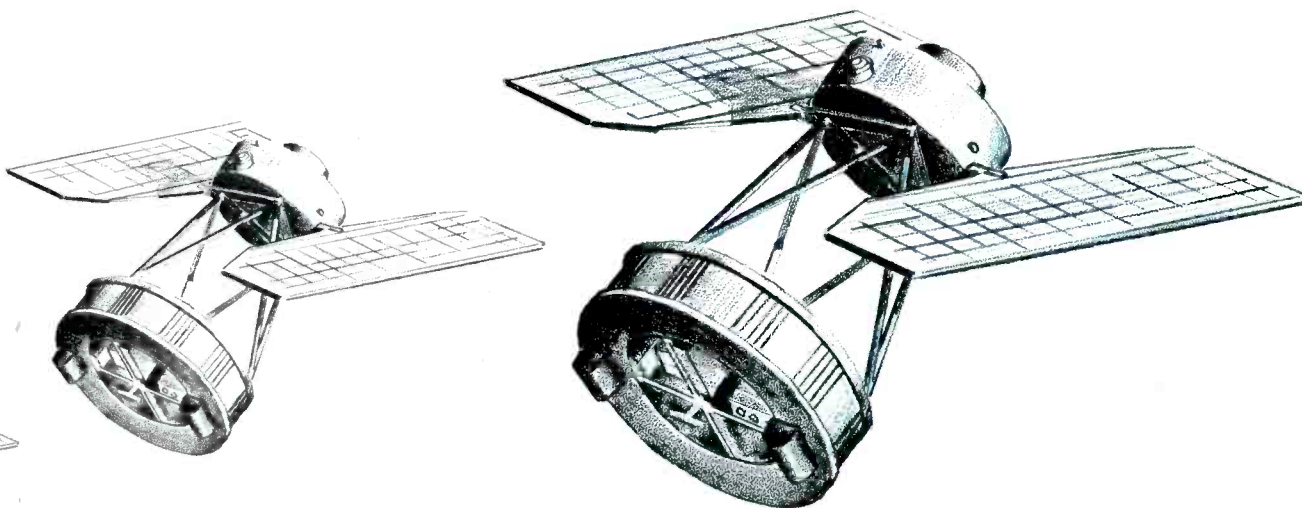
• • •



(Photograph courtesy of General Electric Company)

As the accompanying photograph (taken at General Electric's Missile and Space Division, Valley Forge Space Technology Center) indicates, Nimbus will have undergone extensive testing before it is sent aloft. Nimbus is shown here entering MSD's Environment Simulation Chamber.





Nimbus Weather Satellite

Introduction

A meteorological satellite, Nimbus, scheduled for operation in late 1963, is being developed by the Goddard Space Flight Center of NASA. General Electric Co. is fabricating the spacecraft structure and will integrate the various subsystems produced by other manufacturers. Telemetry Transmitters, employing the ML-518 frequency stable planar triode, have been provided for Nimbus by General Electronic Laboratories.

Stringent transmission requirements include a 45 second warm-up period* for the transmitter followed by a ten minute transmission. The Machlett triode, ML-518** specifically designed for fast stabilization meets this difficult operating condition satisfactorily.

*Cathode temperature stabilization for the planar triodes is reached prior to this period.

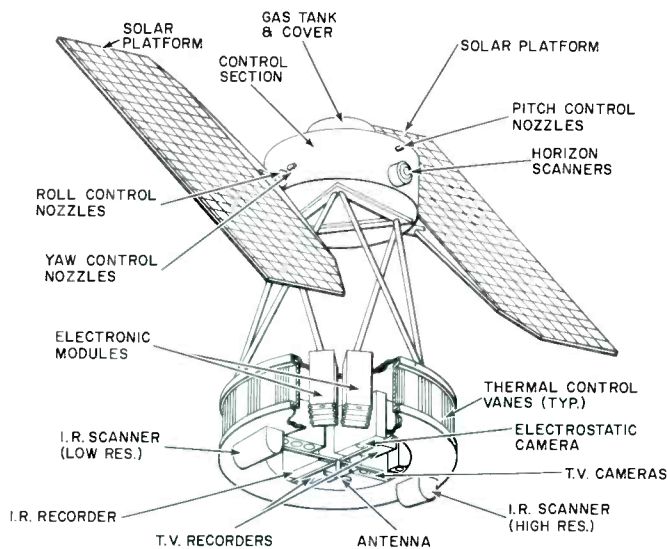
**Frequency Stable Anode Design for Planar UHF Tubes, by Werner Brunhart, Cathode Press, Volume 18, Number 3.

General

Nimbus is designed primarily to maintain a continuous watch, by vidicon cameras, of the earth's daytime cloud cover. (Clouds are, of course, basic weather indicators.) The satellite will follow a nearly circular orbit at an altitude of 600 miles. It will be stabilized about each axis and kept in a perpendicular orientation to the earth's surface. A site in Alaska will acquire and store monitored data from the satellite and will also inject certain command functions.

The Satellite

The Nimbus Spacecraft consists of control and information sections rigidly interconnected (see Figure 1). In operation the control section, electrically powered by solar cells, utilizes inputs from infrared scanners to establish horizon references and thus the desired orientation of the craft. Compressed nitrogen jets and flywheels act to stabilize



(Diagram courtesy of the General Electric Company)

Figure 1 — Nimbus Spacecraft showing major sub-systems and components. S-Band telemetry transmitters designed and manufactured by the General Electronics Laboratories are located in the lower section of the structure.

the unit and provide corrective forces from signals generated by the scanners through a small space-borne computer. Solar paddle/sun orientation is derived from a sun-sensor; yaw gyro drift is also monitored from the sun system.

The information or sensory system of the satellite consists of over 16 different sub-systems including:

- (1) S-Band 5 watt Transmitters having a frequency stability of .005%. (FM transmitters employ ML-518s in 1700 mc band to transmit to the ground station information from the Advanced Vidicon Sub-system and the high resolution radiometer sub-system.)
- (2) Advanced Vidicon Sub-system (To take cloud cover pictures; employs 3 cameras, one normal to the earth's surface, the others displaced to provide a slight picture overlap; pictures from cameras are stored on 4-track tape recorder; upon command from ground station vidicon information is transmitted on S-Band.)
- (3) High Resolution Radiometer Sub-system (To provide nighttime cloud cover picture; utilizes infrared radiation in the 3.4 to 4.2 micron region.)

Other sub-systems include those for telemetry and for measuring infrared radiation from certain spectral bands and earth-sun experiments to determine the role of the sun in earth's weather.

S-Band Telemetry Transmitter

The telemetry transmitter used in Nimbus is a self-contained unit (two are employed to provide the highest reliability practical) designed to operate in the 1700-1850 mc/sec region. Designed primarily for use with FM sub-

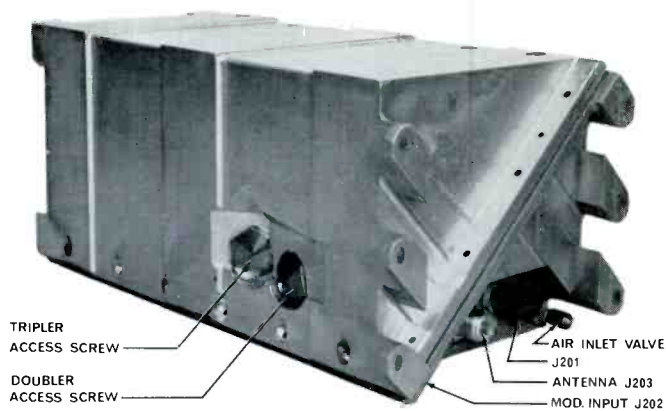


Figure 2 — The S-Band Telemetry Housing employs cast magnesium fabricated in two sections. The total weight of the transmitter is approximately 19 pounds.

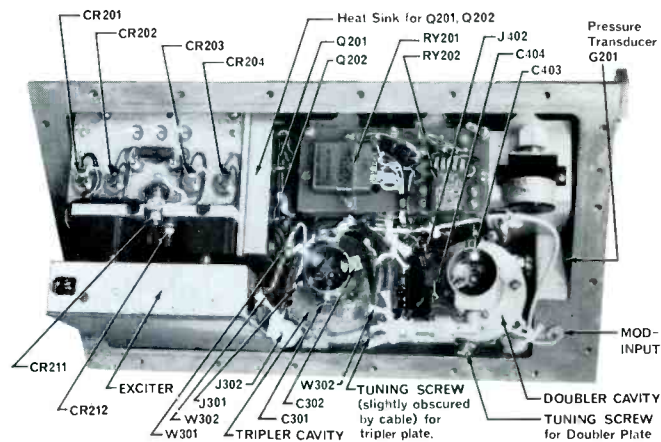


Figure 3 — Block diagram of Model 25A1 S-Band Transmitter.

carrier or sinusoidal wide-band video, the transmitter, General Electronics Model 25A1, can with minor modification transmit asymmetrical data of the PCM or PACM (Pulse Amplitude Code Modulated) type.

Designed for lightness and reliability, the unit is packaged in a cast magnesium two part housing (Figure 2 and 2A), and employs epoxy encapsulated miniature vacuum tube circuit sections and magnesium cavity castings for the final tube sections. A complete unit weighs approximately 19 pounds.

A block diagram showing the major sub-portions of the 25A1 transmitter is given in Figure 3. The basic unit consists of a modulated oscillator, stabilizing circuitry, multiplier chain and output stage as well as a power supply together with auxiliary circuitry for monitoring transmitter performance. Since ruggedness and frequency stability have

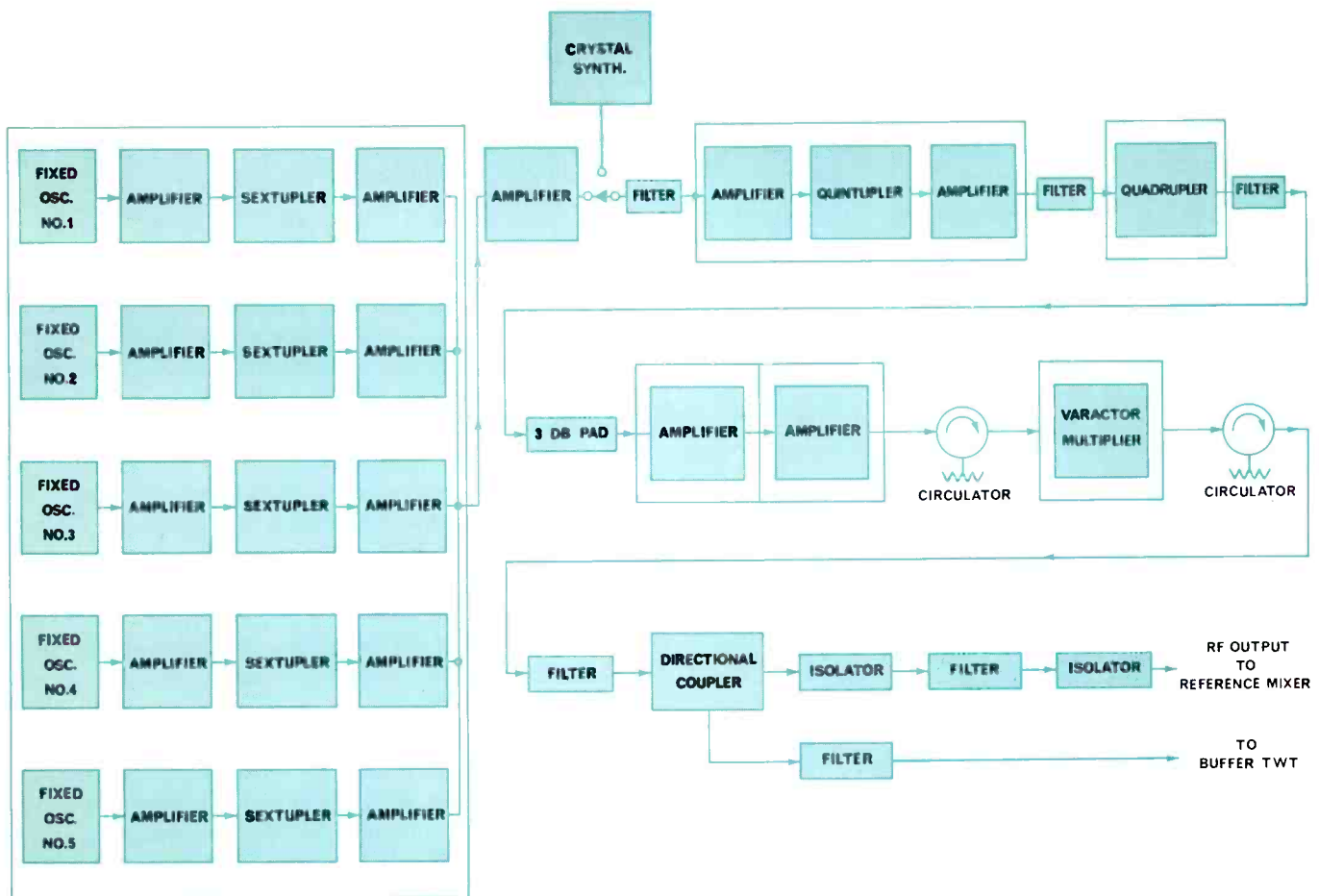


Figure 2A — Model 25A1 S-Band Transmitter.

been critically important in the transmitter design, both circuit configurations and components have been selected with this criteria in mind. The oscillator, for example, uses a Clapp circuit to achieve a minimum of incident frequency modulation (such as might result from external vibration). To further enhance stability, portions of the oscillator are secured to the chassis by epoxy adhesives. A crystal discriminator determines the average frequency of the oscillator, the average center frequency deviating only slightly (less than .005%) from the desired center frequency over 60°C range.

Following this two doubler stages work into a final amplifier stage which, in turn, works into a tripler and a doubler, each employing the ML-518. Operating in a grounded-grid mode the tripler stage utilizes a radial cavity (Figure 4) with capacity loading to minimize volume. The cavity operates at a one quarter wavelength anode; tuning

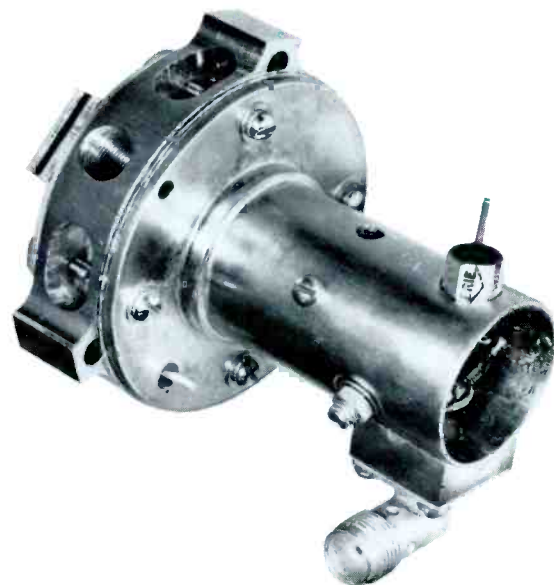


Figure 4 — Radial cavity employed in tripler stage which uses ML-518.

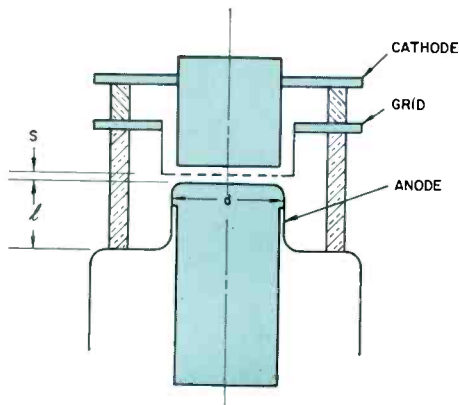


Figure 5 — Typical Planar Tube Design of 2C39WA Construction.

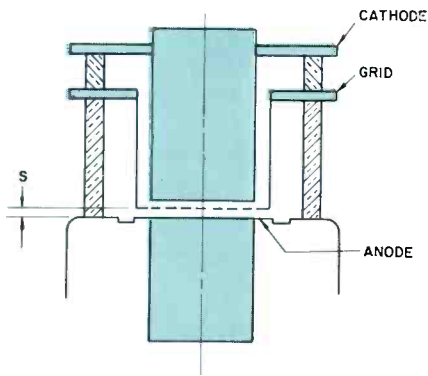


Figure 5A — Planar Tube with Frequency Stable Anode Design as in ML-518 and ML-7855.



Figure 6 — ML-518.

screws vary cavity resonance by variation of end loading capacity. Power transfer from the tripler to the doubler cavity is effected by tapping the plate line at a maximum point.

The final or doubler stage is similar, in characteristics, to the tripler stage. The output, of approximately 6.0 watts, is coupled to the load by means of a loop.

ML-518

The ML-518 is a UHF planar triode employing a frequency stable anode, and high alumina ceramic insulation. Designed to operate as an oscillator, amplifier and frequency multiplier, the tube has a maximum frequency rating of 2500 Mc. Smaller in overall height than the typical Machlett planar triode, the ML-518, which has a maximum plate voltage of 600 v, provides a dimension "A" (bottom of cathode connection to top of anode) of a maximum of 1.507 inches; this compares to dimension "A" of the ML-7855 of 1.815 inches, and which has a maximum plate voltage of 1000 volts.

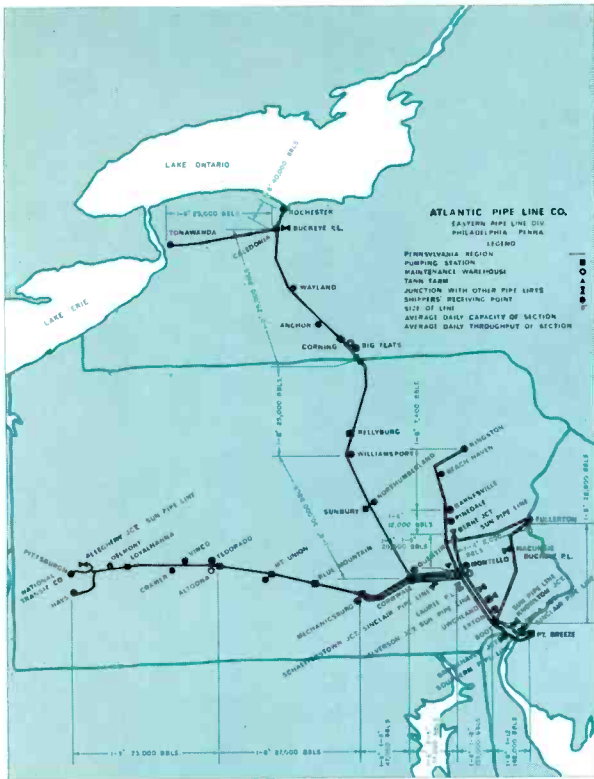
The frequency stable anode effectively eliminates the drift problems associated with conventionally designed tubes used intermittently or required to perform after a 45 seconds warm-up time following cathode temperature stabilization. In the typical planar triode the initial thermal changes effect a difference in grid-anode capacitance. This, in turn, creates a frequency shift, the initial magnitude of which may run into tens of megacycles. With the frequency stable tube, such as the ML-518, frequency drift is small, initially, tens of kilocycles, and stability is achieved within a few seconds. Conventionally, frequency stability does not occur until several minutes — perhaps 15 or more — after application of plate voltage.

In Figure 6 a schematic view is shown of the typical re-entrant anode design. Factors causing anode expansion, hence those that affect frequency shift, are the re-entrant distance of the anode, its material and the temperature change from the initial condition. Re-design of the anode structure, schematically shown in Figure 6, results in a structure whose anode is almost unaffected by thermal changes.*

• • •

The Machlett Laboratories' strong position in specialized electron tube offerings is well exemplified by its UHF planar triode group. Planar types for pulsed service, quick warm-up, high cathode current, or for frequency stability, are now established catalog items. In outer space, or in the inner air space — wherever communications requirements are the most stringent and the design problems most exacting — Machlett planar triodes will be found in operation.

*Both the ML-518 and ML-7855 (operates at higher plate powers) provide stability of operation in telemetry circuits or where voltage fluctuation is a possibility, because of the use of light unregulated supplies. For example, in pulse coded use differing duty cycles will affect the power dissipated by the anode, hence the anode temperature. The frequency stable tube will not be significantly affected by such changes.



Atlantic Pipeline Company:

Microwave User Since 1949

Introduction

Pipeline and other right-of-way companies, confronted with the complex problems of scheduling, precise timing and transmission of varieties of essential data, turned early to the use of private microwave communications. Utilizing circuits and components first developed during the early '40's various equipment manufacturers had readied reliable microwave units by 1948-1949. In 1949 the first privately owned microwave system was installed by the Keystone Pipe Line (now the Atlantic Pipe Line) in five stations between Philadelphia and Reading, Pennsylvania. Soon thereafter, other pipelines became enthusiastic pioneers in this new field of electronics. Continuous growth since this time has seen the installation of nearly 30,000 miles of microwave network by over 100 individual companies.

Utilizing a two thousand megacycle system, Atlantic Pipe Line has generated hundreds of thousands of hours of tube life in a communications system which has grown to 25 stations since 1949. In doing so it has not only developed highly systematized and useful maintenance techniques, but has achieved significant performance criteria through the many records it has kept. Planar triodes are employed in Atlantic Pipe Line's microwave rf equipment as frequency multiplier, transmitter final output and as receiver local oscillator tubes. Of the types used, two manufactured by The Machlett Laboratories — ML-2C39A and ML-3CX100A5 — have seen extensive service. Typical field tube life, as will be noted in more detail below, approximates two years or nearly 16,000 hours.

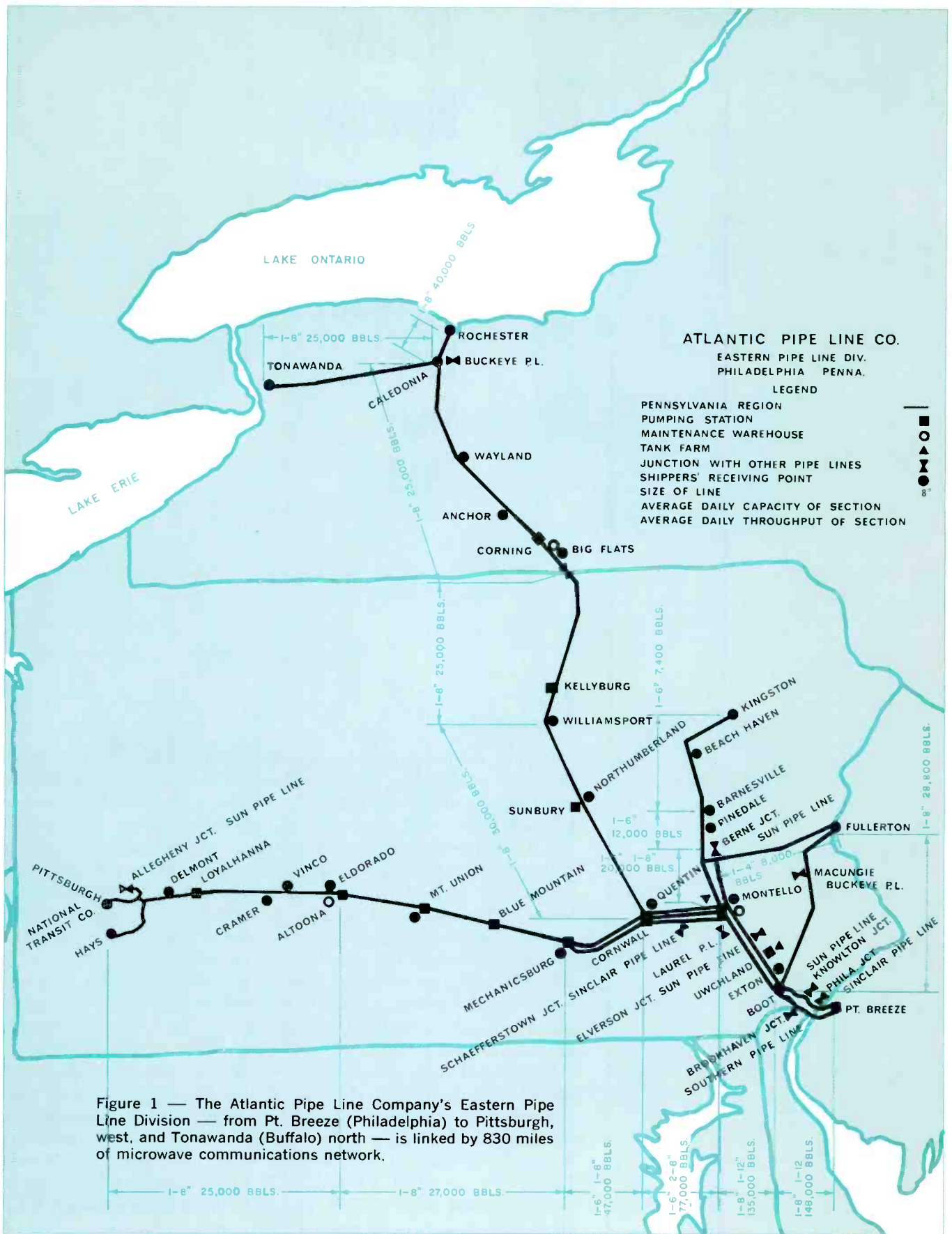


Figure 1 — The Atlantic Pipe Line Company's Eastern Pipe Line Division — from Pt. Breeze (Philadelphia) to Pittsburgh, west, and Tonawanda (Buffalo) north — is linked by 830 miles of microwave communications network.

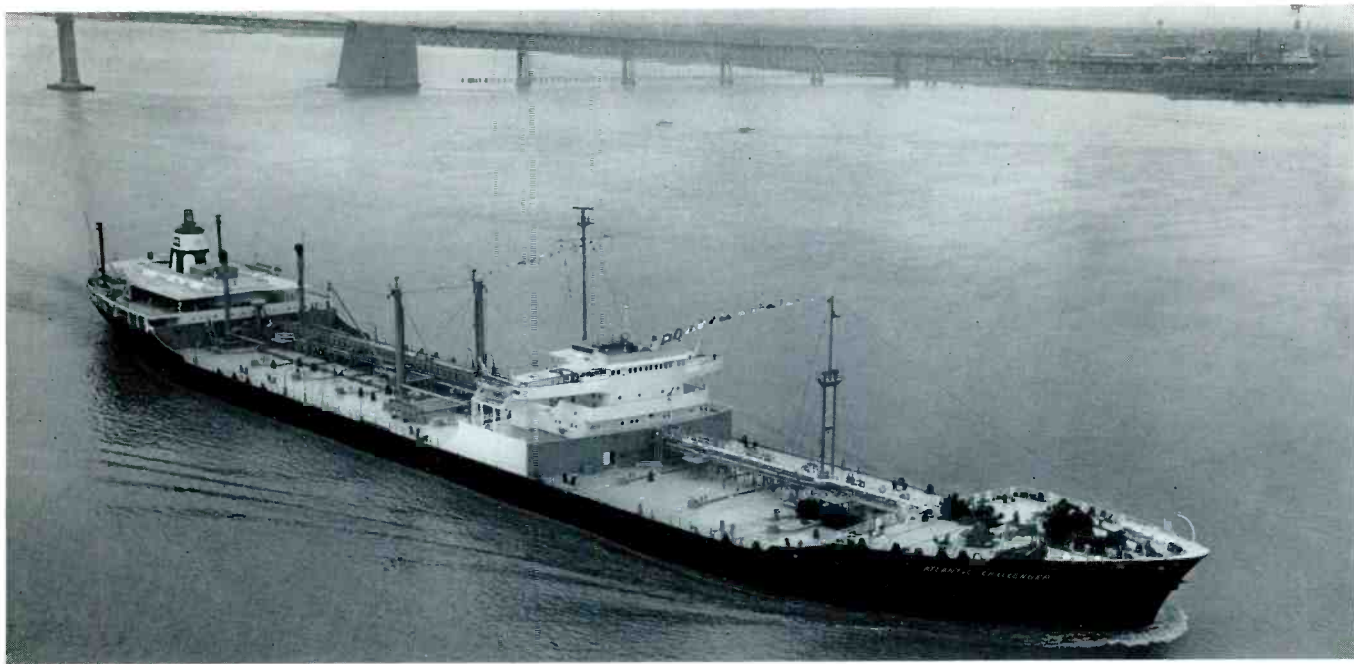


Figure 2 — The S. S. Atlantic Challenger, on its maiden voyage from Venezuela, in 1962, passes under the Walt Whitman Bridge in Philadelphia. 743 feet long, 105 feet in breadth, this huge tanker can bring a maximum of over a million tankfuls of gasoline to the Company's eastern terminus.

S. S. ATLANTIC CHALLENGER
 (the newest and largest Atlantic Refining Co. tanker)
 Length Over All, 743 feet; Breadth, 105 feet; Deadweight, 48,000 tons; Maximum Cargo Tank Capacity, 413,000 barrels (42 gallons per barrel); and Speed, 17.5 knots per hour.

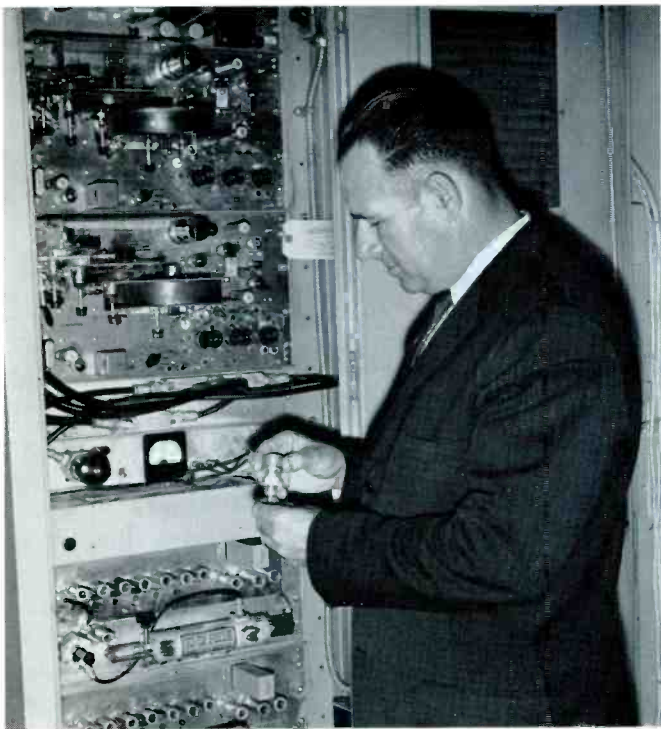


Figure 3 — Mr. L. R. Yoder, Communications Supervisor, inspects an ML-7289/3CX100A5 at the Company's Broad Street (Philadelphia) microwave station.

A Pipe Line System: Continuous Performance

The Eastern Division of the Atlantic Pipe Line Company has a potential throughput of 5,500,000 gallons of petroleum distillates daily. Taking its supply from nearby refineries and marine tanker terminals the Point Breeze Pump Station in Philadelphia receives petroleum products destined for Scranton, Pittsburgh, Buffalo and Rochester, as well as intermediate points and interconnecting pipelines to Cleveland, Ohio and Syracuse, N. Y. Strategically placed pumping stations, operating at pressures up to 1200 lbs. per square inch, move refined oils, gasoline and butane over the Appalachian ridges of central and northern Pennsylvania and up into Western New York State. The daily variety of fluids in the line normally consists of furnace oil, kerosene and various grades of gasoline from a number of shippers. A typical day in the Eastern Division will find as many as 20 separate batches of different products in the line, and an average of 30 deliveries to the 63 delivery points along the system.

To avoid the unhappy result of providing a shipper with several thousand gallons of fuel oil when his needs called for high test gasoline — and even more, to provide the shipper with all the furnace oil he needs when, for example, sudden heating demands require it — calls for painstaking plotting of demand curves on hourly schedule charts of wall sized magnitude. Operating on a three week lead time, deliveries are scheduled to the five minute period.



Figure 4 — Pumping station at Caledonia, New York, at the junction in the line between Tonawanda and Rochester.

Communications: Reliability, Flexibility On Demand

A pipeline requires a variety of communications circuits to meet its daily needs. Point-to-point voice circuits for dispatching and administrative use, remote control of mobile radio base stations, telemetering and remote control of unattended pump stations, alarm and signal systems all go to make up the complex of communications. Rapid pipeline response under critical conditions requires not only rapid communications (as nearly instantaneous as possible) but also the highest order of reliability.

The typical Atlantic PTM microwave equipment provides up to 45 audio channels of 3.5 Kc each. Each voice signal modulates the time of occurrence of a video pulse. These pulses, in turn, amplitude modulate a 1900 Mc transmitter

having output rf power of up to forty-five watts peak. Without the continued, effective functioning of these microwave units, Atlantic Pipe Line could not, except with extreme difficulty, operate properly. Reliable communications require a continuous maintenance surveillance — preventive medicine, so to speak — to keep the system in top operating condition.

Atlantic must keep in peak operating trim 25 microwave transmitting-receiving stations located at 20 to 50 mile intervals. All are unattended. All of them, of course, require towers (up to 200 feet) and feed lines of varied length. Almost all have standby generators for power fault conditions. System maintenance, including the maintenance of associated tone, control, telemetering, telephone units, etc., is obviously no simple task. It requires its own precise schedul-

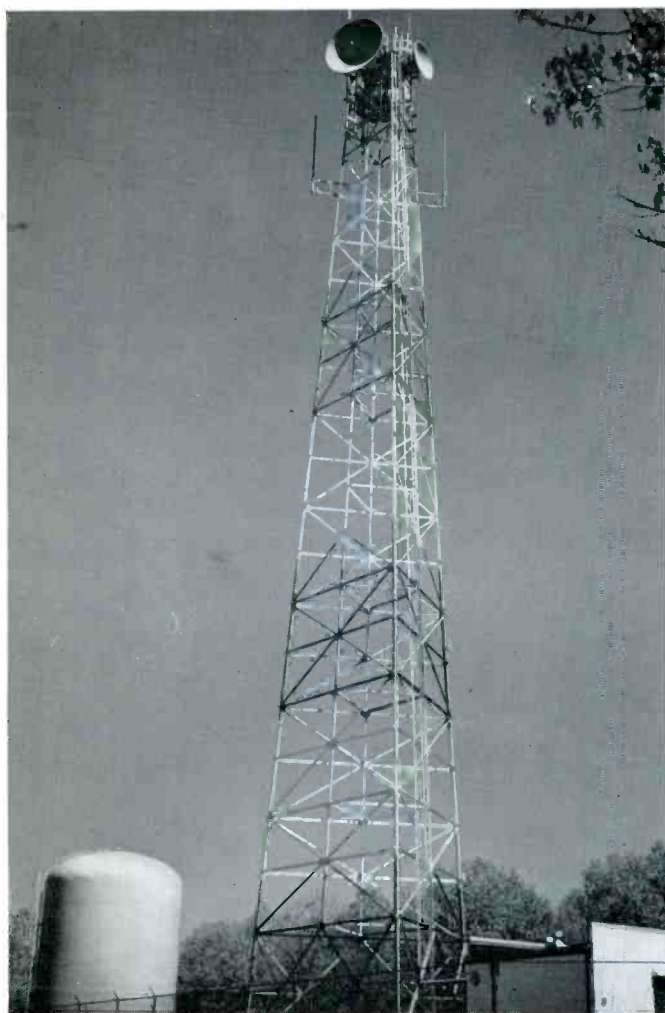


Figure 5 — Valley Forge Microwave Station, unattended operation here is typical of the Company's many installations.

ing and planning. Basic to the maintenance program is the prevention of system outages by the elimination of tube difficulties. Three important factors are operative here: (1) The "pre-signalling" provided by the microwave rf planar triode (2) The extensive records and tube history kept by Atlantic (3) The purchase of the most reliable available electron tubes.

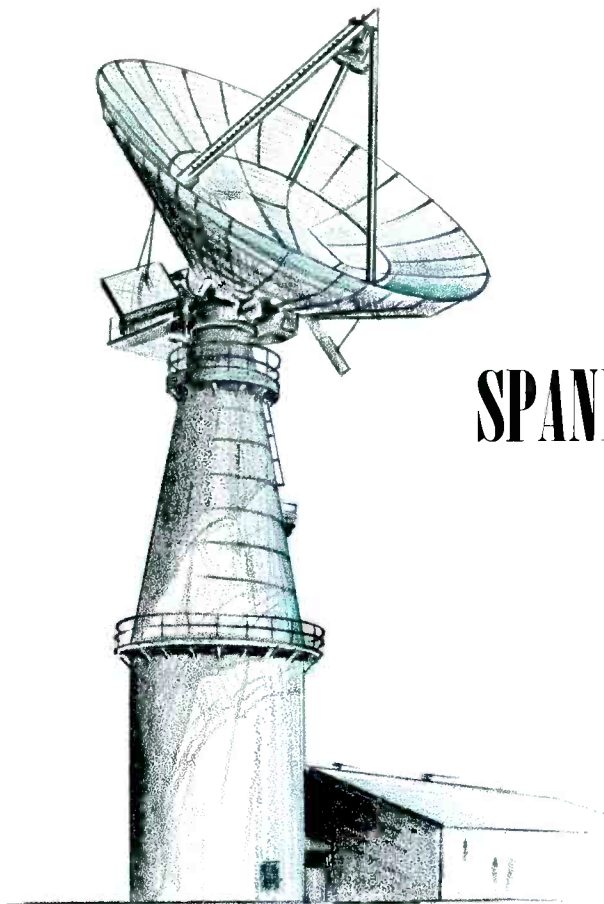
The typical planar tube complement in Atlantic's microwave transmitters consists of three tubes in a multiplier chain (450 Mc, 960 Mc and 1900 Mc) and a final tube at carrier frequency. A planar tube is also used as a local oscillator in the receiver. Since cathode heating power is the single most important factor in planar tube operation, insofar as long life is concerned, precise attention was paid to this matter by the equipment designer, ITT Kellogg. At



Figure 6 — ML-7289/3CX100A5.

the low end and middle of the multiplier chain 5.5v is maintained at the heater terminal; at the high end 5.3v is maintained. Since thermal stability is also of great importance in the maintenance of long tube life, heater power is never shut off except for emergency repairs. Under these conditions, Atlantic finds that the ML-2C39A, used in the first two stages, averages 16,000 hours and the ML-3CX-100A5, used in the higher frequency stages, averages 13,000 hours.

Individual planar tube replacement is kept at an economical minimum, commensurate with the needs of reliability by observing the gradual change of cathode current level. Monthly monitoring of tubes provides this data as well as other information. Tube breakage is almost nil. Field spares are one tube for each four in service.



SPANDAR: NASA's Long Range Tracking

By JAMES S. WALSH, Senior Engineer,
Equipment Division,
Raytheon Company



JAMES S. WALSH

James S. Walsh joined the Raytheon Company in 1956 and has, since then, been active in the field of radar transmitters. Now a Group Leader (Transmitter Section, Range Instrumentation and Surveillance Dept., Surface Radar and Navigation Operation, Equipment Division) Mr. Walsh has had a comprehensive experience which includes work with: hard-tube and hydrogen-thyratron circuits and components; high-stability pulsed coherent amplifier chain transmitters; magnetron, amplatron, klystron, triodes, tetrodes and traveling wave tubes; and instrumentation for measuring time and phase stability of high stability mti radar transmitters. Mr. Walsh, who received his A.E.E. degree from North-eastern University, was the project engineer on the NASA Spandar Transmitter.

Introduction

SPANDAR is the National Aeronautics and Space Administration's long range tracking radar at Wallops Station, Wallops Island, Virginia. The SPANDAR radar system is a successful integration of system components designed by various equipment manufacturers and assembled (with some equipment modifications) by NASA and Lincoln Laboratory engineers and scientists. The antenna, pedestal and tower are similar to those employed in Lincoln Laboratory's Millstone Hill radar; the range unit is a modified Reeves-Verlot unit; the transmitter was designed, constructed, and installed by the Raytheon Company to NASA specifications, written specifically for the SPANDAR system.

Long range tracking of rockets is accomplished primarily by three means; the conventional skin tracking in which tracking is accomplished by employing the return of a signal reflected from the surface of the vehicle transmitted by the ground based radar; beacon tracking in which tracking is accomplished by employing a signal emitted from a rocket-borne transponder, when the transponder is interrogated by a ground based radar; and telemetering tracking in which tracking is accomplished by employing a telemetering signal emitted from equipment borne by the missile. A ground based radar transmitter is not required for the last of these techniques.

The three techniques mentioned each have their advantages and disadvantages and are usually employed to complement one another. The primary advantage of skin tracking is its independence of rocket borne equipment, and the fact, therefore, that it can provide tracking in the event of rocket borne equipment failure.

Radar Transmitter — Its Design and Performance



Figure 1 — NASA's SPANDAR, long range tracking radar, at Wallops Island, Virginia, employs a Raytheon designed, constructed and installed radar transmitter using the ML-7560 as a modulator switch tube. Shown here are the 60-foot parabolic antenna and 90-foot tower of the installation.

Design and Performance Features of SPANDAR

The primary role of SPANDAR, a skin tracking radar, is the long range tracking of rockets or other space vehicles. The system is also equipped with instrumentation for beacon tracking. The antenna system includes a 60-foot diameter parabolic dish mounted on a 90-foot tower. (Figure 1). Acquisition is accomplished either from data supplied by a manually operated optical tracker, or by data supplied from other smaller, shorter range radars.

The performance of the integrated SPANDAR system has been outstanding. SPANDAR has provided skin tracking ranges of approximately three times other Wallops Island radars. Figure 2 is a plot of the track of a JAVELIN vehicle launched from Wallops Island. SPANDAR has tracked the fourth stage of a SCOUT rocket launched from Wallops Island for over 1,000 nautical miles. SPANDAR also tracked the Echo II balloon launched from Cape Canaveral to horizon impact.

The SPANDAR transmitter produces five megawatts of peak power and ten kilowatts of average power at S-Band over the frequency range of 2700 to 2900 Mc. Some of the more salient transmitter features are:

- A. Broad-Banded — needs no tuning over the frequency range of 2700 to 2900 Mc.

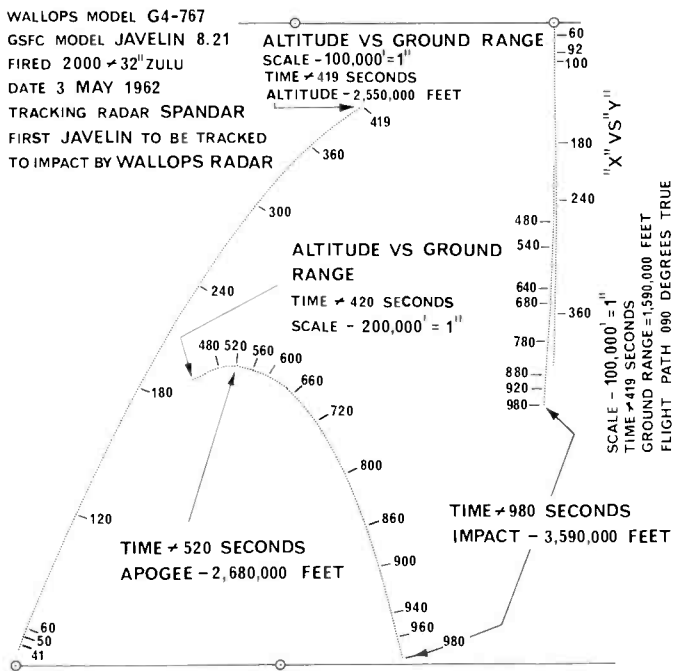
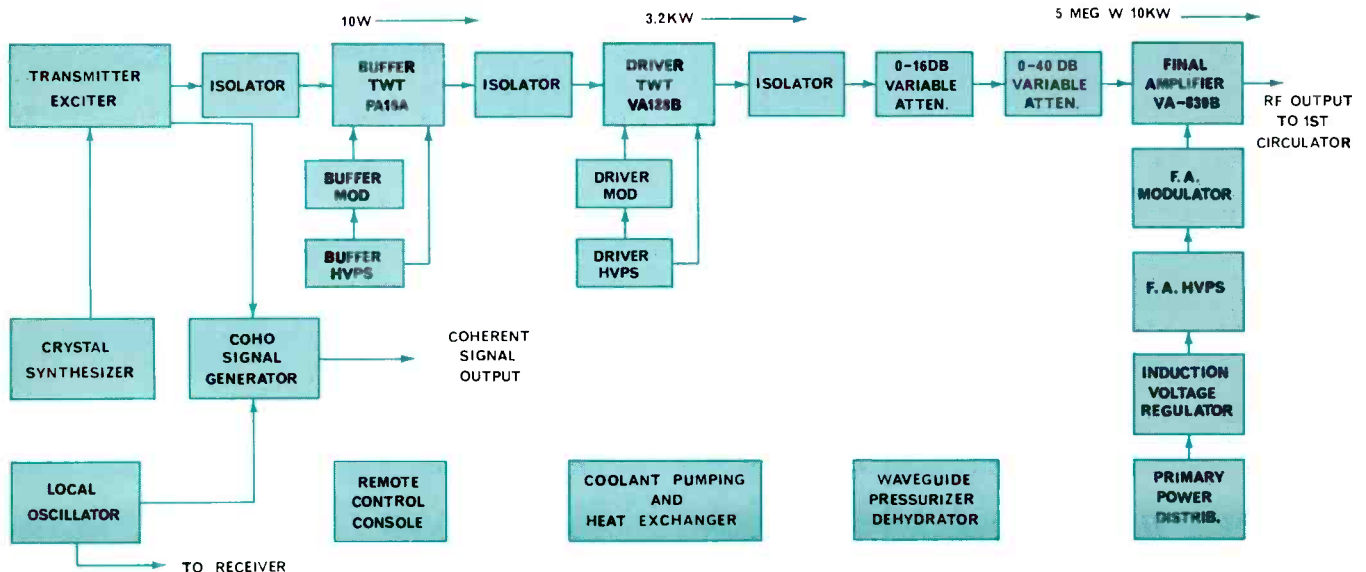


Figure 2 — Plot of a track, made by SPANDAR, of the JAVELIN vehicle.

- B. High Frequency Stability — 1 part in 10^9 short term, 1 part in 10^6 long term.
- C. Continuously Adjustable Output Power — from full output to -40 db.
- D. Continuously Adjustable Output Frequency — from 2700 to 2900 Mc in 100 kc steps.
- E. High Output Frequency Precision — Five (5) fixed transmitter frequencies are provided to a precision of one part in 10^7 .
- F. High Phase Stability — The pulse-to-pulse transmitter phase stability is 0.5 degrees peak-to-peak maximum.
- G. Fast Rise and Fall Times — The rf output pulse rise and fall times are 50 and 100 nanoseconds respectively.
- H. Pulse Coding — The transmitter can produce three one- μ sec pulses, two two- μ sec pulses or one five- μ sec pulse. The time between pulses can be continuously varied between six and forty microseconds or time-tone modulated for beacon tracking purposes.
- I. Pulse Repetition Frequency — 200 to 400 pps.
- J. Power Programming — The transmitter output power can be programmed to vary inversely as the square of the target range from full output power at a target range of 200,000 yards, to -40 db at zero target range to provide protection for "on-board" receiving equipment.
- K. Remote Control — A remote control console is provided for complete transmitter remote control and monitoring.
- L. Local Oscillator — The transmitter is provided with a highly stable local oscillator at a frequency 30 Mc

Figure 3 — Block diagram of SPANDAR Transmitter.



removed from the transmitter frequency for receiver use.

M. Coherent Output Signal — The transmitter provides a highly stable coherent output signal at 30 Mc for all transmitter frequencies.

Figure 3 is a block diagram of the SPANDAR transmitter. As shown in the block diagram, the transmitter is a Master Oscillator-Power Amplifier type system employing three power amplifier stages in cascade. Pulse shaping and power programming are performed in the driver amplifier stage.

Details of the microwave system following the output of the final amplifier have been omitted and will be described separately.

Transmitter Design Details

Final Amplifier Stage

The final amplifier stage employs a Varian Associates VA-839B klystron as the microwave power amplifier pulsed by a hard tube modulator through a pulse transformer. The modulator pulse is designed to overlap in time the rf drive pulse for all transmitter pulse widths, thereby causing the output rf pulse waveform to be determined by the rf driving pulse rather than the modulator video pulse. This technique simplifies the design of final amplifier modulator at the expense, of course, of final stage efficiency. The klystron operates at a peak voltage of 140 kv at 104 amperes. The

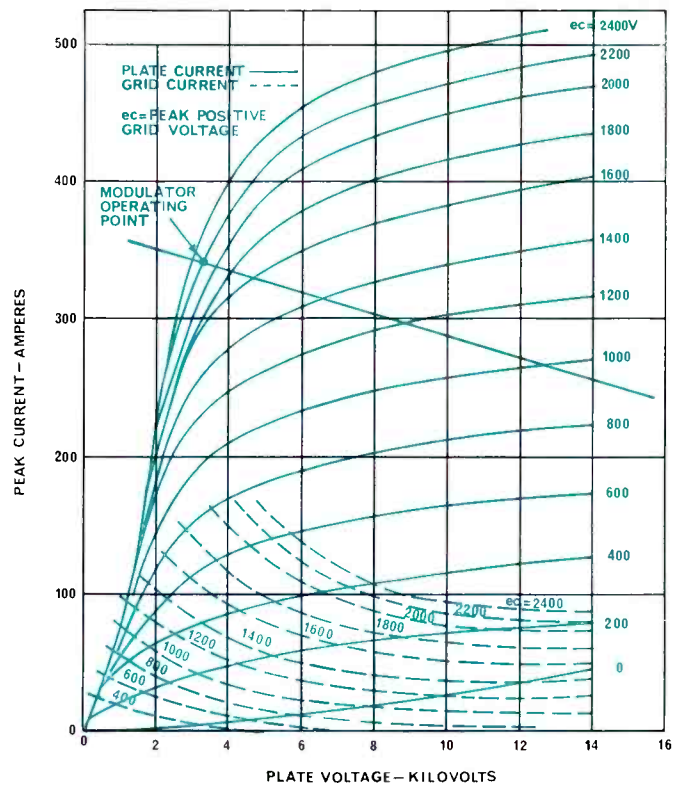
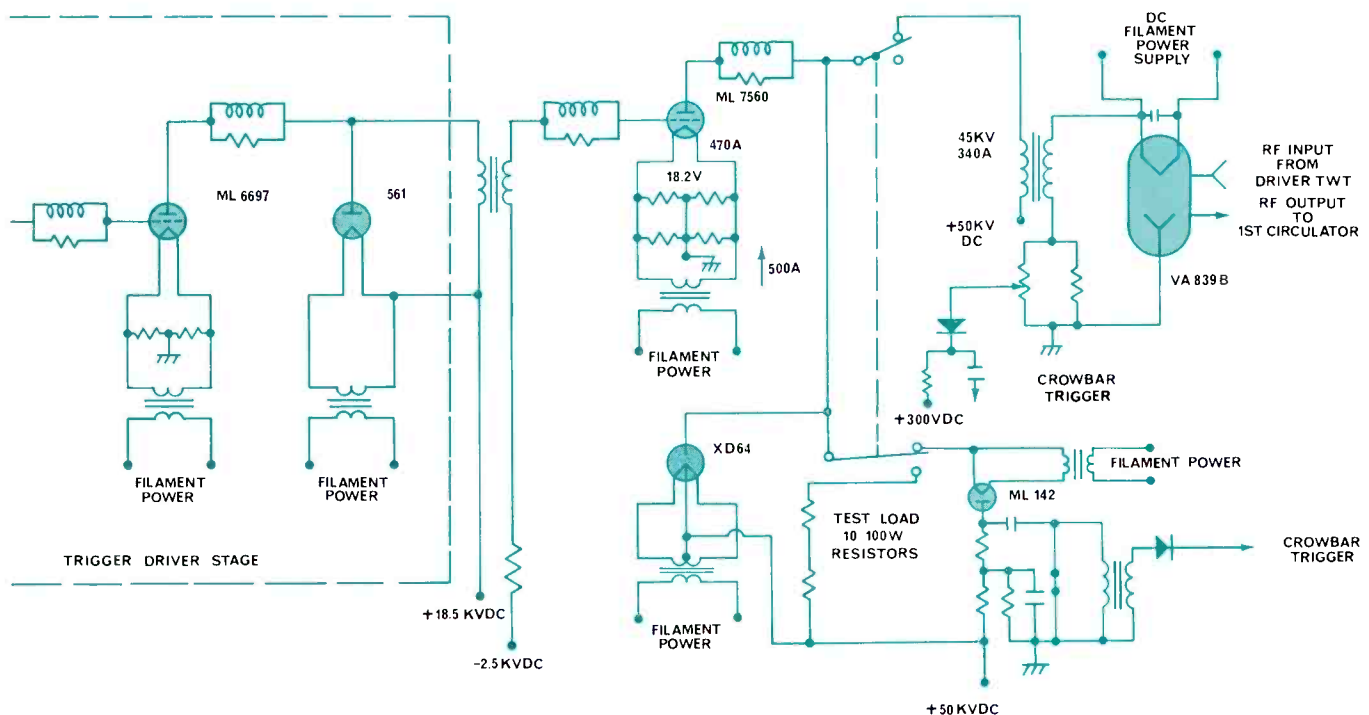


Figure 5 — Plot of ML-7560 plate characteristics with modulator operating point and load line included.

Figure 4 — Simplified schematic of final modulator amplifier.



klystron efficiency is 34% with a power gain of approximately 35 db. Klystron beam focusing is performed by a four-coil electromagnet supplied by four current-regulated and individually adjustable power supplies. The klystron and its electromagnet are mounted on top of the modulator output pulse transformer, and the entire assembly is packaged within a retractable lead enclosure for x-ray protection. Cooling of the klystron and its electromagnet is accomplished along with other transmitter components by a closed-loop cooling system (see Figure 12).

Final Amplifier Modulator

The final amplifier modulator design problem was the most difficult encountered in the overall design of the transmitter. The design was made significantly simpler, however, by the use of a Machlett ML-7560 triode amplifier as the switch tube. Through the use of the ML-7560 it was possible to switch the full peak and average power of 15.7 megawatts and 37 kilowatts, respectively, with a single modulator switch tube. In fact, the modulator employing a single ML-7560 triode is capable of producing 25% more power than is required by the final amplifier. This feature provides both a conservative safety margin for present final amplifiers as well as considerable growth potential for possible future final amplifiers. Figure 4 is a simplified sche-

matic of the final amplifier modulator showing the principal voltages and currents of interest. The ML-7560 is operated at 48 kVdc and produces an output pulse of 45 kv at 340 amperes across the primary of the output pulse transformer. The ML-7560 is driven by a trigger driver which provides a grid pulse of 2.2 kv positive at 205 amperes. Figure 5 is a plot of the ML-7560 plate characteristics with the modulator operating point and load line included. The ML-7560 is driven into saturation to reduce the trigger driver pulse voltage droop, ringing, and ripple being transferred to the output pulse. This technique simplifies the design of the trigger driver and its power supply. Figure 6 is a photograph of the ML-7560 mounted in the modulator cabinet. Also shown in the photograph is the final stage of the trigger driver which employs a Machlett ML-6697 triode as the switch tube. The ML-7560 is water cooled, with a ceramic crock connected in series to provide a 30-foot column of water for insulation purposes.

Output Pulse Transformer

The modulator configuration shown in Figure 4 has advantages from the point of view of modulator design, (for example, the cathode of the ML-7560 is held at ground potential, therefore permitting the trigger driver to be

Figure 6 — ML-7560 in modulator cabinet; shown also is ML-6697 switch tube.

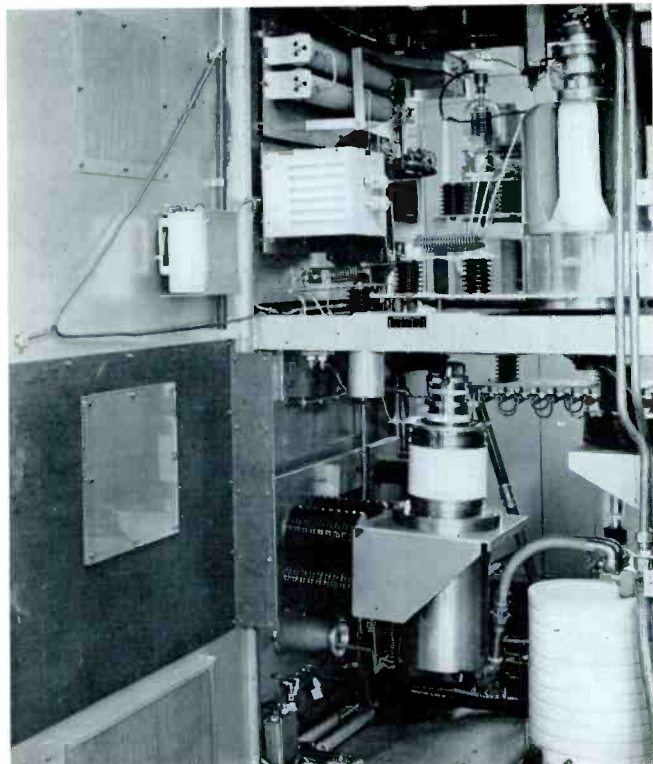
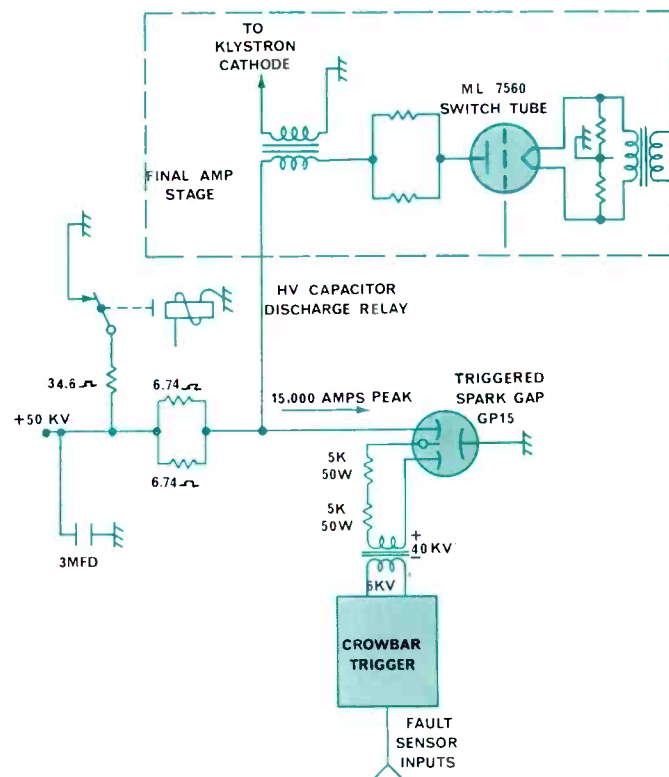


Figure 7 — Simplified schematic of crowbar circuit used to protect klystron and modulator tube.



grounded), but, however, presents a problem from the point of view of pulse transformer design. The modulator configuration chosen requires that the pulse transformer be designed for 50 kVdc between primary and secondary which requires, of course, a relatively large spacing between transformer primary and secondary. This large spacing creates a relatively high transformer leakage inductance. The combination of this high leakage inductance and the high energy being switched results in significant energy being stored in the leakage inductance at the end of the output pulse, as much as 3 joules. Since a modulator is generally designed to gate off the switch tube abruptly, this stored energy will produce an extremely high voltage backswing at the plate of the modulator switch tube, ML-7560. This backswing voltage is difficult to clip by conventional clipping diodes since the primary current flowing just before the end of the output pulse is 340 amperes and this current must be picked up by the clipping diode. The backswing voltage will add to the power supply voltage causing the plate voltage on the ML-7560 to go as high as 100 kv. This, clearly, would be an intolerable situation. The fact that the ML-7560 has ample reserve plate dissipation, under the modulator operating conditions, provided the solution to this dilemma. The ML-7560 is gated off more slowly allow-

ing the energy stored in the leakage inductance to be dissipated primarily in the ML-7560 plate. An ML-7560 plate circuit fall time of approximately $0.5 \mu\text{sec}$ is required to accomplish this. This technique somewhat increases the dissipation in the klystron collector due to the increased fall time. The usual backswing related to the energy stored in the transformer magnetizing inductance is handled by the conventional backswing clipping diode. Other modulator configurations such as grounding the pulse transformer primary and "floating" the switch tube were considered, but discarded due to the complexities of the trigger driver design and packaging.

Final Amplifier Trigger Driver

The final amplifier trigger driver is required to pulse the ML-7560 grid to a positive voltage of 2200 volts peak at a current of 205 amperes, and to overcome the negative 2500 volts bias applied to the ML-7560 grid. An output pulse, therefore, of 4700 volts is required at 205 amperes or approximately 1 megawatt peak power and 2.3 kW average power. The entire trigger driver was designed to operate from a single high voltage power supply. A Machlett ML-6697 was employed in the final stage of the trigger driver and provides the required driving pulse with ample plate current and plate dissipation margin to assure long tube life and reliable operation.

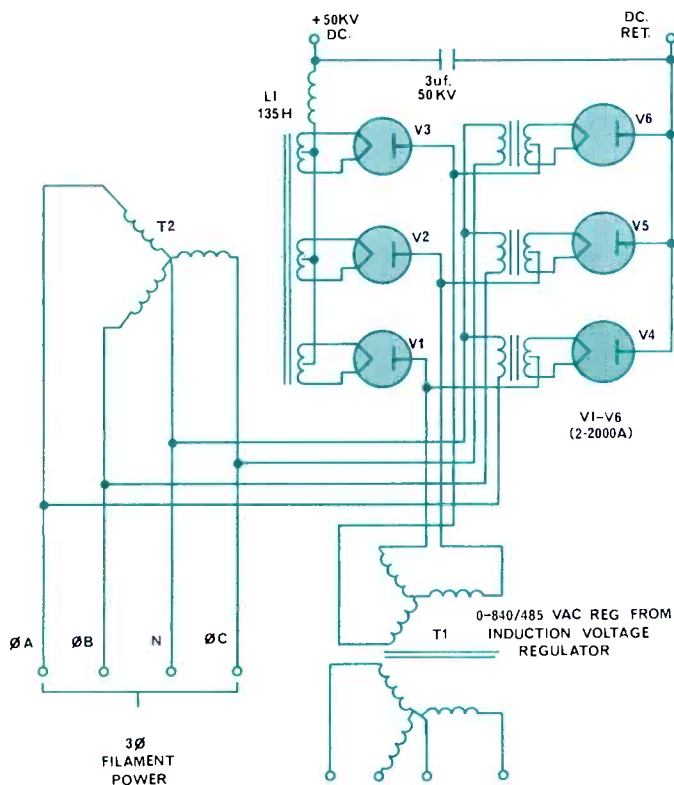
Final Amplifier Bias Circuit

A single supply is provided for biasing the various stages of trigger driver and modulator. The major problem in the design of a bias supply is the reverse current flowing into the supply as a result of the high grid currents being drawn in the modulator and trigger driver grid circuits. As much as 0.5 amperes average reverse current is produced by the ML-7560 alone. This current, of course, varies directly as the modulator pulse repetition frequency and the pulse width. To provide proper regulation, the bias supply employs a "brute-force" technique, using a heavy bleeder current to "swamp" the effects of varying grid return currents.

Modulator Fault Protection

When voltages in the order of 50 kVdc and 140 kv pulse are employed it should be expected that there may be an occasional spark in the vacuum tubes such as the klystron and switch tube. Because of the very high energy stored in the high voltage power supply output capacitance for a modulator of this type, such a spark would be catastrophic unless suitable protection circuitry is provided. Figure 7 is a simplified schematic of a "crowbar" circuit included to provide this protection. The circuit short circuits the output of the power supply and discharges the power supply energy storage capacitors in the event of a power supply load fault. The crowbar reaction time is approximately two μsec when triggered from either of two fault detection circuits. The fault detection circuits sense switch tube voltage drop and

Figure 8 — Simplified schematic of high voltage power supply.



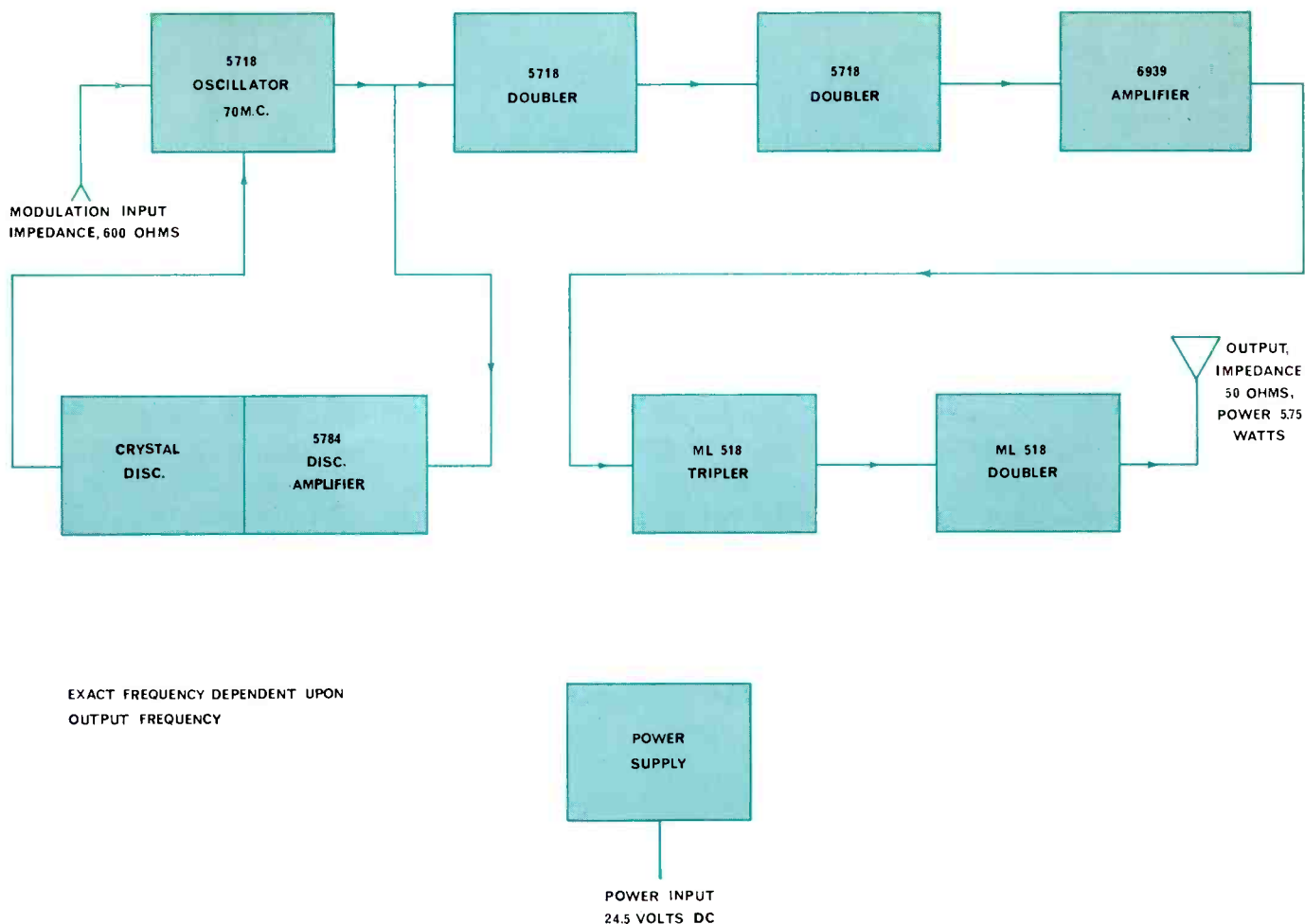


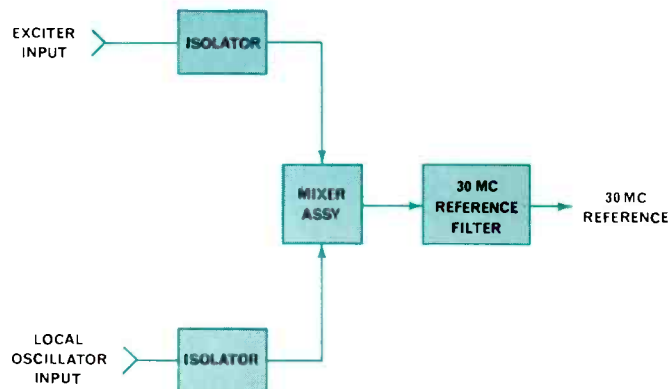
Figure 9 — Block diagram of transmitter exciter.

peak klystron current. In the event of a switch tube spark, the switch tube voltage drop will decrease to nearly zero. This action will trigger the crowbar circuit and short circuit the power supply output voltage. Since, under these conditions, the pulse transformer is between the switch tube and the crowbar, the switch tube circuit will appear as a relatively high impedance compared with the crowbar triggered spark gap and the current will stop flowing in the switch tube and will be conducted to ground by the spark gap. In the event of a klystron arc the peak klystron current will increase above its normal limit. This will also result in triggering of the crowbar and short-circuiting of the power supply output voltage.

ML-7560 Filament Circuit

The ML-7560 employs a thoriated-tungsten filament-cathode which draws 450 amperes of heater current. The presence of this relatively high heater current plus approximately 550 amperes of pulse cathode current presents some interesting filament circuit problems. It is desirable to provide a pulse current path that creates approximately equal pulse current in the two filament conductors. The conventional means of accomplishing this is to ground the center

Figure 10 — Block diagram of coherent signal system for data processing equipment.



tap on the heater transformer secondary and bypass the two ends of the secondary to the center tap with capacitors to provide equal low impedance paths to ground for the pulse cathode current. Since the voltage developed across these capacitors due to the current flowing during the pulse subtracts from the switch tube grid driving voltage, droop in the output pulse voltage is created. The standard technique to reduce this problem is to provide sufficiently large capacitors to reduce this voltage build-up to some reasonable value. With 550 amperes of pulse cathode current, however, the size of these capacitors becomes too large to be considered. Instead of bypass capacitors, 0.45 ohm bypass resistors are employed. Approximately 110 volts is subtracted from the grid driving voltage as a result of pulse current. This voltage is, however, a constant during the pulse and does not create voltage droop in the output pulse. This technique would be prohibitive in terms of power loss in circuits employing switch tubes which consume a relatively small amount of heater power since approximately 300 watts is dissipated in these resistors due to the filament voltage across them alone. This power loss, however, represents only 5% of the heater power of the ML-7560 and is, therefore, not significant. Figure 4 includes the filament circuit showing the voltage and currents of interest. This same technique is also employed in the filament circuit of the ML-6697 in the trigger driver.

Switch Tube Dummy Load

During the installation of a new ML-7560 into the modulator it is desirable, initially, to pulse the tube into a high impedance, low current load instead of its normal high current load. This is because a new tube is likely to spark more frequently at first due to shipping shocks and vibration. A 30,000 ohm resistive dummy load is included in the final modulator for this purpose. During operation into the dummy load the crowbar triggering circuit is disconnected to allow the ML-7560 to spark without triggering the crow-

bar. This procedure allows the sparks to burn out at a safe current level without damage to the ML-7560.

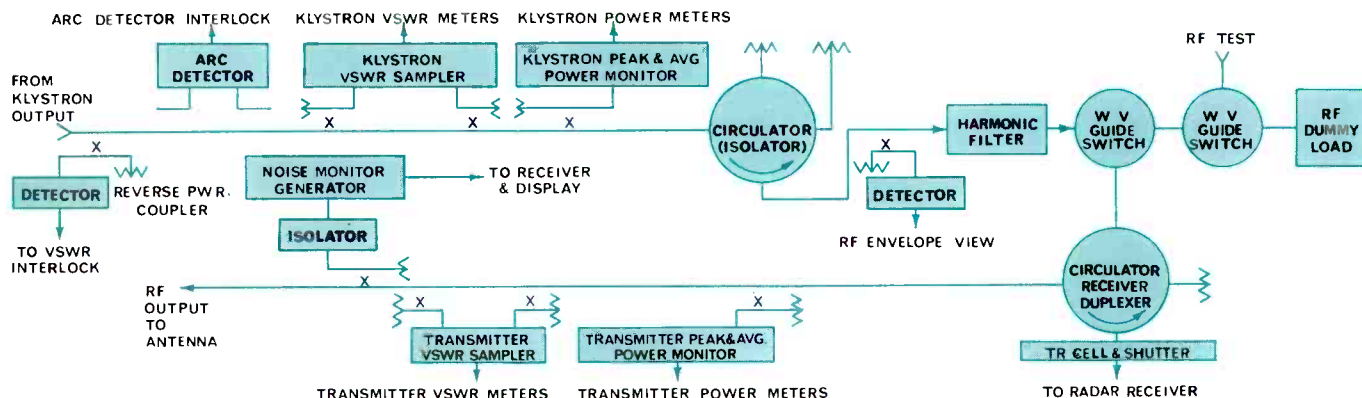
Final Amplifier High Voltage Power Supply

The final amplifier high voltage power supply is designed to deliver up to 50 kVdc at currents up to 1.2 amperes. The power supply is designed to have a maximum output ripple voltage of 0.05% and to have a maximum short circuit current of 20 amperes. The dc output voltage is regulated to within $\pm 1\%$ by an induction voltage regulator controlling the primary voltage supplied to high voltage power supply. The induction voltage regulator is controlled by a differential circuit that senses the high voltage output and compares it to a reference voltage which is produced by a corona regulator tube. Figure 8 is a simplified schematic of the high voltage power supply.

Driver Amplifier Stage

The driver amplifier stage employs a Varian Associates VA-128B TWT as the microwave power amplifier. The VA-128B produces 3.2 kW peak power to drive the final amplifier, at a gain of approximately 33 db. The VA-128B is provided with a modulating grid and, therefore, can be modulated with a low power, high performance modulator. The modulator produces a 900 volts peak pulse with a rise time of less than 50 nanoseconds and a fall time of less than 100 nanoseconds. The top of the modulator pulse voltage is clipped to provide an extremely rectangular flat top driving pulse to the VA-128B grid. The high voltage power supply for the driver amplifier stage is a negative, electronically regulated supply with an output ripple of less than 100 millivolts. Two variable attenuators are provided in the microwave link between the driver and final amplifiers. The first attenuator provides for adjustment of the peak rf drive power to the final amplifier. The second performs the function of the power programmer which varies the transmitted

Figure 11 — Block diagram of SPANDAR transmitter microwave system.



output power from full output to -40 db.

Buffer Amplifier Stage

The buffer amplifier stage employs a Huggins PA-10A TWT as the microwave power amplifier. The PA-10A produces 10 watts peak power to pulse the driver amplifier at a gain of approximately 33 db. The width of the rf pulse is designed to overlap the driver amplifier modulator pulse width in time, thereby assuring that the VA-128B TWT has full rf drive throughout the pulse period. The PA-10A is provided with a modulating grid and, therefore, can be modulated with a low power modulator.

Exciter Stage

Figure 9 is a block diagram of the transmitter exciter or master oscillator. As shown in the block diagram five fixed frequency precision oscillators are provided. These oscillators, operating between 4.6 and 4.9 megacycles, provide the transmitter frequency stability of 1 part in 10^9 short term, 1 part in 10^6 long term. The outputs of the five fixed frequency oscillators are multiplied up six times to the vicinity of 28 Mc by five independent multipliers. Also included as part of the exciter is a Manson Laboratory crystal synthesizer which provides a variable frequency over the frequency band of 27 to 29 Mc in 1 kc steps. The output of one of the five multipliers or the crystal synthesizer is then selected through relays to be connected to the input of a one-hundred times broadband multiplier. The X100 multiplier is divided into three stages, the last stage of which is a

X5 varactor multiplier. The output of this multiplier is, of course, at the desired transmitter frequency between 2700 and 2900 megacycles.

Local Oscillator

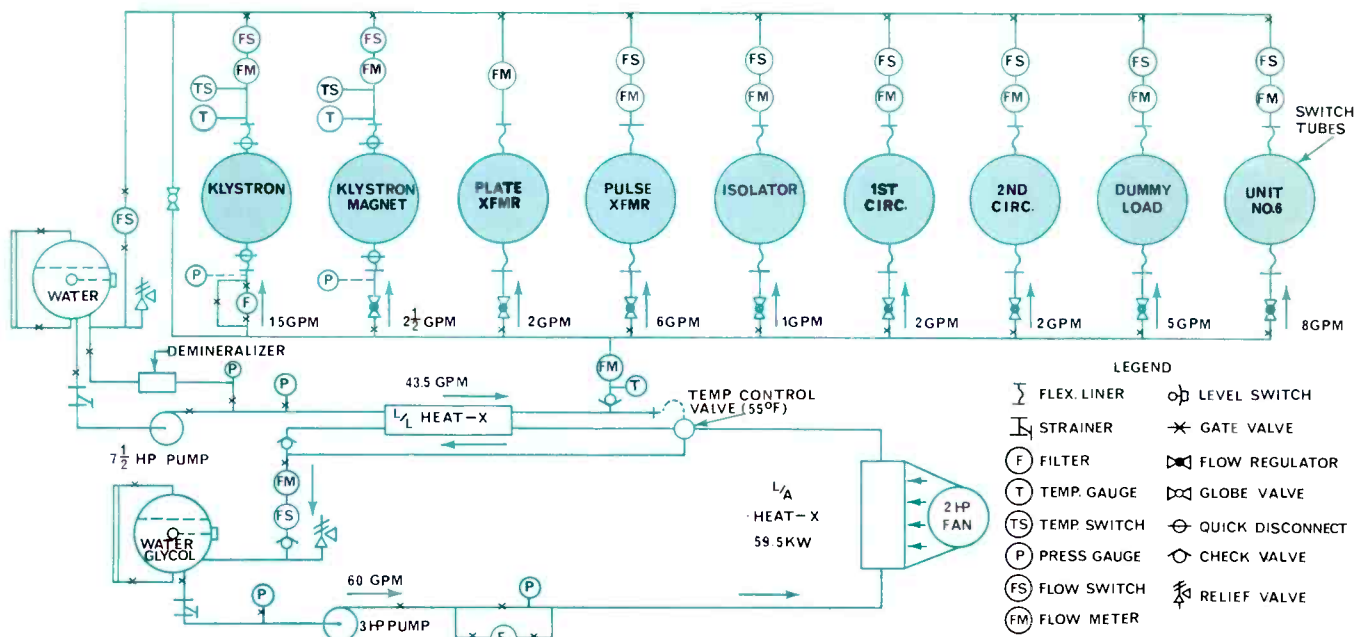
The local oscillator provides an rf signal located 30 Mc above the transmitter frequency. The local oscillator is essentially identical to the transmitter exciter providing the same frequency stability and frequency precision. A Huggins HA-30 TWT is added to amplify the output of the local oscillator to a power level of 100 milliwatts CW. The local oscillator output is used in the radar receiver mixer.

A completely separate local oscillator is employed instead of the more conventional oscillator-mixer configuration to avoid the problem of multiple mixer outputs being introduced into the transmitter channel and being amplified by the broadband transmitter.

Coherent Output

Radar signal data processing frequently requires the use of an IF frequency reference signal that is phase coherent with the transmitted rf signal and the receiver local oscillator frequency. To obtain this signal the output of the transmitter exciter and local oscillator are mixed to produce a coherent output signal at 30 Mc, as shown in block diagram form in Figure 9. The isolators shown are employed to prevent the transmitter frequency from leaking into the local oscillator output and the local oscillator frequency from leaking into the transmitter exciter output, and be, thereby,

Figure 12 — Block diagram of transmitter cooling system showing coolant flow levels in various components of interest.



amplified by the broadband transmitter power amplifiers. Since the coherent signal is derived from the local oscillator and exciter, it has the same frequency precision and stability.

Microwave System

Figure 11 is a block diagram of the SPANDAR transmitter microwave system. Following are brief descriptions of some of the components included.

Arc Detector

A waveguide arc detector is provided to protect the final amplifier klystron from damage due to a possible waveguide arc. The arc detector senses the light of an arc in the waveguide by means of a light sensitive diode. The signal produced is amplified and used to interrupt the trigger to the driver amplifier modulator within one interpulse period.

Klystron VSWR Monitor

The klystron VSWR monitor provides continuous measurement of the VSWR seen by the klystron. A second identical monitor is included at the transmitter output to monitor antenna VSWR. This monitor is also employed during antenna tuning procedures.

Power Monitor

A peak and average power monitor is provided to monitor the klystron output power. The power monitor employs a hot-cathode vacuum microwave diode as a sensing element and provides continuous peak and average power measurement over a 40 db dynamic range in four 10 db steps.

Waveguide Switches

Two waveguide switches are employed to switch among the transmitter dummy load, the output to the antenna and a test port to which test loads can be connected. The rf dummy load provided is capable of operation at full transmitter power.

Receiver Duplexer

A ferrite circulator is included to perform the function of a receiver duplexer. Also included on the receiver arm of the circulator is a receiver protector TR cell and shutter.

Noise Figure Monitor

A noise figure monitor system is included to provide continuous measurement of receiver noise figure.

Waveguide Pressurizer

A waveguide pressurizer-dehydrator system is employed to pressurize the radar waveguide system with clean-dry sulphur-hexafluoride at a pressure of 35 PSIA. The system is the heatless dryer, recirculating type manufactured by Applied Pneumatics.

Cooling System

Transmitter cooling is provided by a two stage closed loop system employing a 50-50 water-glycol solution on the outside of the transmitter building and distilled water on the inside. A liquid-to-air heat exchanger outside the building transfers the heat from the water-to-glycol loop to the outside air, and a liquid-to-liquid heat exchanger, inside the building, transfers the heat from the water system to the water-glycol system. The cooling system is capable of dissipating a maximum heat load of 75 kW at an outside air temperature of 120°F. Figure 12 is a block diagram of the transmitter cooling system showing the coolant flow levels in various components of interest.

Conclusion

The SPANDAR transmitter has fulfilled all of the basic requirements of a transmitter for a long range tracking radar. The transmitter provides a minimum of 5 megawatts across its operating band and up to 7 megawatts in the center of the band. It is completely remote controlled and is equipped with many fault diagnostic type indicators. During the tracking operation of the SPANDAR radar a small control panel in the Master Radar Control console provides the radar operator with all the necessary transmitter controls, such as frequency, pulse width and output power. Frequency and pulse width are changed by a push button control and output power by the turning of a knob.

The transmitter has been in operation at Wallops Island for nearly one year and has logged well over 1000 hours of operation. Although there have been some minor difficulties during the first year's operation, the transmitter has never failed during the tracking of a vehicle.

The same klystron and ML-7560 switch tube are in operation that were in operation when the equipment was accepted by NASA. The ML-7560 has actually improved performance with age. The number of transmitter "kick-outs" due to sparking of the ML-7560 has decreased with time. The problem of possible sparking of the switch tube or klystron caused some concern during the design of the transmitter, particularly if such a spark were to occur during a tracking operation. A fast acting automatic fault clearing circuit was designed to reduce this problem. The fault clearing circuit automatically restores the transmitter to full power output in the event of such a spark during a rocket flight. Restoration of power is complete within 2 seconds after the fault. Testing of this circuit performance has indicated that the radar operator can barely discern that a fault has occurred during the track. Also included is a "flight short" switch which disables all non-critical transmitter interlocks to assure that the transmitter is not shut down during a tracking operation due to a minor failure such as a door interlock.

In conclusion, the transmitter has provided NASA's Wallops Station the power, performance and reliability required for a long-range tracking radar.

New Machlett Developments

With this issue, CATHODE PRESS introduces a new section which will report, in brief, the latest Machlett electron tube designs and improvements.



ML-7480

General purpose, vapor-cooled triode for 50 - 75 kW service to 30 Mc

For industrial heating and AM broadcast applications, the ML-7480 is designed for use as an rf power amplifier and oscillator. Features include: a unique vapor-cooled anode design capable of dissipating 80 kW; a sturdy self-supporting, stress-free, thoriated-tungsten filament; and ceramic envelope, coaxial terminal structure.

Maximum Ratings as RF Power Amplifier and Oscillator Class C Telegraphy

DC Plate Voltage	16000 v
DC Grid Voltage	-3200 v
DC Plate Current	11 amps
DC Grid Current	2.0 amps
Plate Input	140 kW

Typical Operation

DC Plate Voltage	15000 v
DC Grid Voltage	-1600 v
DC Plate Current	7.0 amps
Driving Power, Approx.	0.60 kW
Power Output	80 kW



ML-8317

General purpose, forced-air-cooled triode for 100 kW service to 30 Mc and pulsed applications

Designed primarily for high power, shortwave communications, the ML-8317 is capable of more than 100 kW carrier output in a plate-modulated amplifier. In SSB service, it is capable of 100 kW peak envelope power output under two-tone modulation, and more than 500 kW PEP under 16-tone conditions. In pulse service it is capable of 15 Mw typical output power. Employs high-efficiency radial-fin anode cooler.

Maximum Ratings RF Power Amplifier and Oscillator

DC Plate Voltage	20000 v
DC Plate Current	20 amps
Plate Input	250 kW
Plate Dissipation	60 kW

Maximum Ratings Pulse Modulator or Pulse Amplifier

DC Plate Voltage	50 kv
Peak Plate Voltage	55 kv
Pulse Cathode Current	550 amps
Plate Dissipation	60 kW



DP-18

High power triode for pulse service to 27 Mw

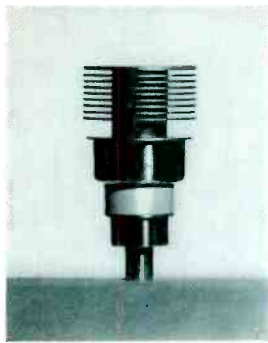
Designed to operate primarily as a switch tube in hard-tube modulators — for radar and similar applications. Employs ceramic envelope, thoriated-tungsten cathode, and forced-oil-cooled anode.

Maximum Ratings Pulse Modulator or Pulse Amplifier

Peak Plate Voltage	180 kv
Cathode Current	225 amps
Plate Dissipation	20 kW

Typical Operation

DC Plate Voltage	170 kv
DC Grid Voltage	-150 v
Pulse Positive Grid Voltage	1300 v
Pulse Plate Current	135 amp
Pulse Grid Current	55 amp
Pulse Driving Power	100 kW
Pulse Power Output	20 Mw
Pulse Output Voltage	150 kv



ML-8403

UHF planar triode provides frequency stable capability and high cathode current service to 3 Gc

ML-8403 is a ruggedized, high-cathode-current, frequency-stable anode, high- μ planar triode. It employs ceramic-to-metal construction, and is designed for use as a grid-pulsed, plate-pulsed, or CW oscillator, frequency multiplier, or amplifier in radio transmitting service from low frequency to 3 Gc.

Maximum Ratings

CW Oscillator and Amplifier

DC Plate Voltage	2000 Vdc
DC Grid Voltage	-150 Vdc
Plate Dissipation (forced-air-cooling)	100 W

Maximum Rating

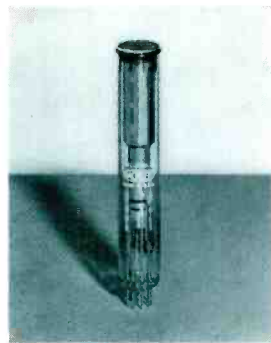
Plate-Pulsed Oscillator and Amplifier

Peak Plate Pulse

Supply Voltage	3500 v
----------------	--------

Maximum Ratings Grid-Pulsed Oscillator and Amplifier

Pulse Length	6 usec
Duty Factor	0.0033
DC Plate Voltage	2000 Vdc
Peak Plate Current from dc Supply	5.0 a



ML-7351A

Highest sensitivity, tipless vidicon for low light level or slow-scan applications

ML-7351A is a tipless vidicon designed to provide extremely high sensitivity under 2870°K illumination. At 6000 Å the output is 25 ua/uW.

For slow-scan TV; operates with lower dark currents — at ASA 1200 a dark current of only 0.05ua is required (approx. 1/4 of comparable tubes).

Operates with less than 0.05 ft-c. faceplate illumination, or average scene illumination of less than 2.5 ft-c. with f/2.0 lens.

Dimensions: dia. 1 1/8"; length 6 1/4".

ML-2058G

High resolution 2" vidicon

Operates with conventional image orthicon deflection coils.

Offers 50% amplitude modulation at 1100 TV lines. Limiting resolution is 2000 TV lines. Also available with x-ray sensitive photoconductor. Maximum length is 12 in.



ML-8443

Compact 5" DVST for airborne radar applications where space is a premium

ML-8443 direct-view storage tube offers bright visual display of half-tones and compact size without any sacrifice in performance.

Size: 5" dia. 8" max. length

Resolution: 70 lines/in

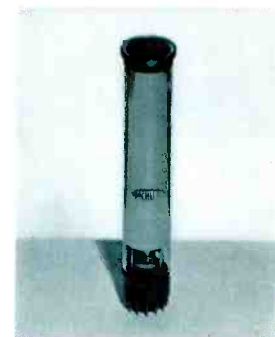
Storage Time: 1 minute minimum

Deflection: Magnetic

Focus: Electrostatic

Writing Speed: 200,000 in/sec

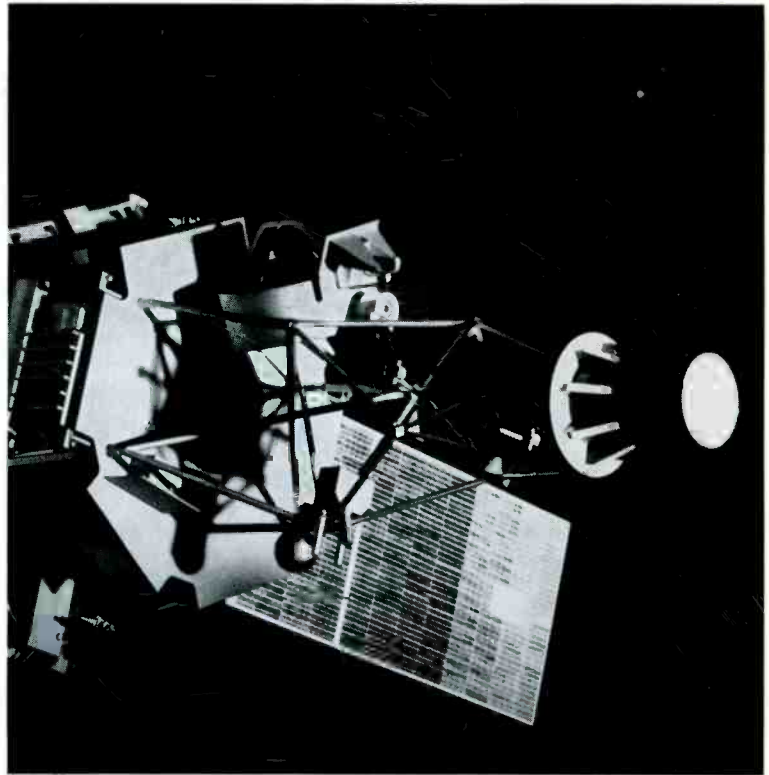
Brightness: (At 6.5 kV view-screen potential) 1000 ft.L



UHF



ML-6771 PLANAR TRIODE



The **only** electron tubes aboard the **MARINER II** in rf circuits are the Machlett ML-6771 planar triodes, adapted specifically for this application

Space communications from the Mariner II Venus experiment were successfully maintained by the two 3-watt transmitters and $\frac{1}{4}$ watt driver, each powered by a Machlett special ML-6771 planar triode.

High reliability* is the reason that Jet Propulsion Laboratory, designer of the rf cavities, has chosen Machlett planar triodes.

*High reliability means, here, excellent cathode emission stability; and uniform long-life, performance achieved through the highest Quality Control standards.

Send for
UHF Planar Triode Brochure



An Affiliate of Raytheon Company

THE MACHLETT LABORATORIES, INC.

SPRINGDALE, CONNECTICUT