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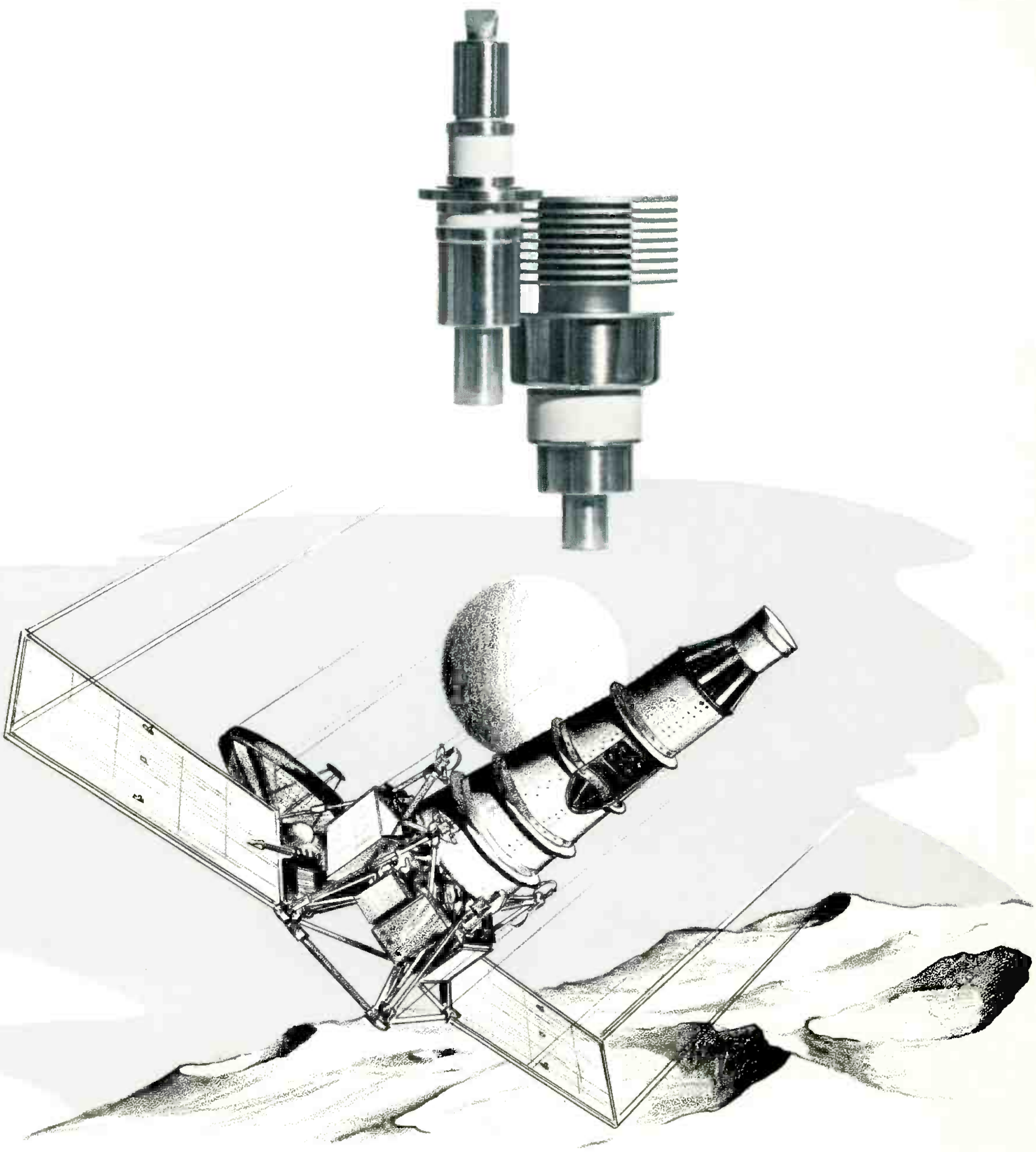

VOL. 22 • NO. 2 • 1965

Al Browdy

COVER . . . Ranger IX, in the final seconds of the terminal phase, descends toward the Moon's surface. Machlett planar triodes, ML-7855 and ML-546, respectively, transmit television picture information and telemetry data.

MACHLETT CATHODE PRESS

Vol. 22, No. 2, 1965

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IN THIS ISSUE

The next issue of CATHODE PRESS, Vol. 22, No. 3, devoted exclusively to Machlett x-ray products, will not be mailed to electron tube readers. This issue will, however, be available upon request. Volume 22, No. 4 will be the next electron tube issue.

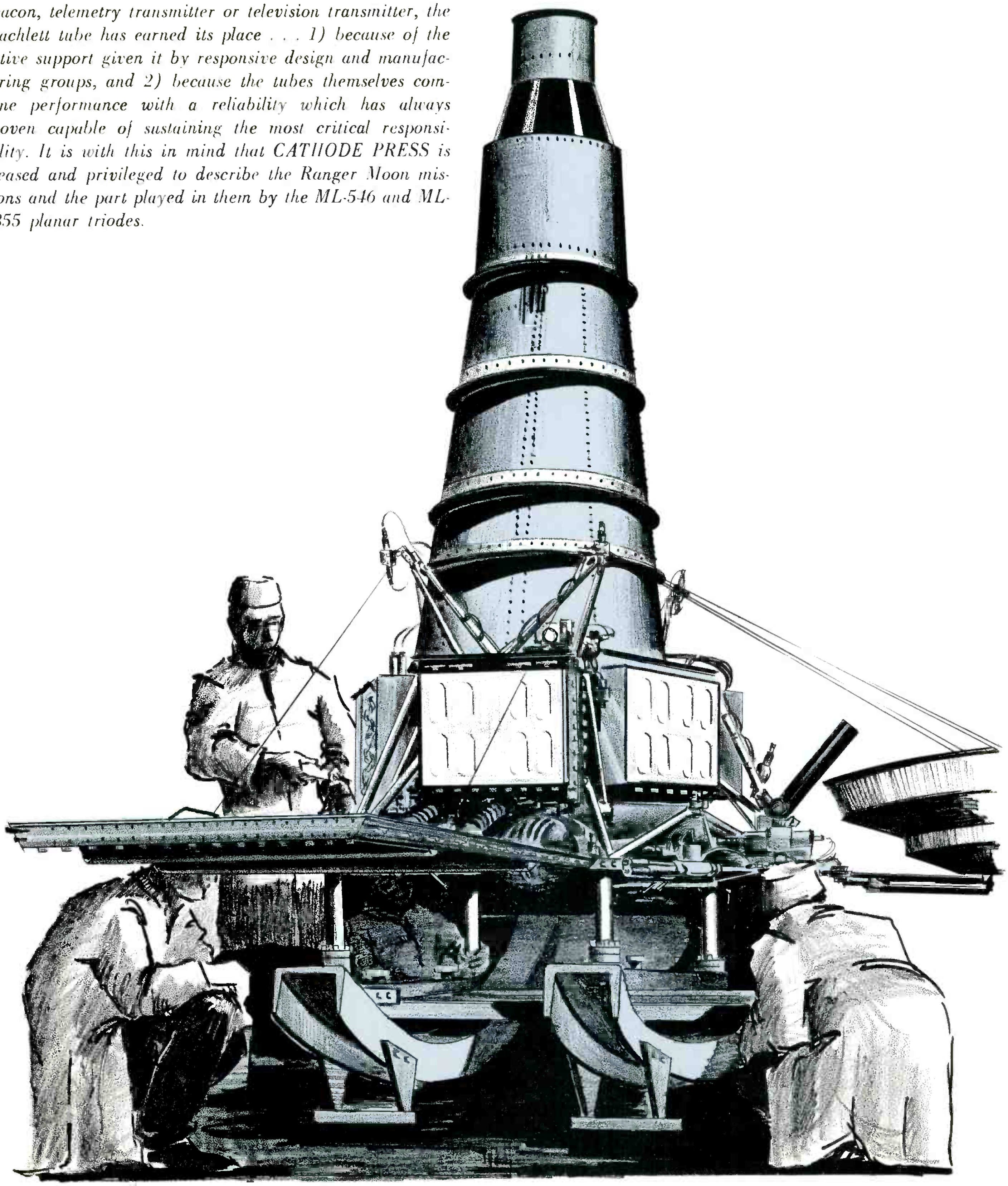
Product Lines represented in this issue:
Large Power Tubes
Small Power Tubes

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

PRINTED IN U.S.A. JULY 1965

Editor's Note:

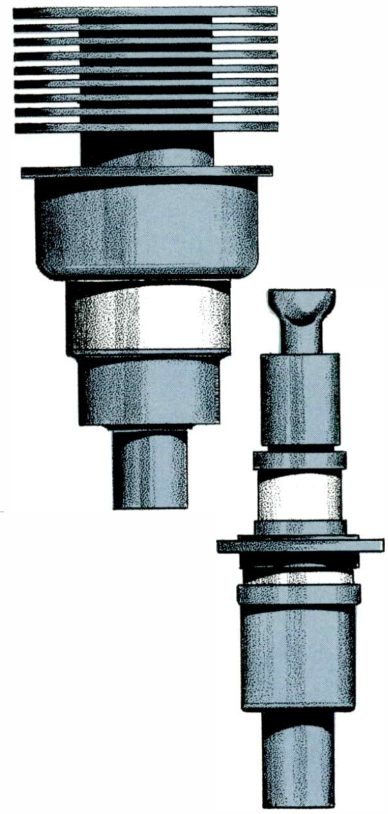
Three of the nation's important space programs — Mercury, Mariner II and Ranger — have successfully employed the Machlett planar triode. Whether in a radar beacon, telemetry transmitter or television transmitter, the Machlett tube has earned its place . . . 1) because of the active support given it by responsive design and manufacturing groups, and 2) because the tubes themselves combine performance with a reliability which has always proven capable of sustaining the most critical responsibility. It is with this in mind that CATHODE PRESS is pleased and privileged to describe the Ranger Moon missions and the part played in them by the ML-546 and ML-7855 planar triodes.



Transmitting Tubes for the Rangers—

ML-7855 Television Transmitter

ML-546 Telemetry Transmitter



Introduction

The Jet Propulsion Laboratory significantly takes its name from the source of thrust which has propelled this nation into space. Nearly thirty years ago, when rockets evoked thoughts of celebration, firecrackers and pin wheels, the Laboratory, working as an adjunct of the California Institute of Technology, commenced its first studies in rocketry. Their initial success came in providing a jet assist for aircraft takeoff. It is fortunate that the wings did not precede the airplane on that occasion and the first assisted flight was, despite an enshrouding volume of black smoke, successful. Jet propellants led to rockets, rockets to experiments and experiments to telemetry to tag the course and read the instruments of the skybound vehicle. Telemetry signals must, of course, be received and from this eventually came the Deep Space Network of receiving stations, essential ground anchor for JPL's space system.

In 1958, JPL, which had been operated by Caltech for the Army, was transferred to the National Aeronautics and Space Administration for which the country's first space exploration missions (Pioneer) were undertaken. Deep space explorations followed, Mariner II to Venus, and still continue: Mariner IV en route to Mars. Now concluded are the tremendously successful Rangers VII, VIII, and IX which comprise a technical tour de force combining in addition to telemetry and instrumentation, television cameras, transmitters and antenna; extraordinarily precise vehicle orientation, and re-orientation, and rocketry with a range of the 370,000 pounds thrust of the Atlas Agena launch vehicle to the mid-course maneuver rocket whose 50 lb. thrust bursts were controllable in millisecond periods.

In all, the Rangers returned 17,259 pictures to earth. The first of these came in late July 1964, and, while later results may have been more impressive technically, the sense of accomplishment and excitement revealed by the first Post Impact Conference, Friday, July 31, 1964 helps indicate the magnitude of the results. It is well worth a pause to review this moment. Quoted here are the opening remarks of this session. Dr. Wm. H. Pickering is Director of JPL; Dr. Gerard P. Kuiper, principal investigator of the lunar photographs, is from the Lunar and Planetary Labortory of the University of Arizona at Tucson.

"DR. PICKERING: The quality of the pictures are such that the first pictures are more or less typical of what one gets with telescopes here on the Earth.

As we go into the Moon, then, the quality continues to improve; the resolution continues to improve as we come down to the final pictures just before impact.

We are fortunate in that, as you know, the pictures are taken at regular intervals. It is not a continuous set of pictures in the sense of an ordinary television picture, but rather these are sort of a series of snapshots taken a second or so apart. We were fortunate in that the last picture was taken very close to the surface, in fact, only about a half of the last frame was transmitted before it hit the surface, so we did get a picture then quite close in.

I hope that when we come here with the pictures we will be able to give you some of the actual facts concerning the geometry of the pictures, and the altitude from which they were taken and so forth.

I see my colleagues at the back of the room and they are on their way in now. If I can have them come on down here and up on to the stage, I will be glad to introduce them to you.

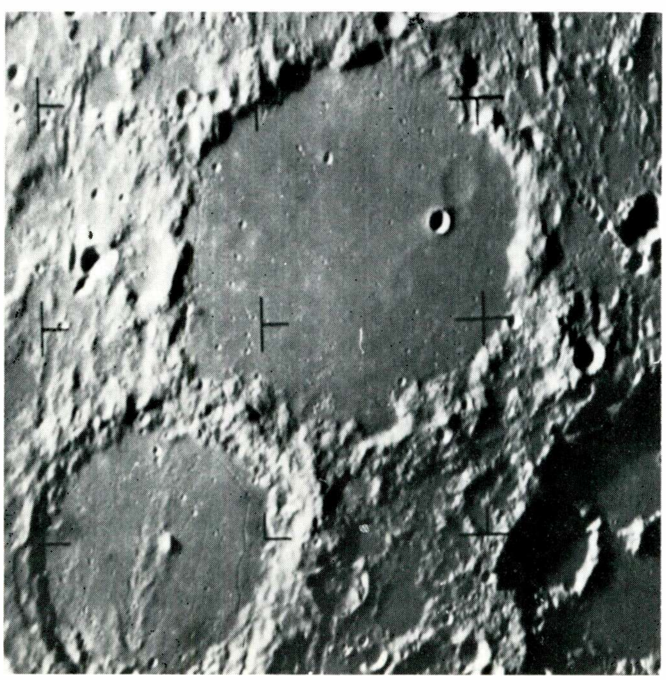
The scientists concerned with these experiments have had their first look at these pictures. I am sure that they will be the first to tell you that it is only the initial look. The pictures are going to take a great deal of study before we obtain all of the information which is contained in this set of pictures. . . .

I would like now to begin to show some of the slides.[1] I would like to ask Dr. Kuiper to comment on these slides as we go along. Dr. Kuiper.

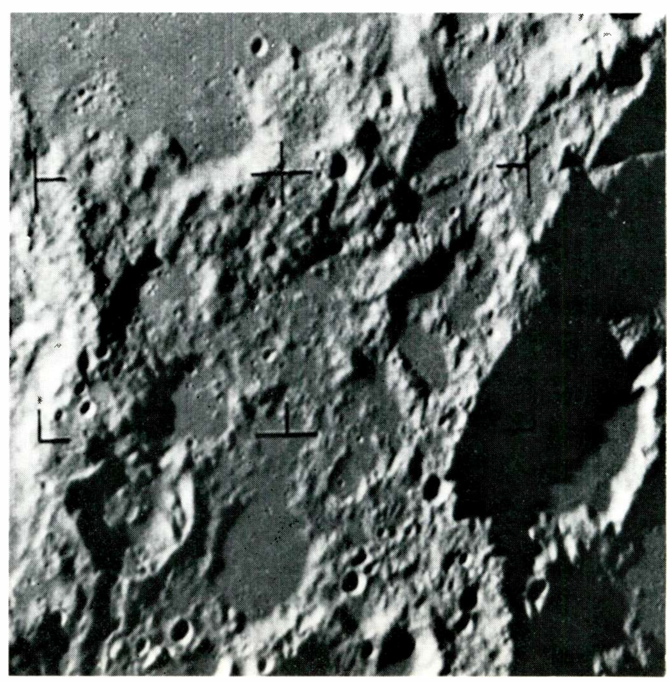
DR. KUIPER: . . . This is a great day for science, and this is a great day for the United States. What has been achieved today is truly remarkable. We have made progress in resolution of lunar detail not by a factor of 10, as the Ranger pamphlet hoped would be possible with this flight, nor by a factor of 100, which would have been already very remarkable, but by a factor of 1000. This means that the Moon, which to the unaided eye of course is seen at a distance of about 240,000 miles, and which in a good telescope can be brought to a distance of 500 miles equivalent, has been brought in this experiment; in this Ranger VII experiment, to a distance of half a mile. This of course covers only a small region of the lunar surface, but the sample shown is a very representative sample and therefore the amount of information that has been gained about the lunar surface is truly remarkable.

[1]Moon pictures shown in this article are representative of those referred to here.

Ranger IX moon pictures, March 24, 1965. The first picture: 18½ minutes from impact. Altitude 1470 miles. Full scan B camera. Best resolution, approximately 7/10 mile. The crater Alphonsus, with a central peak, is at the lower right. (This series of photographs is courtesy of Jet Propulsion Laboratories.)



9 minutes 18 seconds before impact. Altitude 775 miles. B camera. Alphonsus is at the right.



This first slide shows a frame obtained in the beginning of the sequence with the "A" camera, one of the six television cameras, and shows a resolution which is very similar to what had previously been obtained from the ground, that is, from observatories.

So what you see here at the moment is just an ordinary good photograph which might have been obtained in, let us say, with a 100-inch telescope, 200-inch telescope, or any of the other large telescopes.

Now, the next slide shows an improvement already by a factor of the order of five. This, then, is already very much better than what has been achieved from the ground.

And the next, the third slide, shows yet another step of a factor three to five, and here we have numerous small craters covering the lunar surface of dimensions which have been totally unobservable in the past. So here we have gained a factor already more than ten.

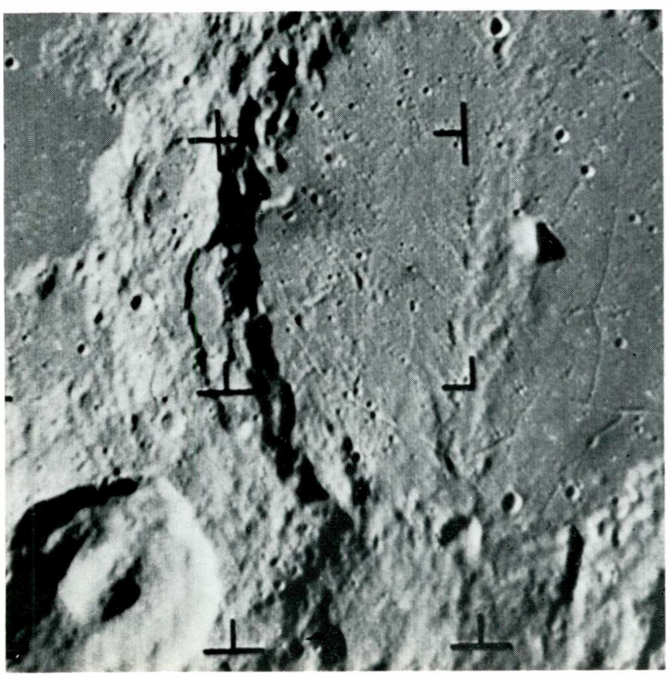
Now, the fourth slide goes further and shows a remarkable clustering of very small craters, and this region appears to be somewhat anomalous in the sense that it has been produced by the impact of the very large Crater Copernicus, which I am sure is familiar to many of you.

This Crater Copernicus, when it formed, tossed out thousands, literally thousands of rock fragments which made secondary craters on the moon. And what you see here in the center of the picture and a little below it is a nest of these secondary craters. The density of these craters is truly enormous, and this is not representative of the entire lunar surface. And I am sure that the warning which has been gained here is very important, as an important implication for the future programs, the landing in particular, because obviously regions which are as badly battered as this one ought to be avoided in the Program Apollo.

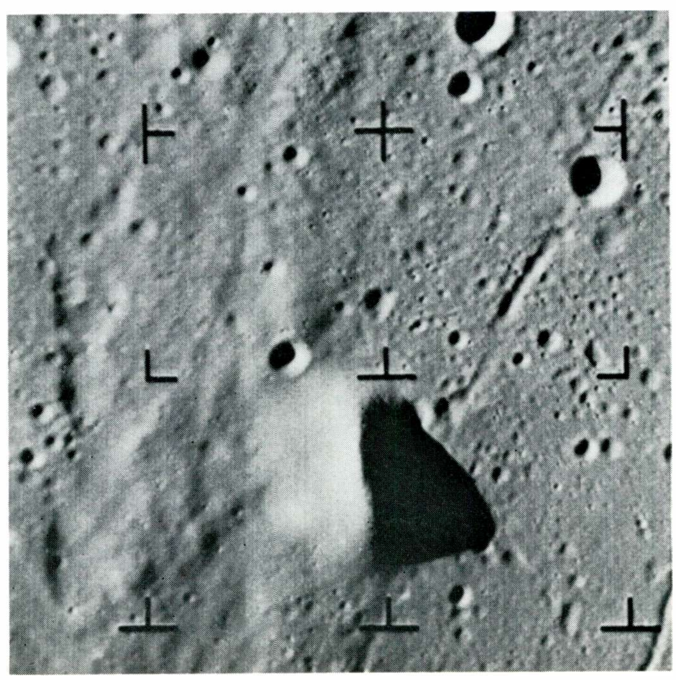
The next slide shows yet another factor ten or so in resolving power, and here we see a totally new type of feature, a large number of craters which look very soft, which have sort of a worn appearance. The edges are rounded; the edges of the craters are rounded.

But you will note that in addition to this large number of soft craters which have dimensions from about 50 to 300 feet in diameter, you have also a number of very tiny craters. So this shows that the soft appearance of these large craters is not due to poor focus or motion of the

2 minutes 50 seconds before impact. Altitude 258 miles. A camera. Alphonsus fills the right half of the picture.



38.8 seconds before impact. Altitude 58 miles. A camera. Central region of Alphonsus is shown.



spacecraft or anything like this.

The definition of the optics was very good, indeed, as you can judge from inspection of the very small craters which are completely sharp.

So we have a large number of very small craters, as well, and then there is a feature which is very interesting, the only feature of its kind so far noted on the records which have been obtained today.

Incidentally, the number of records obtained was 4316 so that this gives you an idea of the amount of work that is ahead before the results of this tremendous mission can be fully evaluated and fully announced.

On the left side, a little above the center, you see some odd dark dots in the crater, and these dots appear to represent shadows of a rock mass which is apparently buried in this crater, and it stands to reason that what we are looking at here is a secondary crater, that is, a crater made by a fragment by very likely the large Crater Copernicus which we can still observe in the crater it formed.

In other words, there is an enormous fragment, something like 300 feet in length, which was apparently forced out when Copernicus formed. This is a very preliminary conclusion, mind you, . . .

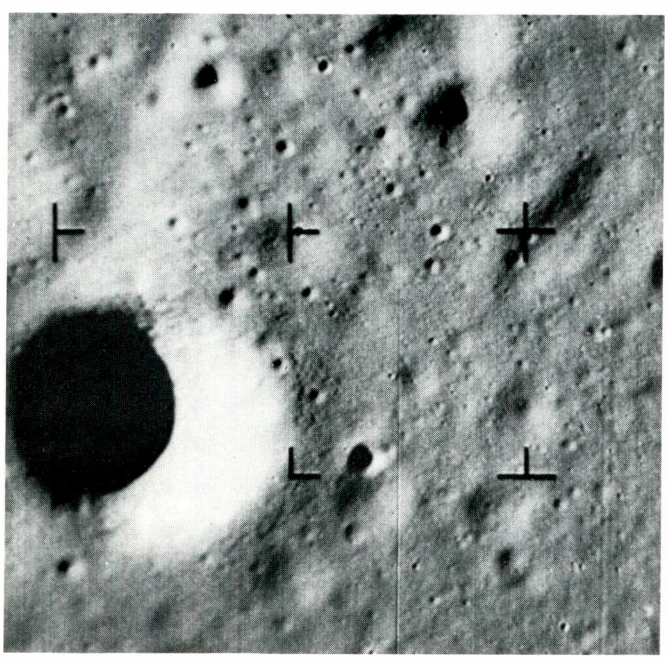
I might mention that the sun was 23 degrees above the horizon in the area taken here, so from the known position of the sun above the horizon and the observable shadows, one can derive conclusions on the slopes of these craters, and one finds, then, that some of these rocks are much steeper than 23 degrees because they cast very distinct shadows.

Now, the next frame is taken with the "B" camera. This is the first of the frames I am showing you of the "B" camera. So I have shown you here a series, I believe, of six photographs taken with the "A" camera.

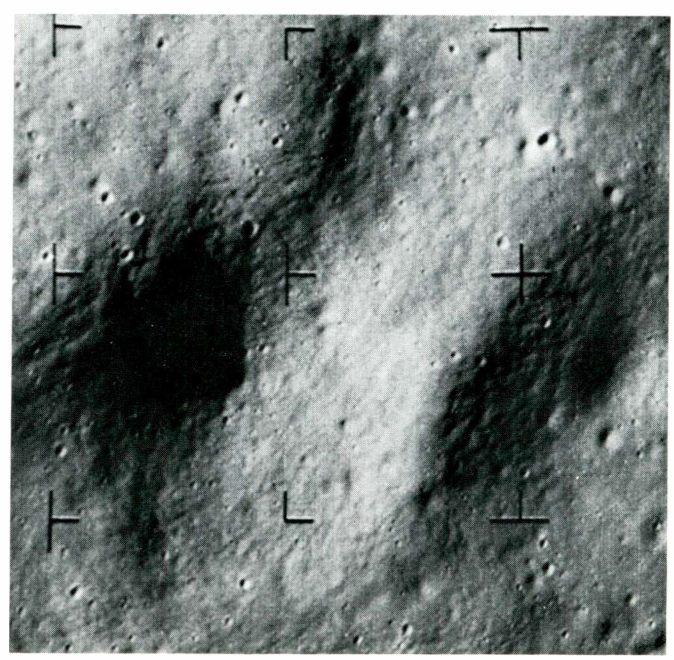
Let me tell you a little bit about this "A" camera. It has a field of 25 degrees on the side, and therefore it covers a good sized area. In fact. the first of these "A" frames taken cover almost the full width of the moon, as seen at last quarter.

The "B" camera has a longer focal length, three times longer focal length, three inches versus one inch. . . . And, therefore, because the focal length was longer, the field is correspondingly smaller in degrees. . . . instead of 25 degrees, we have about an 8 degree field here, 8 degrees

8.09 seconds before impact. Altitude 12.2 miles. A camera. Region shown is immediately to the right of the central peak of the crater Alphonsus.



5.5 seconds before impact. Altitude 8.3 miles. Last full B frame. Structure in shadow area begins to appear. Smallest craters shown approximately 30 feet in diameter.



by 8 degrees.

Now, the crater you see there is the Crater Guericke, and it can be observed from the Earth quite well, but the photograph here shows an enormous amount of detail, something like ten times the resolving power of what an Earth-based photograph shows.

So this already is a very beautiful photograph, and I can assure you when I had the privilege of seeing these "A" and "B" frames today for the first time, of course, the 400 frames, every one I thought was a bull's eye, as far as quality is concerned.

I mean I have never in my experience as a scientist seen a series of scientific documents where not is there just a good selection of good quality picture among a whole lot of indifferent pictures, but every picture — literally every picture of the "A" and "B" series — is of high quality. It is an extraordinary series.

You are not aware that you are looking here at a television picture at all. That is because there are 1150 lines and not the regular 500 or so lines on the frame, so the lines are so close that it simulates a photograph. . . .

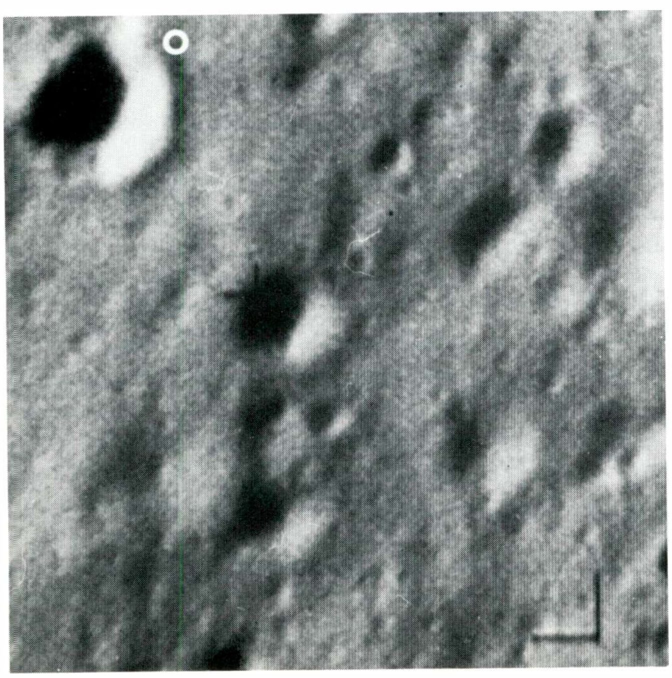
Now, the picture on top is of special interest. This was the last gasp of the spacecraft. The spacecraft took this picture approximately a thousand feet above the lunar surface. The field you see here is 60 by 100 feet, and the smallest craters that can be seen — this slide is slightly too light to bring this out to advantage; the original frame, as this was done under very great pressure, mind you — everybody has worked at the limit of their strength to get this ready for this conference.

But the original (photograph) shows more clearly than the reproduction here, the craters down to sizes of three feet, and the best resolution obtained is approximately a foot and a half. This is a thousand times better than the best photographs which were available up to yesterday, a thousand times better.

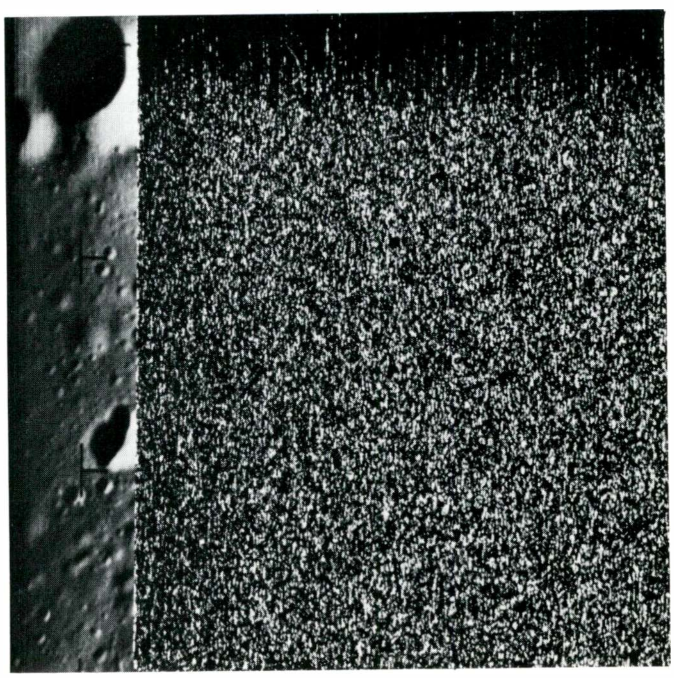
Now, the frame was not complete before the spacecraft had the opportunity to complete the transmission of the data on the vidicon. The spacecraft hit the moon, was destroyed, and the transmission stopped.

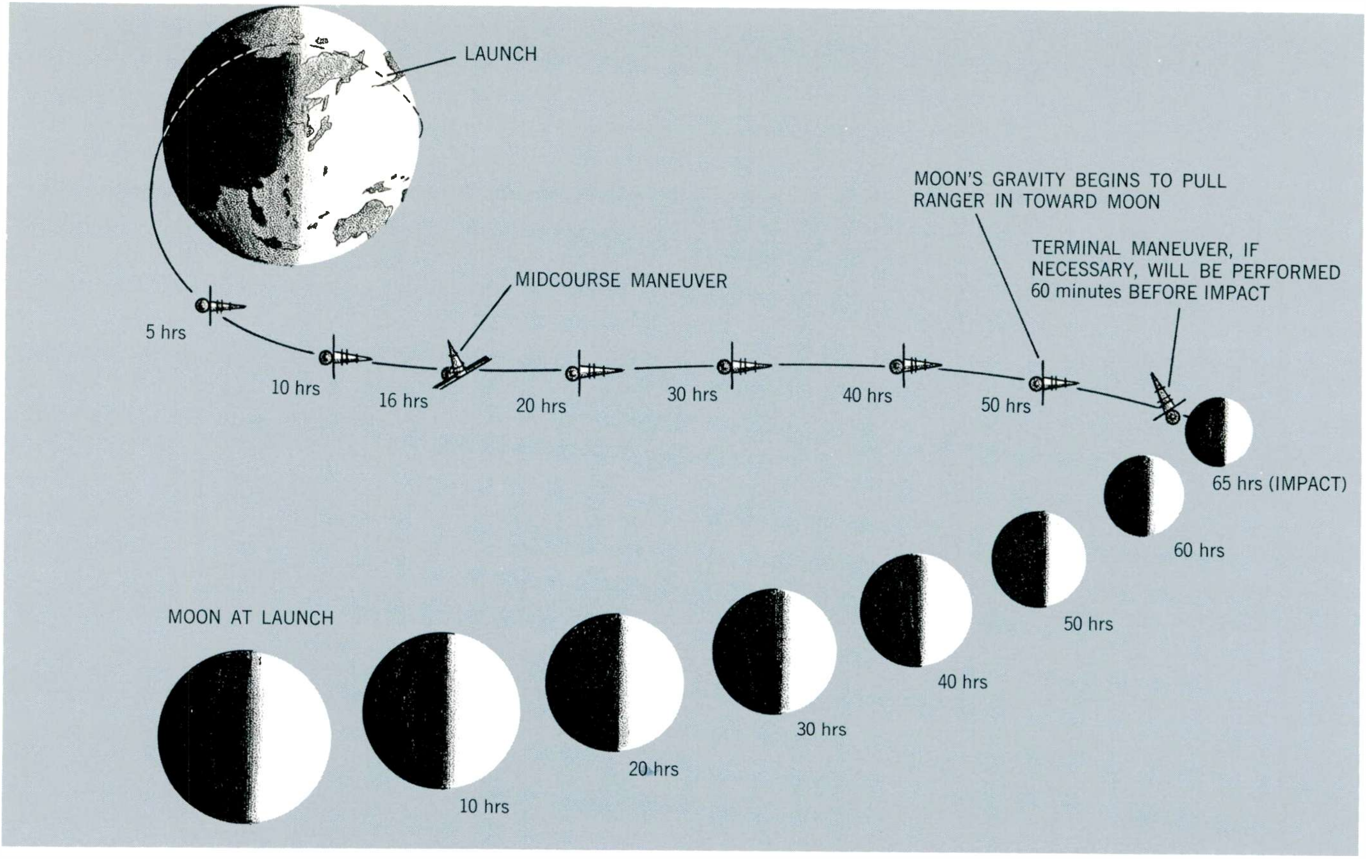
So on the right-hand part of the frame here, this noise-looking material, that is simply receiver noise on the Earth, and at that time the spacecraft suddenly stopped transmitting. . . ."

0.453 seconds before impact. Altitude 3/4 mile. Ranger IX impacted in area shown by circle on edge of twenty-five foot crater. Smallest visible crater, 2½ feet across.



Altitude 6/10 mile. B camera. Photograph interrupted by impact. Highest resolution achieved by Ranger IX, 10 inches.





Ranger — Exploration for an Exploration

Ranger has made the first moon step, next is Surveyor[2], then the manned landing, Apollo[3] (Simultaneous with Surveyor will be the Lunar Orbiter[4] program.). Ranger's primary task has been to provide a seeing eye for Surveyor plans and equipment design: to determine where best to land the craft, and, to the extent possible, the surface environment it will encounter. A macroscopic vacuum surface environment is nearly incomprehensible to the earth bound man living at the floor of an air ocean. Although the electron tube engineer is probably as familiar as anyone with the mysteries of materials in a vacuum — for example cold welds between ultra-clean degassed metallic surfaces (and surely the moon surface must be well outgassed!) — no one can say what mountain climbing, hiking, skiing or camping in vacuum will be like. We must guess, of course, and Ranger has helped. It has brought the limit of resolution from 600 to .3 meters.

[2]Surveyor: Soft land on the moon; television survey of moon surface; analyze surface samples; obtain bearing strength. Advanced mission may put vehicle (Rover) on moon. Seven launches planned. Target date, launch periods: 1965 to 1967.

[3]Apollo: Manned lunar exploration. Target date: 1970's.

[4]The Lunar Orbiter will circle the moon taking photographs, at altitude of approximately 25 miles, of large areas of the moon's surface. This program is directed by the NASA Langley Research Center.

The Television System

In the accomplishment of this feat JPL, in its design philosophy, was guided by the idea that use of components of demonstrated performance, manufactured with skill and precision well beyond acceptable terrestrial parameters would provide the fundamental reliability required. Such, indeed, proved to be the case — virtually every component used was a design of long standing (important improvements were incorporated in some, the vidicons, for example). Further, the projected mission for the advanced Rangers — the space television flights — had to be developed within the framework established by the early Rangers. This meant, as the Program Proposal stated the "Television Payload will be fully compatible with the [then] present Ranger spacecraft mechanical, thermal and electrical interface requirements". This payload was to be "dependent upon the Ranger Spacecraft only for the receipt of instructions through the spacecraft command receiver, and the transmission of the video signal over the high gain antenna and stabilization". Designed and built by the Astro Electronics Division of the Radio Corporation of America the final payload (see Figures 1 and 2) was a 380 lb package containing two wide angle and four narrow angle television cameras, camera sequencers, video combiners, telemetry system, transmitters and power supplies.

The design had a climactic aspect: to get the highest resolution possible; yet to achieve this within the constraints of demonstrable reliability. For this latter reason a fixed focal length optical system was employed. Use of high speed short focal length optics minimized effects of uncompensated image motion (by allowing short exposure time) and permitted design of a compact light camera whose most important work would be done just prior to impact so as to satisfy the high resolution requirements. Since resolution and altitude vary inversely and since 'useable altitude' depends on scan rate, the final images will be determined by the final velocity of the vehicle (6000 mph) and the vidicon readout time. As it worked out for Ranger IX, the final pictures were made less than 1/2 second before impact and could resolve a distance of about 1.6 feet. Speed of the focal plane shutters for the Partial Scan Cameras was 1/500th second, for the Full Scan Camera 1/200th second.

Ingenuity and tube design helped achieve the quality of these final pictures. The Ranger IX vidicons, for example, had a higher output (20 nanoamperes vs 10 nanoamperes at 0.4 foot candles) and a higher scanning resolution (1150 lines from 800) than vidicons used on previous Ranger flights. Computer controlled processing of the received signal through use of a digitized tape eliminated, or greatly reduced, noise interference patterns (either external or internal for the vidicon). Designed into the system itself was an unusual raster formation used to obtain high resolution. By this means only the central 300 the nominal 1152 television line raster were used. This allowed a 200 millisecond frame time and a corresponding altitude of 600 to 300 meters for exposure of the last complete frame. Reduction of the scanned area accelerated read-out: the smaller area required a fewer number (by the square of the ratio of the two areas) of informational bits to be sampled, hence transmitted. Hence, for a fixed bandwidth and a ratio of four-to-one in the tube areas scanned at an equal line density, the read-out time was reduced by a factor of 16.

To obtain maximum system utilization, as well as provide reliability, cameras were sequenced so that as one recorded an image, the next was erased. The two F-scan (full scan) cameras transmitted every 5.12 seconds, the

Figure 1 — Ranger IX television cameras consisting of two wide-angle 25 mm lens cameras and four narrow angle 75 mm lens cameras. Three cameras used an F-2 aperture; three used an F-1 aperture. (Photograph courtesy of Jet Propulsion Laboratory)

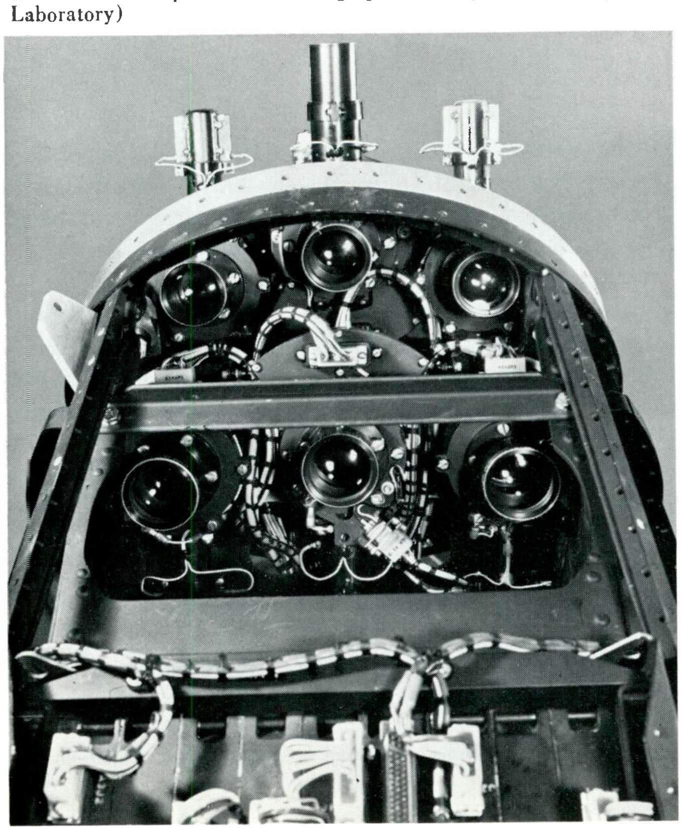
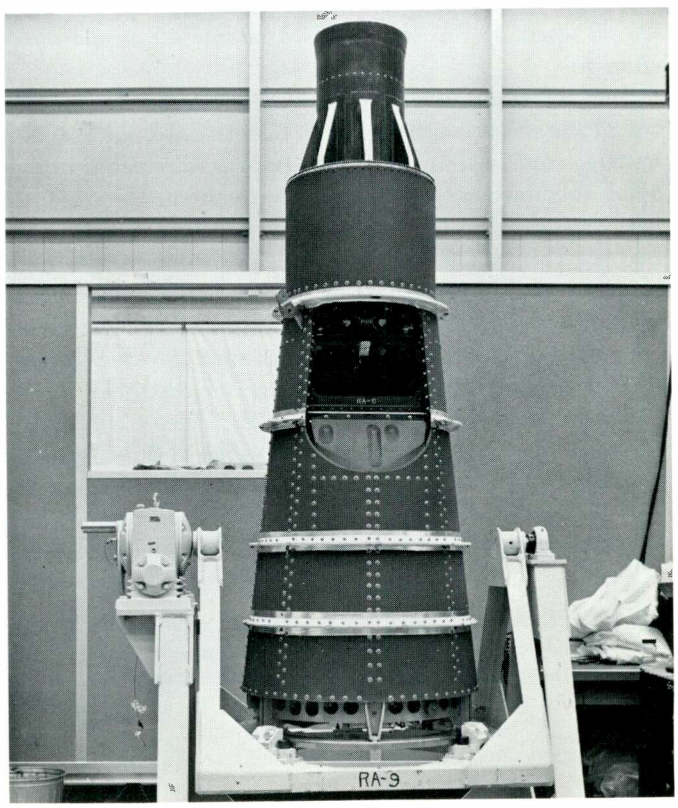


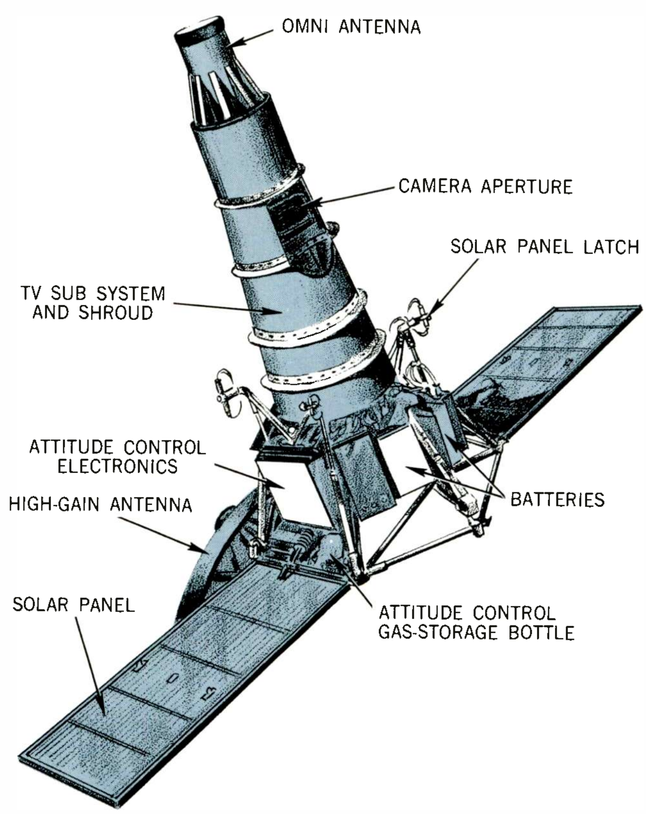
Figure 2 — Ranger IX television payload, showing camera aperture. Omnidirectional antenna is at the top of the structure. (Photograph courtesy of Jet Propulsion Laboratory)



four P-scan (partial scan) cameras transmitted every 0.84 seconds.

Camera signals were directed to one of two video combiners (one for the F and one for the P cameras) which sequentially combined the output of the cameras to which they were connected. Video combiner output was converted to an FM signal, then becoming an input for the 7 watt driver of one of the two identical 60 watt transmitters. F-camera pictures were earthbound on 959.52 mcs, P-camera images on 960.58 mcs. These relatively modest bandwidths provided adequate frequency range for the sequenced signals.

Camera sequences instructed the cameras to: snap shutter, read-out vidicon faceplate, and to erase faceplate and prepare for next picture. Image erase was accomplished by use of special lights flashed to saturate the photoconductive layer which was then scanned twice by the read-out beam to remove all trace of the previous image.



Ranger Television Subsystem

Since the television requirement[5] was dominant, the telemetry — television — antenna design inter-relations had to reflect this primary need. Both telemetry and television signals must share a common antenna, yet telemetry interference could not be tolerated. Back-up provision was also required should the high gain dish fail. These requirements determined system configurations. With regard to the telemetry transponder itself reliability from launch to impact was the first criteria; for the television transmitter, a dominating factor was a fast, stable response. For example, on Ranger VII the transmitter was allowed an 80 second warm-up followed by a 13 minute 40 second operating life.

The communications system (See Figure 3) evolved from these needs consisted of two 60 watt L-band FM transmitters, combined in a 4 port Hybrid Circulator before being combined with the beacon transmitter. The modulating signal consisted of camera video and the telemetry subcarrier. Transmissions beamed toward earth by the high gain antenna were received by the 85 foot parabolic Goldstone antenna which is equipped with an L-band maser pre-amplifier. The 60 watt transmitters provide a substantial power margin above the receiver threshold.

The frequency most available for the video transmission was the 960 mc band. Available bandwidth at this frequency was 1.6 to 2 mc, maximum. During multiplexed transmission of "bus" and "payload" each TV channel bandwidth is compressed to 0.9 mc to provide an acceptable overlap of the spectra of the two systems. As a consequence of this, a video baseband of approximately 200 kc was chosen. It accommodated well the camera and optical requirement and provided a good solution to competitive design requirements.

Given the video baseband, the Ranger high gain antenna and ground receiver, the required power for the TV transmitter was set at 60 watts. While additional power would have provided additional margin[6] the many problems involved worked against it. Since the transmitter was considered "a vital component which must be operated under stress conditions at the 60 watt level", a second, alternate 60 watt unit was provided. In the final system each transmitter served one camera group.

The cameras were time multiplexed into the modulator under control of the camera sequencer. The design was such that failure of any camera would affect no other camera unit, sequencer or modulator. The switched-in

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[5]As the JPL design proposal has pointed out, even though a "high resolution television picture" may be the stated objective of the mission, the picture itself was not thereby defined. It must be "defined by the number of television lines, its aspect ratio, the contrast, the resolution, frame time and signal to noise ratio". These factors and their inter-relationships served to inform the design of the television system.

[6]A 120 watt single transmitter had been an early alternate consideration but, within the state of the art, it proved not to be a feasible choice for development.

standby mode was selected, then as the preferred technique; the problems associated with switching being fewer or of lesser magnitude than those associated with rf coupling. The switching was done on the rf feedlines.

Although various methods were tried to avoid or reduce the 3 db coupling loss associated with coupling the TV transmitters into the antenna system, these resulted in undesirable phase shifts. Further, the coupling loss proved not to be critical inasmuch as system margins were satisfactorily high.

The directing thoughts behind design of the rf link for transmission and reception of the multiplexed camera chain and telemetry were: 1) reliability; and 2) minimum effect on the Ranger Bus. Primary among considerations to be resolved was the elimination or minimization of the interference with existing 960 mc bus tracking transmitter while sending the television signals on the 959.5 and 960.5 mc carriers. By this means (splitting the 60 watt transmitters to transmit on either side of 960 mc) continuous tracking was permitted, though with some slight increase in the video S/N ratio.

System Operation

Prior to entry into the terminal phase of the mission, scientific and engineering data were commutated by the 15 point switch; the transmission was received and recorded by the Goldstone transmitter from the telemetry transmitter. Entry into the terminal phase mode activated both TV transmitter and all cameras and initiated both video transmission and rapid telemetry data sampling. (Figure 4) Reception was provided through the Goldstone parametric amplifier.

The Telemetry System

Although the televised information was primary, the telemetry link was essential — not only to command the Ranger, but to understand its actions and be able to take corrective action when or if necessary. Over 100 engineering data points were monitored during the cruise mode of the mission. These points in themselves attest to the complex precision of the flight. While one might, for example, readily anticipate transmission of 'autopilot' information (roll, yaw and pitch), there is much that is peculiar, if not unique, to control in the space environment. Some of these items whose coded signals were returned to earth were: Earth Brightness; Mid-Course Motor Control Nitrogen Pressure; Solar Panel Voltage; Yaw and Pitch Sun Sensors; Antenna Reference Hinge Angle; and "Solar Panel Unfolded".

Additional television data was relayed during television operation. Data encoders translated engineering measurements for the telemetry transmission to Earth and a detector and decoder, in the command subsystem, translated incoming (binary coded) commands to the spacecraft. Commands received were channeled by the command subsystem to proper designation. Real-time commands actuated the designated relay within command decoder to execute the command. Stored commands were relayed to the Central Computer and Sequencer in serial binary form to be held and acted on when needed.

Telemetry Transmission

Two modes of TV telemetry transmission were available:

1) using the "bus" (or Ranger vehicle) encoder and associated transmitter;
2) frequency multiplex with the video, or the normal mode;

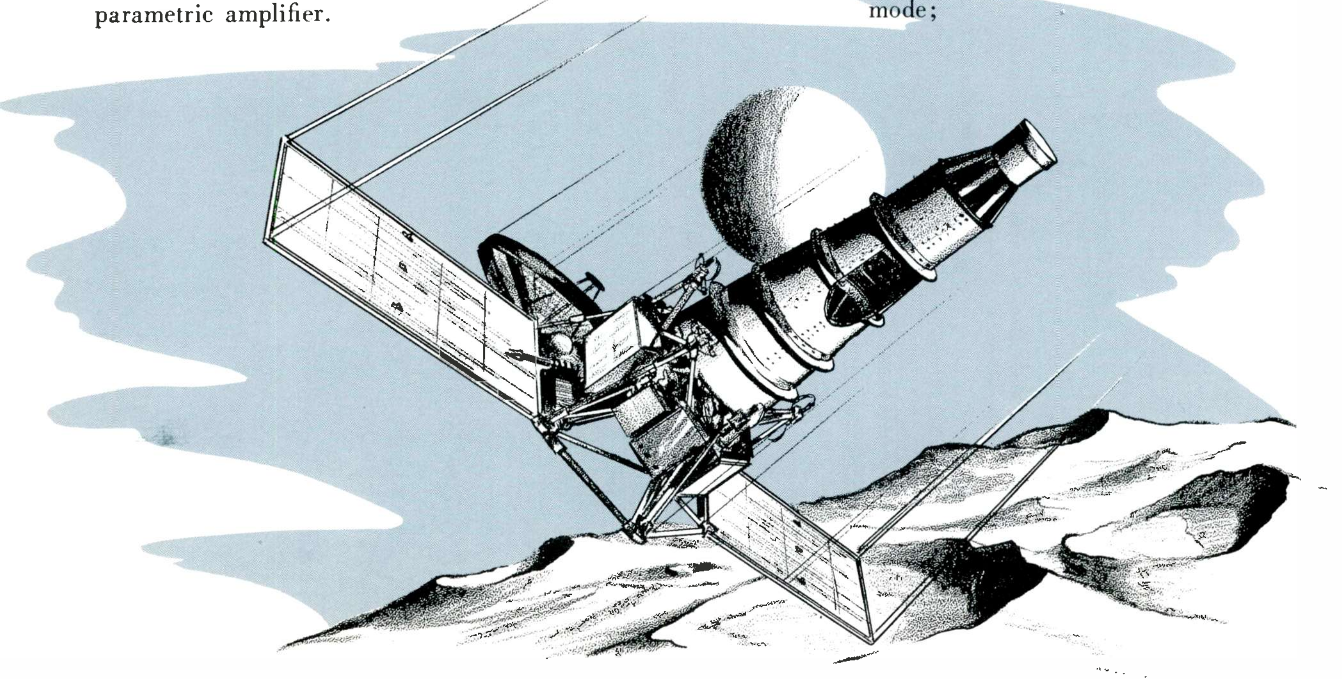
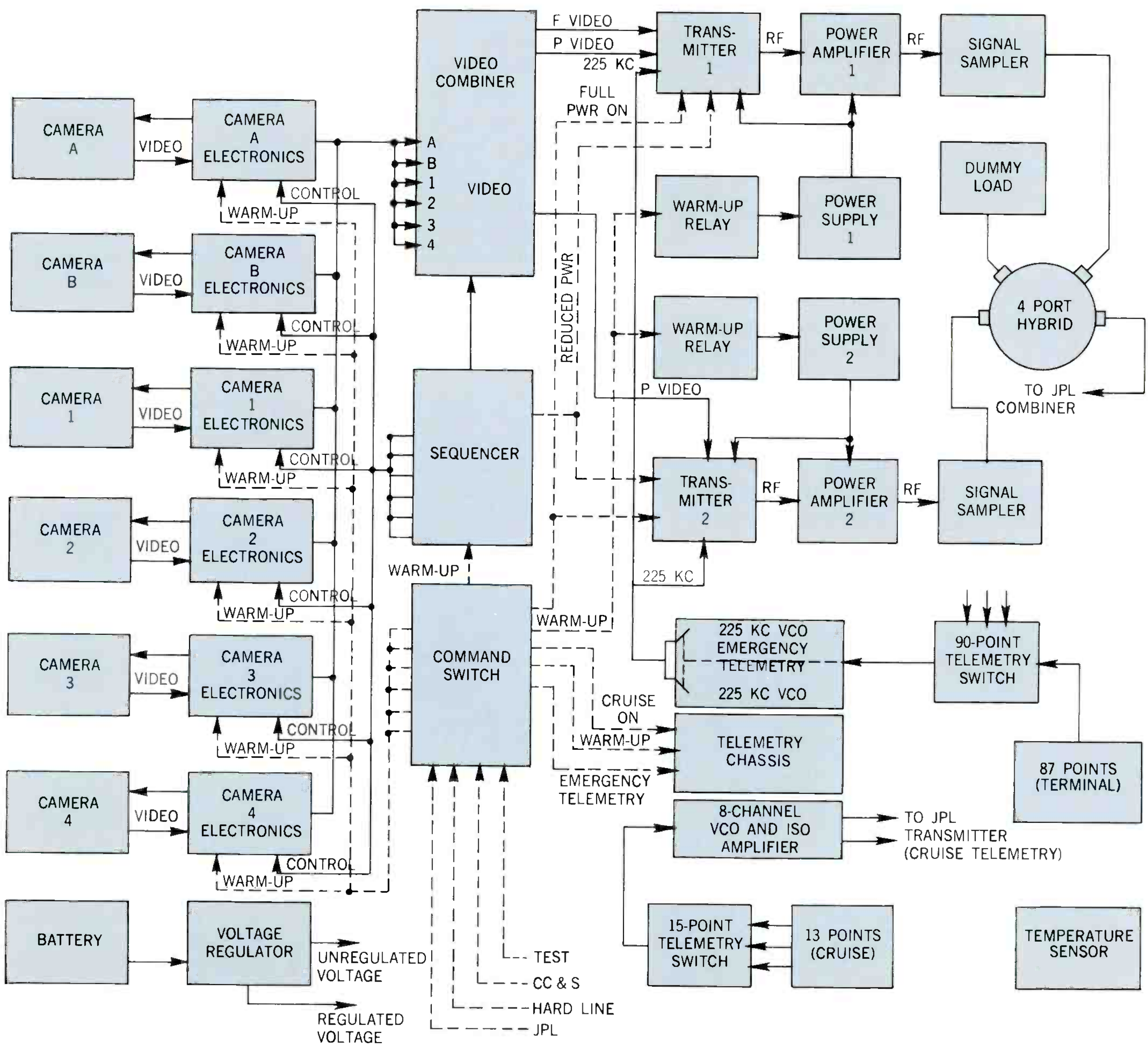


Figure 3 — Ranger IX during "payload phase". Camera aperture is visible in upper half of the spacecraft structure.

During the cruise period, when the first mode is employed, a fifteen-point sampling switch operating at a rate of one point per second samples the points to be monitored. The output of this switch drives a sub-carrier oscillator provided on the bus. An ac amplifier and a transformer connect the output across the spacecraft interface, where it is mixed with other telemetry for transmission over the JPL beacon transmitter.

A more detailed diagnostic telemetry is employed during terminal mode, wherein a 90 point sampling switch operating at a rate of 3 points per second samples TV subsystem parameters. The switch output is used to drive two 225 kc voltage-controlled oscillators connected in parallel. These two outputs are connected so that one VCO is mixed at modulator 1 and the other at modulator 2. The VCO frequency was chosen so that it was located above the highest video frequency in the base band of the system. The resulting signal, encoded by PDM to maintain ac-

Figure 4 — Schematic drawing of Television Payload, Television Transmitter, and Telemetry Systems.



curacy and linearity, modulates the 225 kc oscillator, the signal from which is combined with the video of the modulator input. The 225 kc base band thus achieved is transmitted using the 19 db gain of the directional antenna.

Tracking data from the transponder is collected by the Deep Space Network[7] and fed into a large scale computer. The Ranger's actual trajectory is derived from this and guidance commands (roll, pitch and motor burn) as required are returned to the "bus". Roll and pitch provide spacecraft orientation, while motor burn controls velocity increment required to alter either flight path or time of flight.

* * *

Sharing both equipment and time with the Ranger television payload the telemetry design brought interlocking influence to bear on the entire communications system.

Ranger TV Transmitter Design

Modulation method, power level and system compatibility — all conceived in terms of maximum possible reliability in performance — combined to determine the form and type of television transmission system that was to be designed.

Studies had shown that FM modulation of the television signal would, within the current state of the art, (circa 1961) afford the best combination of power requirements and equipment/component availability. FM had, accordingly, been chosen. Other methods considered were FM-with-feedback (probably the best solution regarding video transmission vs power level — but equipment design was not yet ready); double sideband AM, vestigial sideband AM, vestigial sideband FM and PCM.

Power level was seen in relation to the ability to obtain high quality pictures from single frame photographs of rasters for the given $(S/N)_v$[8] ratios, for "triangular"[9] noise and "flat"[10] noise, of values sufficient to represent a satisfactory minimum performance at the FM threshold. Taken together, with still further considerations, the most important of which is the relationship between the $IF^{C/N}$ and baseband rms to rms S/N, it was determined that a 60 watt transmitter output would provide a 6.2 db system margin above the ground receiving equipment threshold. And further, that this would, in turn, provide a 2.5 db margin, even if all the system tolerances (total 3.7 db) were negative. The transmitter then, would not be as powerful as had been contemplated (a 120 watt unit had been planned) but it would have 6 times the output as the 10 watt transmitters on the Rangers III, IV and V. The following

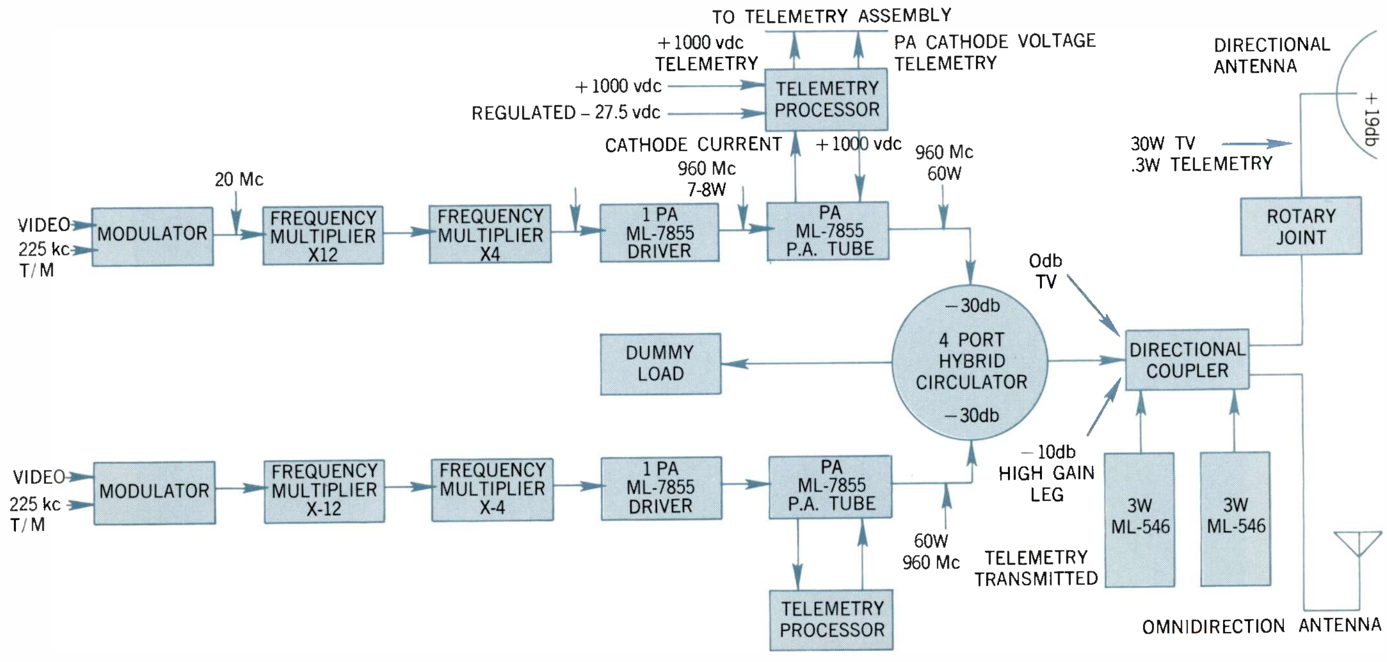
[7]The Deep Space Network (or DSN) consists of six permanent communications stations (Woomera, Australia; Canberra, Australia; Johannesburg, S. Africa; Madrid, Spain; and two at Goldstone, California), a spacecraft monitor station at Cape Kennedy, the Space Flight Operations Facility in Pasadena, California.

[8]$(S/N)_v = \text{video signal noise} = \frac{\text{peak to peak video without sync}}{\text{rms noise}}$

[9]"Triangular" noise refers to FM system noise which increases with frequency increase.

[10]"Flat" noise refers to AM system noise and does not change with frequency.

Figure 5 — Ranger IX Television-Telemetry Subsystem.



describes the Rangers VII, VIII and IX transmit-receive system performance:

TABLE I

		Nominal Value	Tolerance
Transmitter Power = 60 watts		+17.8dbw	±0.9 db
Losses			
Free space (240,000 statute miles)	203.9 db		
Ground Antenna	−44.7 db		±1.0 db
Space Vehicle Antenna	19.0 db		±0.5 db
Vehicle RF Losses	2.0 db		±0.5 db
Polarization Loss(1)	0 db		+0.2 db −0.0 db
Antenna Pointing Loss	0.3 db		+0.3 db −0.1 db
Totals	142.5 db		
Received Signal		−124.7dbw	
Equivalent noise input (235°K in 1.6MC)		−142.9dbw	±0.5 db
Receiver C/N		18.2 db	
Margin above 12 db C/N		6.2 db	
Sum of tolerances			±3.7 db
Margin above maximum pessimistic tolerance		2.5 db	

As shown in Figure 5, each television transmitter leg consisted of the following sub-assemblies:

1. FM Modulator
2. X12 Multiplier
3. X4 Multiplier
4. Intermediate PA
5. 60 watt PA
6. Transmitter Power Supply
7. Telemetry processor and rf combining section, consisting of:
   a) a stripline, 4-port hybrid ring
   b) dummy load

The telemetry transmitter, designed and built for JPL, as a part of their television subsystem, by the Astro-Electronics Division, Defense Electronic Products of the Radio Corporation of America, employed a Resdel P-30 E, (Figure 6) later modified to P-31EJ, cavity in the power amplifier. Originally designed as a 25 watt unit (yet having a power capability to 59 watts) employing the ML-7289/3CX100A5 it was subsequently modified to accept the ML-7855 and re-rated to 60 watts. The cavity amplifier had been accepted by JPL because of the manner in which it had met and exceeded their published performance specification. Some of the tests which had preceded this amplifier acceptance included:

Thermal-Vacuum Test. In this test during which the unit's temperature gradually rose from approximately +10° to nearly +80°, the power output was plotted against time and temperature. During the "mission on-time" the heat rise was not significant (it was in the order of

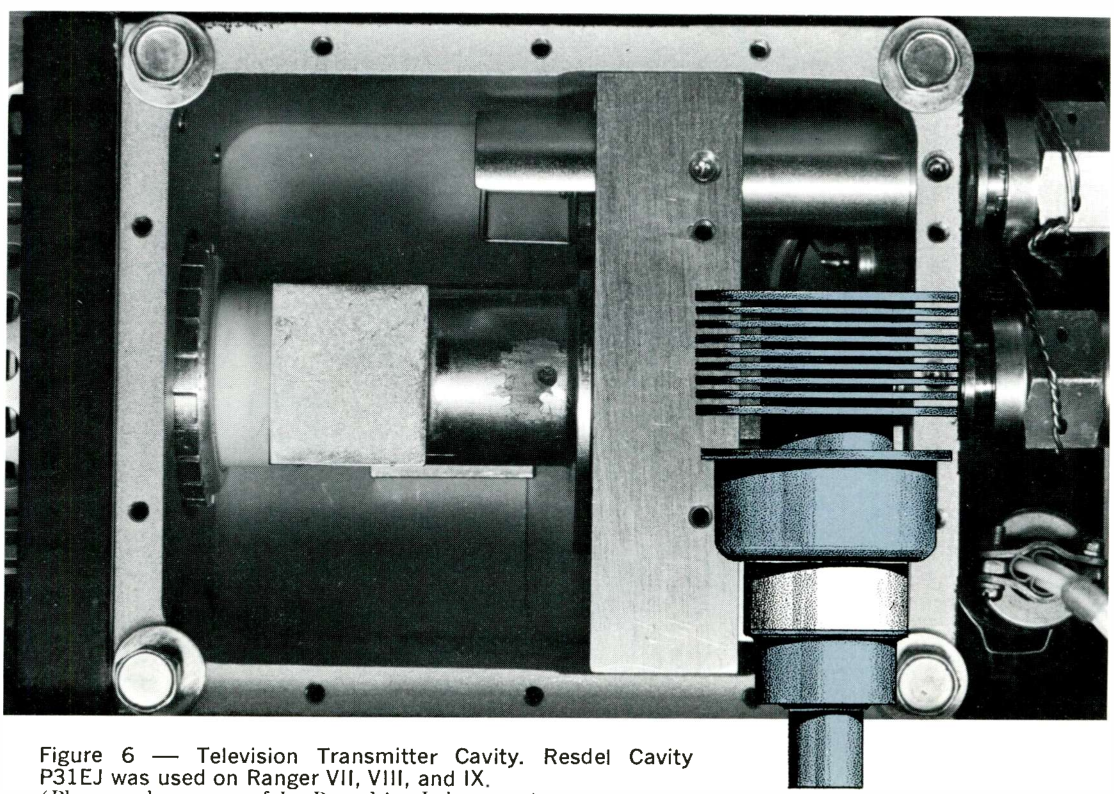


Figure 6 — Television Transmitter Cavity. Resdel Cavity P31EJ was used on Ranger VII, VIII, and IX.
(Photograph courtesy of Jet Propulsion Laboratory.)

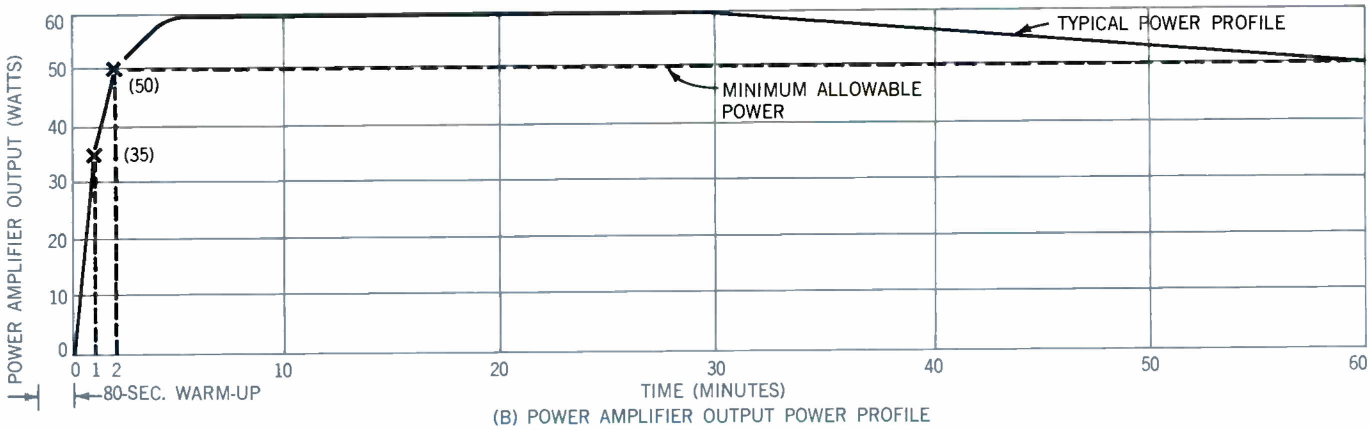


Figure 7 — Power Amplifier Output Power Profile. Amplifier reaches operating power two minutes after "On" time, following 80 second warm-up.

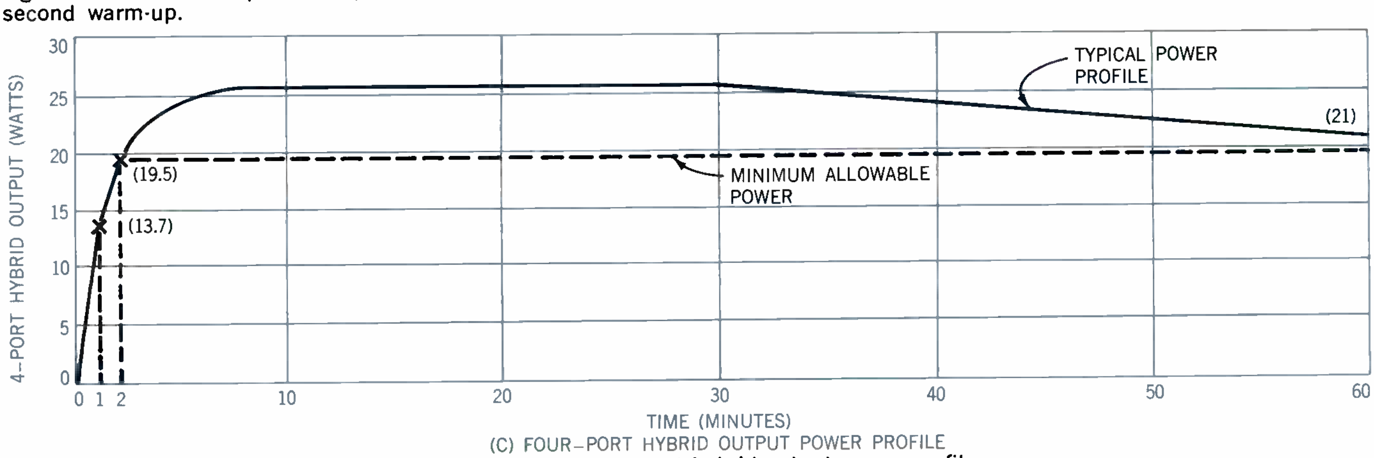


Figure 7A — Four port hybrid output power profile.

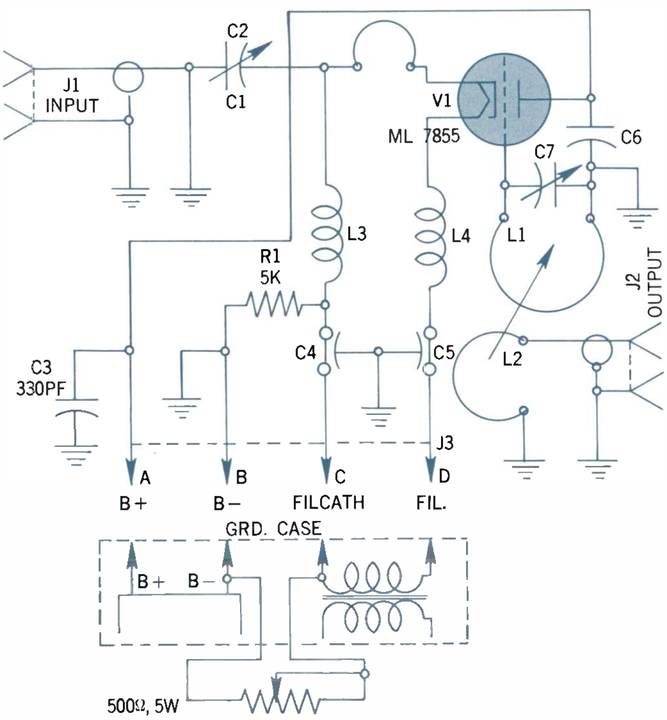


Figure 8 — Schematic drawing of P31EJ Resdel cavity employing ML-7855, as used on Rangers VII, VIII and IX.

10°C) and the power out was virtually unaffected.

Vacuum-Voltage Tests. Following an extended period, during which=the amplifier had been maintained in a vacuum of between 8.2 x 10^{-6} and 2.6 x 10^{-6}, voltages to +1500 V were applied without causing arcing or corona. To assure that the unit, which operated at 1 kvdc, would not arc, the entire power amplifier was pressurized at one atmosphere. To further assure high voltage stability the incoming 1000 volts was brought to the amplifier by coaxial cable.

Given high credit for combining efficient performance with good stability, the amplifier, as has been noted, had

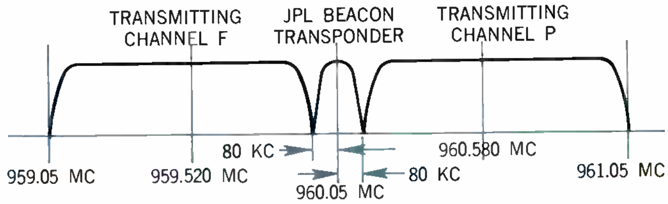
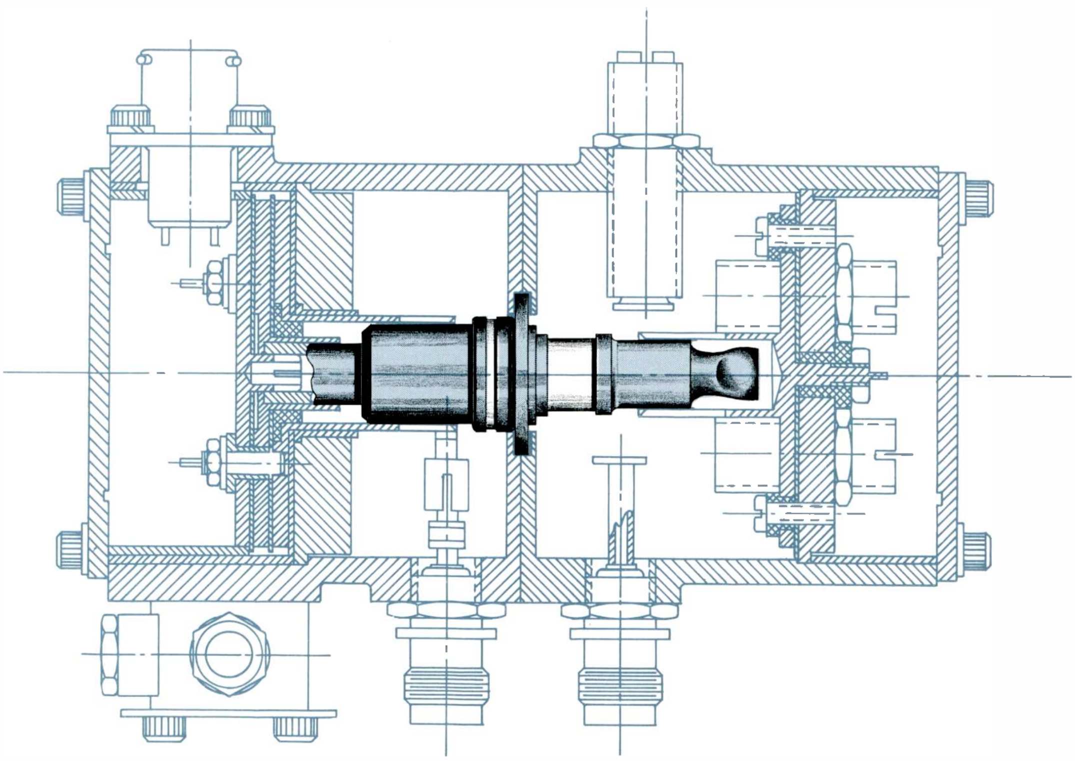


Figure 9 — Transmitting Frequency Allocations for the Ranger Spacecraft.

the capability of operating at a 59 watt level with the ML-7289/3CX100A5. It became apparent, however, that the mission/warm-up/on-time specification would not be satisfactorily met with the ML-7289/3CX100A5. To permit the transmitter's use of the required 60 watt level during the allotted on-time during (the terminal phase) the amplifier would have to be on frequency at power within 80 seconds. The conventional planar triode would not establish adequate thermal/frequency equilibrium within a period measured in less than several minutes. As a consequence, the ML-7289/3CX100A5 caused an unacceptable frequency shift.

As clearly indicated by the power output profiles of Figures 7A and 7B, plotting power against time, use of the frequency-stable ML-7855[11] provided a satisfactory solution to the problem. (In addition, the ML-7855 cathode — a "matrix" cathode[12], known in Machlett tubes as a Phormat cathode — provided a high margin voltage stability, Phormat cathodes having operated satisfactorily without arcing at voltages which destroy conventional cathodes.) The second of the two figures, Figure 7B plots the actual amplifier response operated for Ranger IX. These response curves show how well the predicted and the actual performance coincided.



Television Transmitter Operational Requirements

As shown by Figure 8 the ML-7855 was operated in a grounded grid configuration. Principal specifications for the 60 watt transmitter are these:

Each transmitting channel shall provide an output of approximately 900 kc. The "full-scan transmiter" will be tuned around 959.52 megacycles ±0.0035%; similarly, Channel P (partial scan) centers around 960.580 mc ±0.0035%.

Deviation and Linearity:

Total deviation 346±34 kc over +0.125 to −1.875 dc input range.

Deviation Linearity within 5%

Modulation Distortion and Linearity

At center frequency total 2nd and 3rd order harmonic distortion shall not exceed 5% for 2v, peak to peak, sine wave input over 10 — 100 kc input frequency range; ranging to 10% over 200 — 225 kc range.

Amplitude range ±1.5 db, 1 — 70 kc; to ±3.0 db at 225 kc.

Center Frequency and Stability

After 80 seconds:

F Channel carrier center frequency 959.52 mc ± 0.0035% P Channel carrier center frequency 960.58 mc

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11 "Frequency Stable Design for Planar UHF Tubes", by Werner Brunhart, Chief Engineer, Small Power Tubes. CATHODE PRESS, Vol. 18, No. 3, 1961.

12 "Phormat Cathode", by Werner Brunhart, CATHODE PRESS, Vol. 18, No. 3, 1961.

±0.0035%. These frequency limits to be maintained for base plate temperature of 0°C to +85°C. For wider limits, −10°C to +65°C, frequency stability will be ± .005%.

Intermediate Power Amplifier

Rangers VIII and IX employed an IPA producing approximately 25% greater drive than on Ranger VII. Also employing the ML-7855, this IPA was operated in a constant current configuration, a mode which served to maintain a full, constant power output.

Telemetry Unit

The introductory paragraph in the JPL specification for the telemetry amplifier cavity for the beacon transmitter reflects the standard they required — and received — from those manufacturers participating with them in the Ranger Program. The specification says:

"Foremost in importance in the manufacture of this unit is the necessity of quality control far in excess of the degree commonly accepted as 'good commercial practice'. This unit is designed for use in Deep Space applications and as such must be manufactured to the highest degree of reliability industry can offer. This unit is classed as a UHF (cavity type) amplifier in the L-band frequency range . . .".

The device[13] itself, a quad cavity amplifier, is comprised of two redundant sections, each driving an antenna (See Figure 12). Each section consists of a 1/4 w cavity driving a 3 watt cavity. 7 mW of power drives each section for a power gain of 16.32 db.

Requirements for temperature/power output stability were strict: a minimum deterioration of 0.3 db with the cavity temperature varied over the range of −10°C to +65°C in a dry atmosphere. To maintain constant performance, which included wide changes of temperature during operation, the quad cavity was fitted with an ingenious tuning probe[14] inserted in the plate line. The probe (Figure 10) exhibited a negative characteristic with temperature, shrinking with heat, expanding with cold. As the cavity temperature drops the cavity shrinks increasing the tuning length and decreasing the operating frequency. The probe, however, expands, comes closer to the plate and effectively shortens the line, thereby increasing the operating frequency, restoring it to the desired value. Figure 11 shows a typical response over a 75°C range. Construction of the probe is as simple as it is effective[15].

Phase stability of the amplifier in a static condition must be such that it would add no perceptible phase error to the driving signal when monitored on a noise-free, phase coherent receiver with a 100 cps noise bandwidth. In view of the fact that Ranger used a phase-lock system for communication and space craft command, the phase stability characteristic (notably associated with triode amplifiers) was of particular importance.

The amplifier, to be acceptable for operation in the "deep" vacuum of interplanetary space, was tested under simulated conditions simulated with 500 volts (twice the maximum operating voltage) impressed on the plate of the amplifier tube. This tube, the ML-546, (a special version of the ML-6771), was the active element of the cavity. Its manufacture and evaluation, specified and monitored by JPL, was carried out entirely by Machlett engineering personnel.

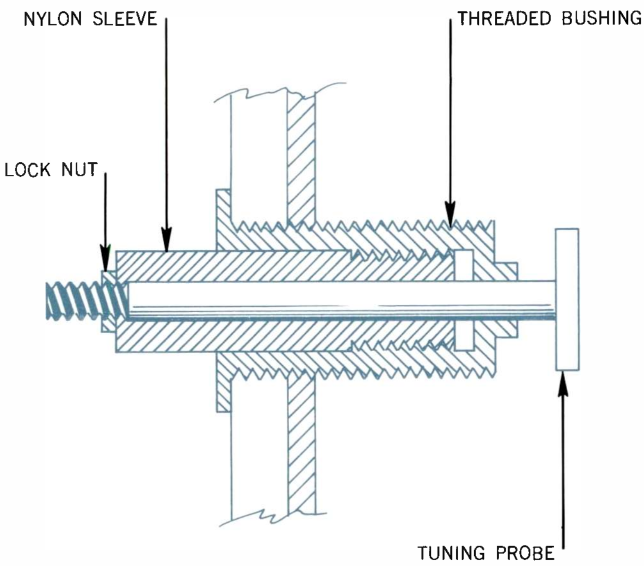


Figure 10 — Tuning probe with negative thermal characteristic used in telemetry cavity to maintain stable frequency/power output (From NASA Tech. Brief 63-10179).

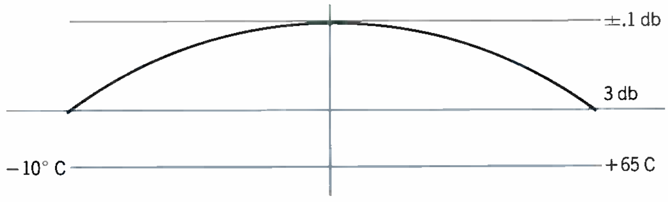


Figure 11 — Quad cavity power output over 80°C range, from −10°C to +65°C.

[13]Manufactured by Resdel Engineering Corp. to JPL design and specifications.

[14]NASA Technical Brief 63-10179, May 1964.

[15]"A nylon sleeve is fitted between the tuning probe and the threaded bushing in which it is mounted. The sleeve is tapped to permit adjustment of the threaded probe for proper tuning. The nylon has a higher expansion ratio than the surrounding metal of the compensator housing. As the temperature rises, the nylon expands and carries the tuning probe away from the plate line. This action maintains the desired negative grid characteristic of the capacity of the tuning probe as related to the plate line."

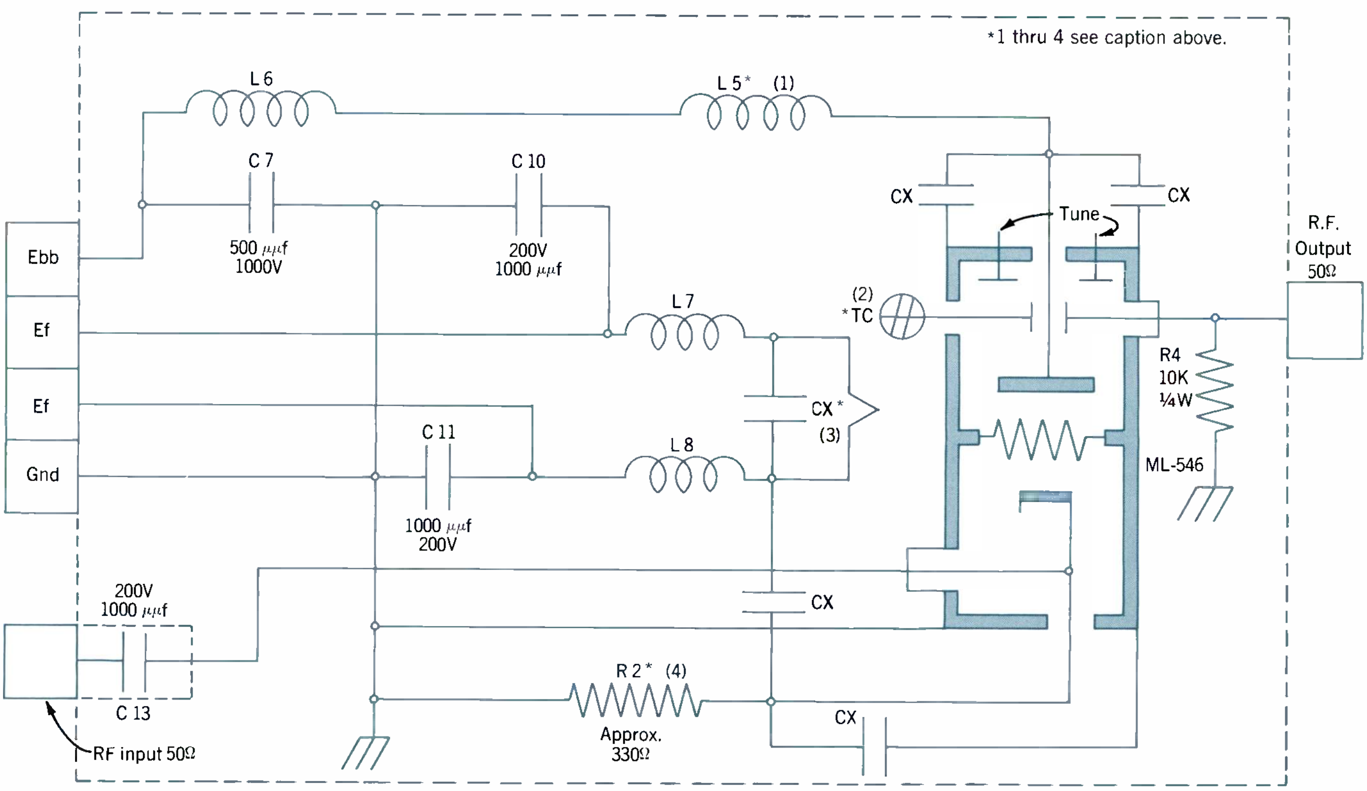
To assure reliable cavity performance, the switching function was assigned to the cathode heater circuit, so that switching could take place at low voltage; plate voltage was left on continuously. (See Figures 13A, B, & C.) This method of operation prevented — or at least reduced to the vanishing point — the possibility of arcing, especially in the period following launch, and lasting about 23 minutes[16], during which time the Ranger passed through the ionized upper layer of the earth's atmosphere. To further reduce arc possibility during this period, the entire unit was operated at reduced power, 150 v only being impressed on the ML-546 anode. At the threshold of interplanetary space, electrical conditions having improved, the plate voltage on the telemetry unit was increased to 250 v.

Operation requirements for the ML-546 included two conditions: one for launch + 23 minutes, the other for cruise. The low power condition (Condition II) is this:

[16]*This is a busy period. During the first eight minutes the Atlas (1st stage) and Agena (second stage) rockets have boosted the Ranger to a point 115 miles above Africa. Atlas has been jettisoned and Agena awaits the time for a final burst of acceleration, one which, for the electronics practitioner must surely be dazzling. Electron transit time would scarcely seem to be much more rapid — though, of course it is; as for the sportsman who finds achievement in reaching 100 mph in something like a minute, one may offer a sympathetic nod — for Agena, during its final 90 second burst ± .1 second, accelerated the Ranger by seven thousand miles an hour to a terminal speed of 24,525 mph ± 8 mph. (To this incredible mastery of control add the fact that the craft had to penetrate a ten mile "window" in order to be on course for the moon, and permit the "mid-course" maneuver, a trajectory correction made after 16 hours of flight). With the Ranger established on its way, Agena leaves, reorients itself so as to miss the moon and starts toward an elliptical solar orbit. The Ranger tumbles slowly as Agena leaves; cold gas jets, under gyroscopic control provide the impulses needed to stabilize the craft and orient it to the sun. The telemetry power is on full now; the command and control system has been released to give flight commands; in a little over a half hour the solar panels will open, the TV system will be readied, but held inoperative; and finally after about three hours the sun and the earth sensors will have acquired their targets, the high gain antenna will have been deployed and craft will sail securely toward its mid-course point. One can imagine the stewardess taking orders for dinner and the pilot assuring us that we're right on course and should be passing just a little to the left of sunrise as we round the turn.*

Figure 12 — Low gain and high gain sections of Quad Cavity. ML-546 shown schematically. Both cavities operate with 110v E_{bb}, 5.2v E_f during post launch period, and 250v E_{bb}, 5.7E_f during Ranger cruise mode.

(1) L5 through L8 .22μhy
(2) Thermal Compensator
(3) All CX capacitors are built in
(4) R2 value selected for proper performance



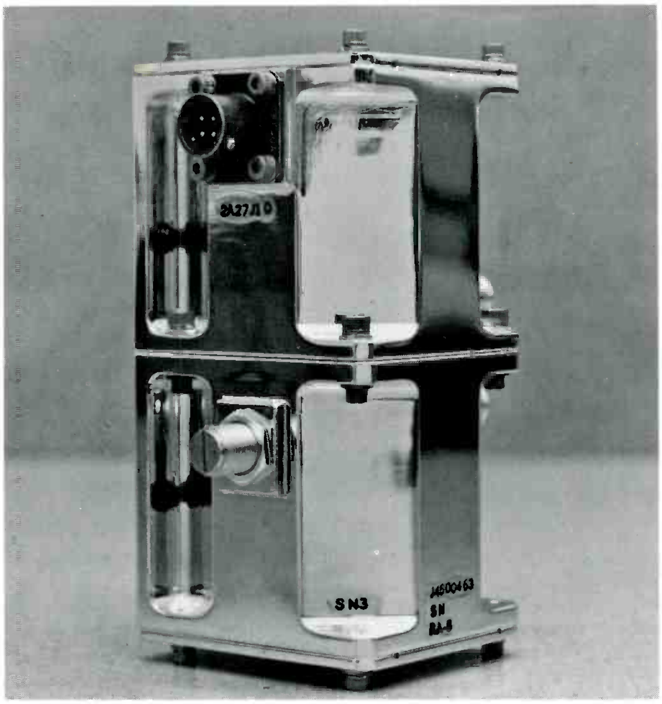


Figure 13A — Driver cavity of Telemetry Unit, an ML-546 operating in grounded grid configuration similar to that of High and Low gain cavities, is employed. (Photograph courtesy of Jet Propulsion Laboratory)

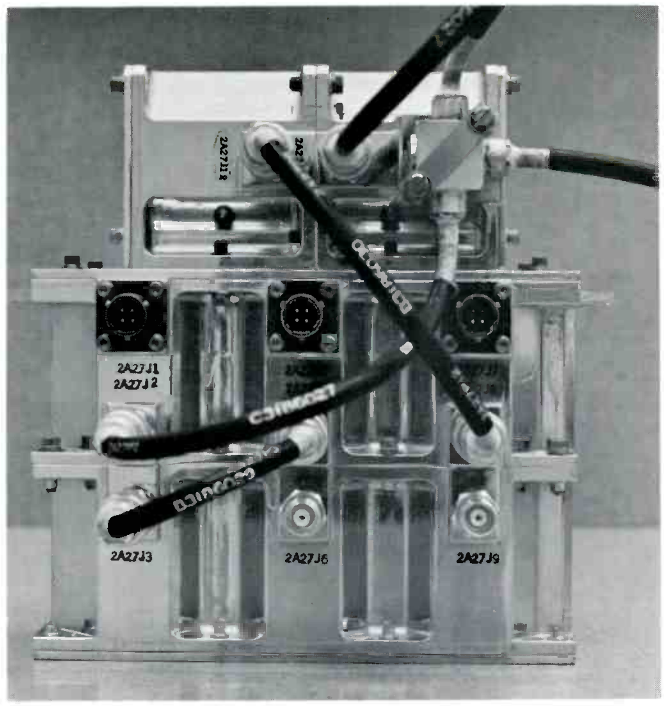


Figure 13B — Quad Cavity assembly complete with driver unit. (Photograph courtesy of Jet Propulsion Laboratory)

E_f	5.7 V dc
I_f	550 ma dc
E_p	110 V dc
L_p	7 ma dc
P_o	0.25 w (in the 960 mc quad cavity)
P_i	0.005 w at 960 mc
Minimum power gain	50
Minimum plate efficiency	32.5%

The cruise condition, (Condition I) is this:

E_f	5.2 V dc
I_f	510/550 ma dc
E_p	250 v
I_p	21 ± 1 ma dc
P_o	3.0 w minimum (in the 960 mc quad cavity)
P_i	0.25 w at 960 mc
Minimum power gain	12
Minimum plate efficiency	54%

ML-546 and The Quad Cavity

Since the performance at the quad cavity depended on the tube/cavity match, and since the cavity design was firmly established, it was Machlett's assignment to construct and match to the cavity a tube which would provide the desired output and bandwidth at a minimum VSWR. Whereas delivery specifications called for a maximum VSWR between of 1:70 to 1, the units submitted by Machlett ranged between 1:08 and 1.60.

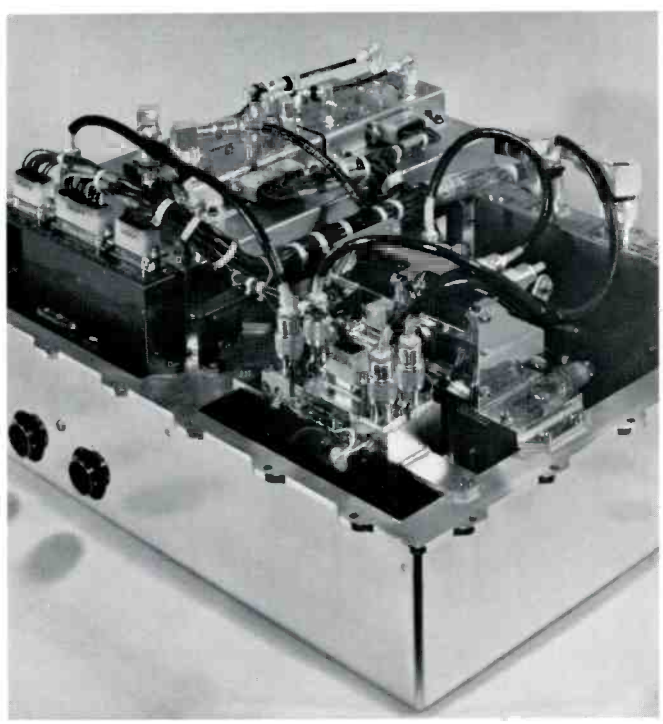


Figure 13C — Telemetry Assembly; quad cavity and driver in foreground. (Photograph courtesy of Jet Propulsion Laboratory)

Manufacturing specifications — ML-546

Although the basic tube design remained unchanged, the JPL specifications for the tube's manufacture were specific and exact, concerning quality levels for components, manufacture and testing, as indicated by these examples.

Ceramic: Inspection of the high quality alumina ceramic to be 100 percent die checked; examined for cracks under 10X magnification before and after the plating cycle.

Cathode Assembly: Cathode spraying was performed by engineering personnel and inspected microscopically after coatings had been deposited.

Grid Assembly: Here again, a microscopic examination was employed to check against particles, determine character of mesh tension and finish of grid edging.

Final & Post Assembly Tests: X-ray examinations were performed to determine freedom from solder voids, and particle contamination to check seal conditions, getter and heater locations.

Each tube was heated to a temperature of +125°C and then checked in the final test jig to determine that no change in characteristics had occurred.

100% tests were made for seal torque and tube concentricity. 10% of tubes made to these specifications were tested, electrically and mechanically, to destruction to determine tube limitations. Microscopic examinations of these tubes followed.

The precision with which Machlett achieved the needed ratio may be appreciated when it is considered that tube dimensional tolerances had to be kept within a few microns. The capacitance measurements for the ML-546 were to be held, for the grid-cathode capacitance to 1.925±.025 pf and to 4.05±.10 pf for the grid-plate. Corresponding measurements for standard tubes are, g-k 1.75 to 2.30 pf and g-p 3.60 to 4.55 pf. The grid-cathode spacing of the ML-546 was adjusted to these extremely tight measurements (an order of magnitude closer than normal) with correspondingly outstanding results. Test data taken from the ML-546 operated in the JPL test cavity (at E_f 5.7 v) and test system indicates, for example, for 3 shipments, an average VSWR of 1.34.

Test of the Tubes

After aging, the tubes are subjected to the normal static tests in order to verify that their characteristics are acceptable. Over and above these standard tests, it was mandatory that each tube be tested in the final equipment circuit[17] under actual flight conditions. Only this test really

[17] Performance and final test equipment consisted of a two bay test jig containing a single cavity 960 mc JPL unit electrically equivalent to the flight mode cavity and the equipment listed below:

a. Test Signal Generator, Hewlett-Packard Mod. 612
b. JPL D-6771-1 Cavity Amplifier
c. Dual Directional Couplers, H-P Mod. 766D
d. Power Monitor, H-P 430C

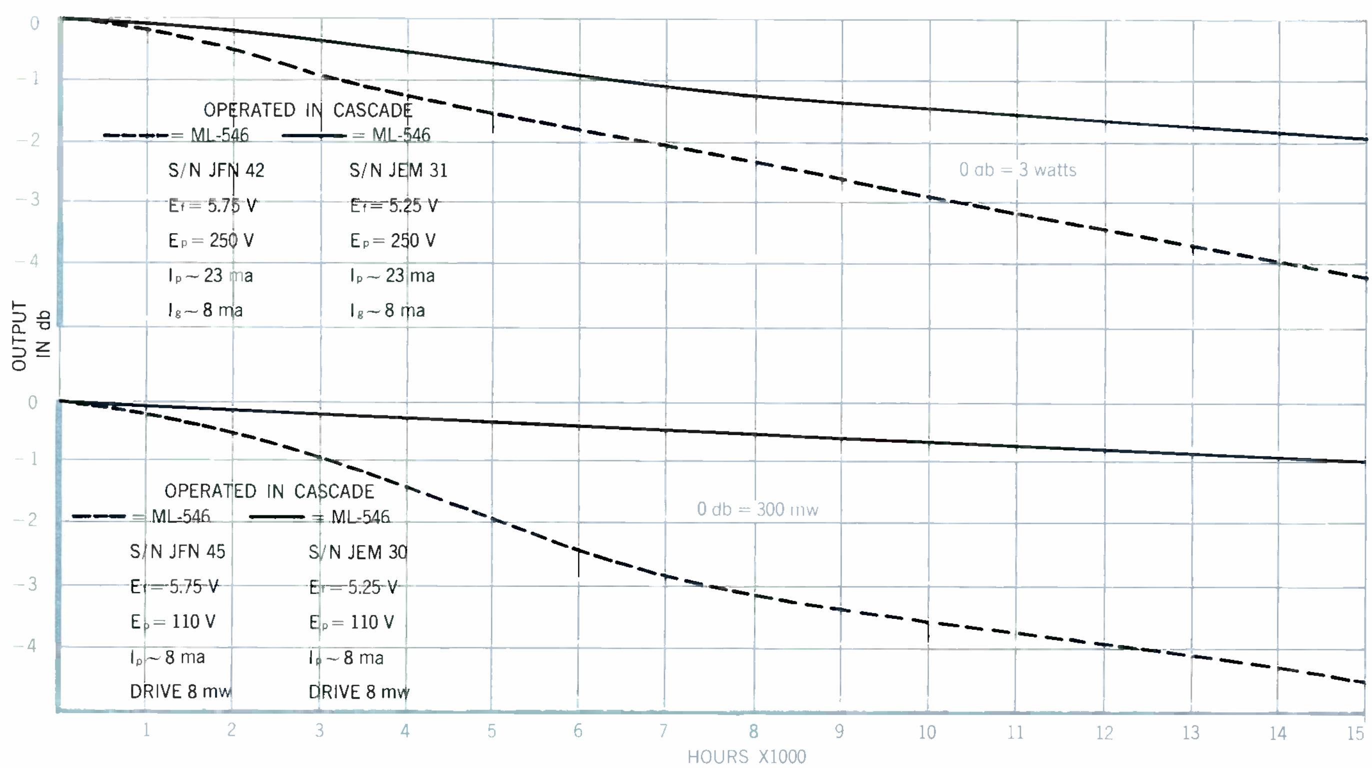


Figure 14 — JPL life test data for ML-546. Maximum power loss, 4½ db at 14,500 hours. Tests were concluded prior to tube failure.

proved if the tubes were acceptable. The test in the final equipment is repeated a second time. The first test is done only after the tubes have been shelf-aged for several days. Only tubes which repeat original test data within the accuracy of the instruments are accepted. After this the tubes received an ambient temperature cycle of about —62°C to +150°C. Then, the final test is again performed in the flight test circuit.

Following this, the tubes were shipped to JPL, which then conducted its own series of tests. The tubes were tested in the final circuit for at least 400 hours. Only tubes which performed well and showed no performance changes up to this point were accepted for flight equipment. In the flight equipment itself, all components undergo extensive testing lasting to 1300 hours.

Performance tests made included those at 5.2 and 5.7 E_f. Gage, measuring and test equipment were themselves monitored for required accuracy and calibration. As described by the JPL specification: "The Contractor shall have available a set of master gauges, standards, and appropriate instruments to conduct regularly scheduled calibrations of his inspection and test equipment." Records of these inspections were maintained and were at all times available to JPL.

Proof of the fine results achieved by this superior diligence was revealed in several ways.

1) No Machlett tube failed in any Ranger flight.
2) With power levels measured in 1/10ths of a db the system power output was constant from the telemetry unit to the antenna (the link itself dropped by about 30 db over the mission range).
3) With telemetry power levels only measured and under tube "burn-in" (100 hours) and stabilization (350-400 hours) power level variations did not exceed 0.1 db.
4) Life test measurements made by JPL. Over a period of nearly two years (the tests were actually terminated prior to tube failure) ML-546 tubes were operated at 5.2 and 5.7 v respectively. (Figures 14A and 14B). Tubes shown are operated in cascade, with the operating values shown. Figure 14B shows, for example, that power output was degraded by only — 1¾ db (0 db = 3 watts) following nearly 15000 hours of operation. Output degradation was —4 db for the tubes operated at 5.7 v E_f.

e. Thermistor Mount, H-P 477B
f. 50 ohm load, Microlab, Mod. TB-5FN
g. Power Supplies — 2% regulation, or better.

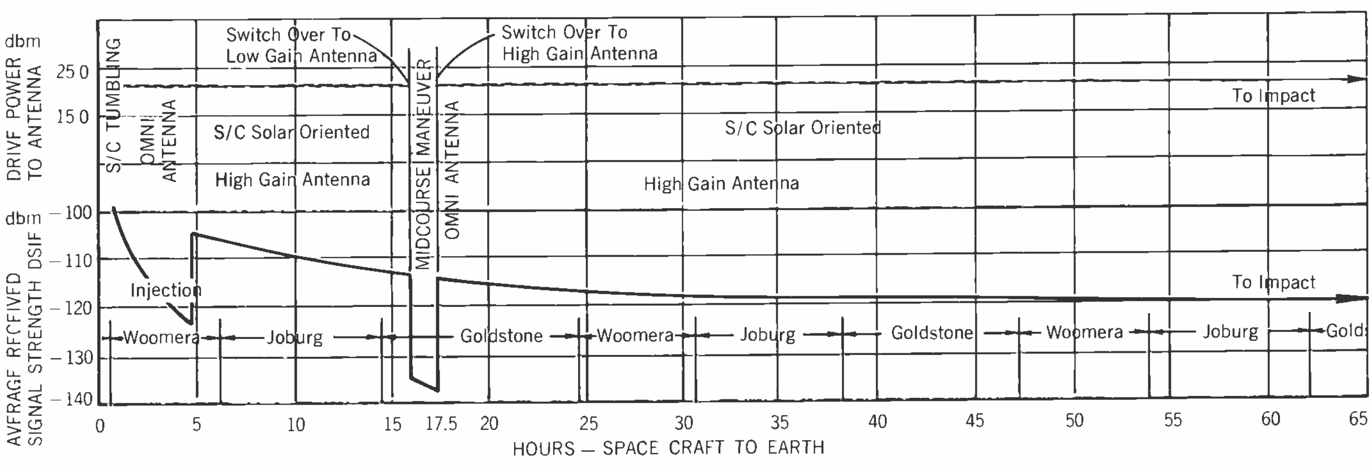
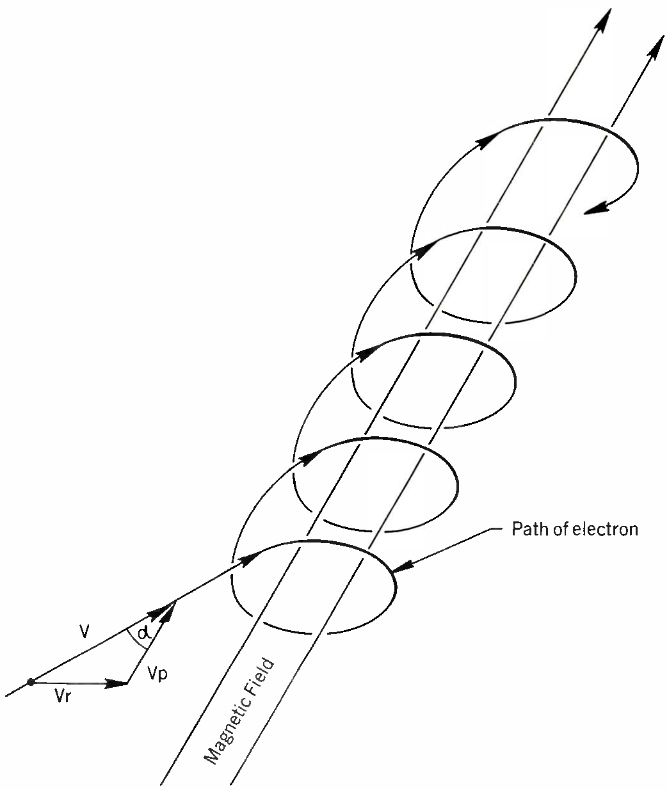


Figure 15 — Ranger IX mission profile, telemetry. A: Hours vs. Average Received Signal Strength. B: Signal strength at the telemetry transmitter. (Source: Ranger VII).

• • •

"Space hours" provide a new measure of national discipline. Where costs must be reckoned in at least hundreds of thousands of dollars per hour; where a ratio of ground support to "flight personnel" must be a minimum of several thousand to 1; where the ratio of the unknown to the possible and to the hoped for is so vast; and where, in the final analysis, the pride and future of a nation provide the informing context, then "space hours" become a new and supremely important unit of measure. Paradoxically, perhaps, the participant in "space hours" must — in this age of uniformity and mass production — be a specialist. Space requirements demand a measure of uniqueness from the individual, whether he be a craftsman, technician, or engineer. Each must join in each project (no one space vehicle has an exact twin) to do his specific best in an undertaking of whose technological complexity is matched only by its great and human significance.

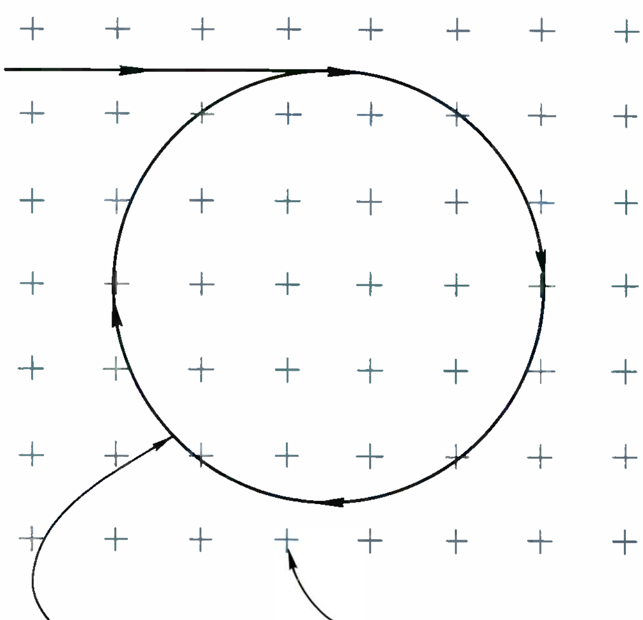


Magnetic

by *DR. J. A. RANDMER, Chief Engineer, Large Power Tubes*

Summary

This article briefly describes the most disadvantageous effects of grid currents in power tubes. It recounts the various means, such as additional grids, electrostatic beaming, etc. which have been used to reduce these grid currents. Finally, it describes the principles and some practical results of a new magnetic beaming method which has proven to be very effective in reducing the grid currents.



Electron path clockwise. If magnetic field would be reversed it would be counter clockwise.

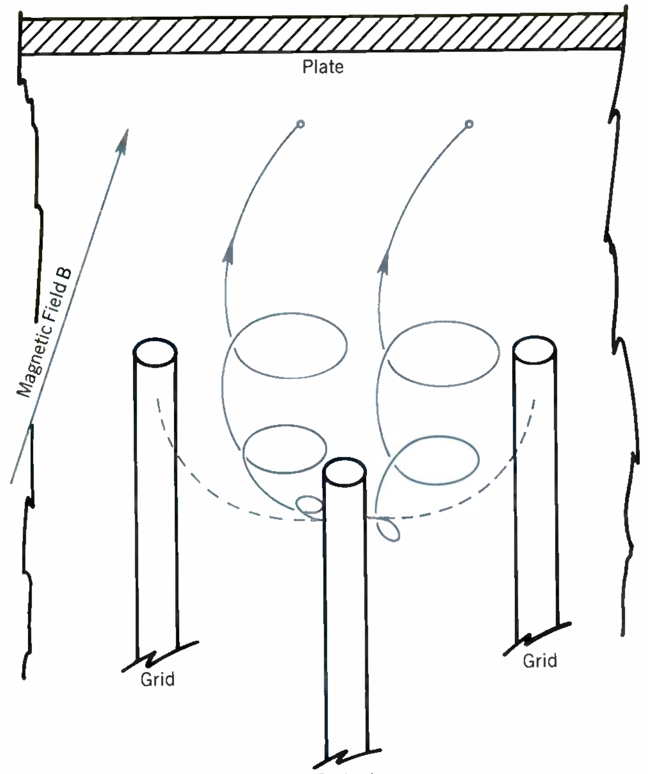
Magnetic field, direction perpendicular to and into paper plain.

Grid Currents — The Nuisance in Power Tubes

Ideally a grid or a set of grids should control the electron current flow to the anode without any interception of electrons. The power gain of such a tube would be infinite, except for losses associated with the circuitry used to provide the grid control voltage. This mode of operation can be realized in practice if the control grid potentials, including the peak excursions, are held always negative in respect to the cathode. However operation of power tubes is characterized by the fact that in the majority of cases the control grid has to be driven positive. This is necessary in order to obtain the substantial current flow necessary for power generation. As soon as the grid is made positive, it attracts a portion of the electron flow which leads to three major disadvantages:

First, since the grid draws current it requires driving power to establish the positive control grid potentials which reduces the power gain. Second, the grid is heated by electron bombardment, and third, because of the current interception of the grid, a part of the available cathode emission

Beaming In Power Tubes



cannot be utilized for the useful task of generating output power. Of these three factors the grid heating imposes probably the most serious limitations. In applications it usually limits the output power which can be obtained from a tube since excessive grid heating would result in sufficient primary grid emission to make grid control difficult or impossible. In tube manufacturing it poses a variety of difficult tasks, such as the suppression of primary grid emission and the maintaining of the grid geometry at high temperatures. This applies to most types of operations, whether they involve the generation of some form of rf power or the various pulse modulator applications. It also applies to multigrid tubes except that for such tubes the power output is limited by the permissible screen grid dissipation.

Reduction of Grid Currents by Beaming

One of the reasons for the growing popularity of power tetrodes is their relatively high power gain. This is due to the fact that more current can be drawn in these tubes from the cathode with the control grid at negative instantaneous potentials. As noted above, the limitation imposed by the control grid dissipation is shifted in tetrodes to the screen grid. This grid must be held at a relatively high positive potential in order to perform its function and hence it attracts a part of the electron current. In order to minimize the current interception by the screen grid, the control and screen grid elements are carefully aligned forming an electron optical system which causes the electrons leaving the cathode to be compressed into beams which pass between the screen grid wires. Only electrons travelling at the periphery of these beams are intercepted by the screen grid. The electron optical action of the aligned grid and screen grid is a typical example of electrostatic beaming.

In triodes significant electrostatic beaming action has been achieved in the shielded grid designs. Examples of shielded grid triodes are the ML-6544[1] and the RCA 6949[2].

The typical construction of such tubes shows a precise radial alignment of cathode, control grid and shield grid wires which extend in the axial direction of the tube. Each cathode wire, or an emissive strip of coating in the case of an oxide cathode, forms an electron optical system with two control and shield-grid wires which are precisely spaced in relation to the cathode wire or strip. This system gathers the electrons into a radial ribbon beam and reduces grid currents considerably. Accordingly these tubes require relatively low driving power. For instance, the RCA-6949 can develop 500 kW of CW power with only 2 kW of drive power. The ML-6544 which has a pulse cathode current rating of 75A can deliver a 50 A plate current pulse at a plate voltage of 2 kV and a grid current of about 2 A. The ML-6426 which is a conventional triode having a 85 A cathode current rating draws under similar conditions a grid current of about 10 A or about 5 times more. The ML-6544 has a perveance which is about 40% higher than for the ML-6426. However, the improved performance of the ML-6544 is mostly due to the beaming action.

While shielded-grid triodes have relatively low grid

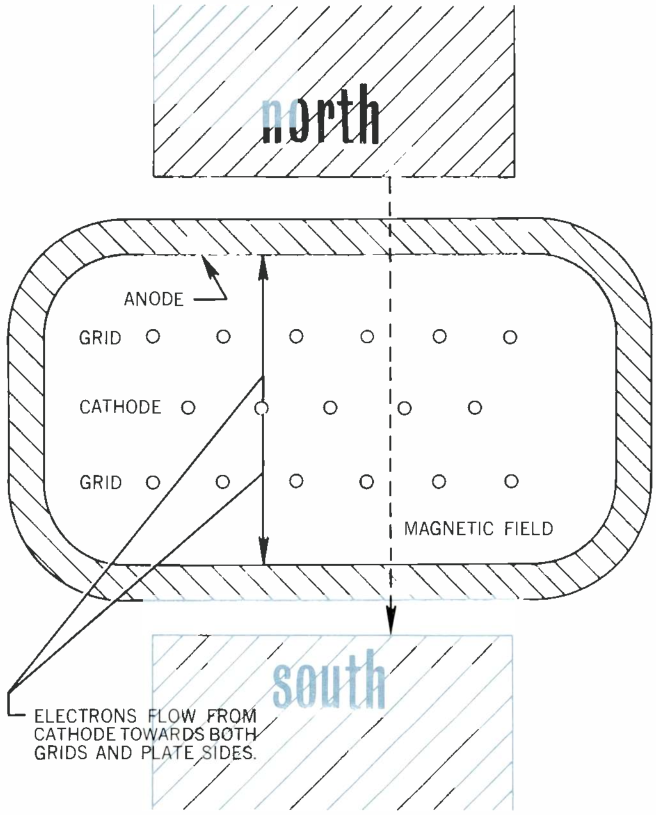


Figure 1 — Schematic Cross Section through Magnetically Beamed Tube.

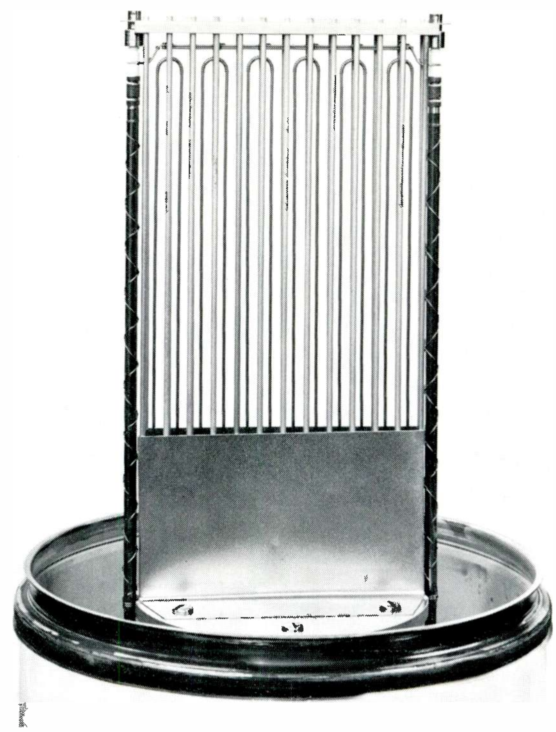


Figure 2 — Electrode structure of LPT-14.

currents, they have also a number of drawbacks, such as high input capacity, relatively low plate efficiency, and relatively high cost which to a large extent is the consequence of the precise alignment needed in the electron optical system. Their application has therefore been limited to relatively few specialized cases.

At Machlett Laboratories, efforts toward further, improved means of eliminating grid currents have been continued and have more recently lead to the introduction of magnetically beamed grid controlled power tubes.

Basic Construction of a Magnetically Beamed Tube

A schematic cross section through a magnetically beamed triode is shown in Figure 1, and a side view of the electrode structure of an experimental model in Figure 2. Somewhat similar to shielded grid triodes, the cathode and grid wires extend again straight in the axial direction of the tube. However, the cathode, grid and anode are not concentric as in conventional tubes, but are arranged in parallel planes. All grid wires are electrically interconnected and are at the same potential. The anode has two extended flat surfaces which are connected by relatively narrow side walls. The cathode wires are held in the center plane of the anode between two arrays of grid wires. In this arrangement an electron current can be drawn from the cathode toward both grid and plate sides. The poles of the external magnet are arranged parallel to the cathode, grid and anode planes so that the direction of the lines of force of the magnetic field are perpendicular to these planes and therefore essentially parallel to the direction of the electron flow. A completed experimental magnetically beamed tube is shown in Figure 3 with its permanent magnet and water jacket. Figure 4 shows the mounting of the magnet on the water jacket which contains the tube. The developmental type number of this tube is ML-LPT14* and its characteristics will be used in further discussions. The flat anode is clearly visible in Figure 3.

Without a magnetic field, the described electrode system functions essentially like a normal triode. The main advantage over a conventional concentric tube is a better utilization of the emission capability of the entire cathode surface. In conventional tubes the cathode wires are arranged on a cylindrical surface which is surrounded by a concentric cylinder of grid wires. Therefore only somewhat more than half of the cathode wire surface faces the grid and the anode. The other part or the "back side" is turned

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*This triode will soon be available in water, vapor and air-cooled versions under the tube type numbers, ML-8618, ML-8619, and ML-8620 respectively. These tubes will be described in more detail in a future issue of *Cathode Press.*

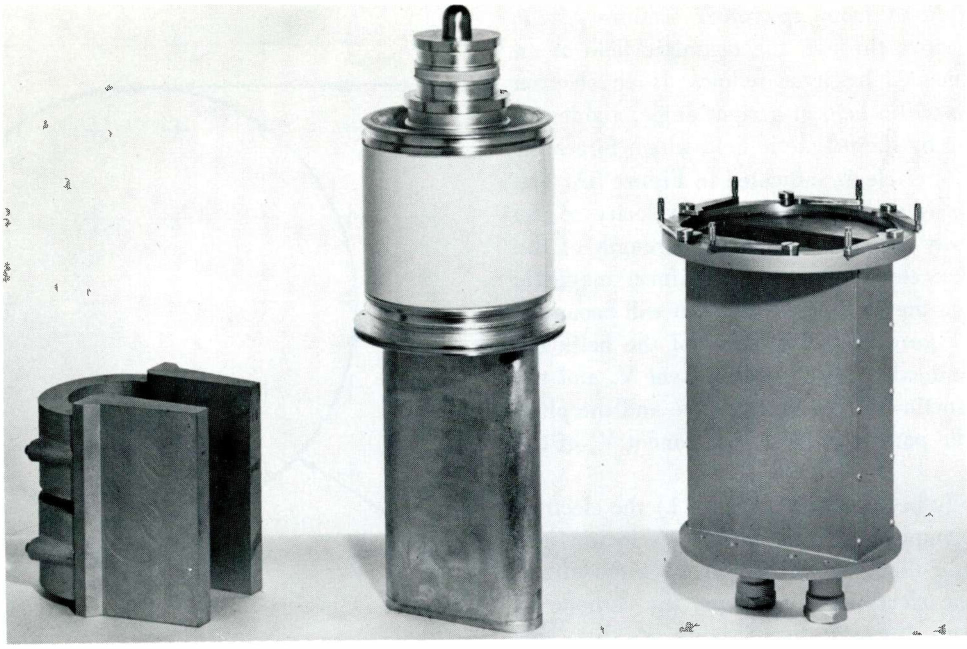


Figure 3 — Magnet, tube, shown with flat anode clearly visible, and water jacket of the magnetically beamed ML-LPT14.

away from these electrodes and is in effect shielded from them by its own curvature. It takes, therefore, a considerably higher grid potential to obtain emission from the "back side" of the cathode wires as compared to the cathode area facing the grid.

High grid potentials are usually avoided since they lead to high grid currents and hence to excessive grid heating. Consequently the emission from the "back side" is not utilized in conventional tubes except in pulse applications in which the duty of the operation is sufficiently low so that the necessary high grid voltage and current peaks can be developed without an excessive average good dissipation or excessive momentary grid heating during the pulse. In the "double sided" construction shown in Figure 1, there is no "back side". This means that for comparable cathode currents a smaller cathode area is needed than in conventional tubes or that the emission efficiency in terms of peak cathode currents obtainable per watt of filament power can be higher in this type of construction.

Action of Magnetic Field

The magnetic field has no effect on electrons which are moving parallel to the magnetic field lines whereby it does not matter whether the electrons move in the direction of the magnetic field or opposite to it[3]. Their velocity is determined only by their initial velocity and by the presence of any accelerating or decelerating electrical fields. In the magnetically beamed tube (Figure 1) these conditions apply only to the electrons emitted from a narrow line along each side of the cathode wires directly facing the

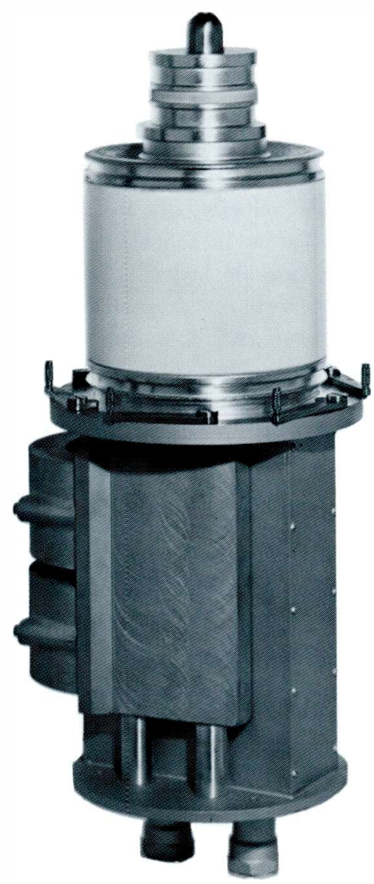


Figure 4 — Assembled magnet, water jacket and magnetically beamed tube ML-LPT14.

anode. Electrons emitted from any other sections of the cathode wires will move through the magnetic field at an angle and are influenced by it as follows. If an electron enters a uniform magnetic field at a right angle, a sidewise force will be exerted by the magnetic field which forces the electron to describe a circle as indicated in Figure 5A. The radius of the circle is proportional to the velocity of the electron and inversely proportional to the strength of the magnetic field. If an electron enters a uniform magnetic field at an angle then the path of the electron will become a helix as shown in Figure 5B. The radius of the helix depends on the perpendicular velocity component V_r and the strength of the magnetic field as stated above and the pitch is proportional to the parallel velocity component V_p of the electron.

In the magnetically beamed tube (Figure 1) the electron motions are more complex since the electron velocities are not uniform meaning that the radius and the pitch of the helix changes as the electrons travel from the cathode to the anode. However, the significant point is that any electrons which have sidewise velocity components toward the grid wires, such as electrons emitted from the sides of the cathode wires, are forced by the magnetic field into helical paths which keep them confined in a beam which passes between the grid wires with considerably less interception by the grid than without a magnetic field. Figure 6 shows these helical trajectories in a prospective diagrammatic form. For simplicity the forward grid and anode planes have been omitted. The dotted lines indicate trajectories which in the absence of a magnetic field would end on the grid wires. As an electron is drawn from the cathode, it starts immediately to curve in the magnetic field due to its side velocity. As the forward and side velocity components grow in the electric field, the spiral radii and the pitch become larger. The sidewise velocity components increase with the magnitude of positive grid drive, but for practical grid potentials and the relatively large electrode dimensions and spacing which are prevalent in high power tubes, it is possible to provide sufficiently strong magnetic fields to limit the radii of the trajectories to such an extent that most of them do not extend to the grid wires. While the computation of the trajectories is rather complex it is possible to establish relatively simple equations permitting computation of the necessary magnetic field strength for given electrode configurations with relatively good accuracy. For a configuration as depicted in Figure 2 the magnetic field strength is in the order of 700 gauss. This field reduces the grid currents at high positive grid drive to a few percent of the plate current as compared to 20 to 30% in conventional tubes.

Experimental Results

Figure 7 shows constant grid voltage characteristics for the developmental triode, ML-LPT14, illustrated in Figure 3 and 4. This tube has a magnetic field of about 700 Gauss.

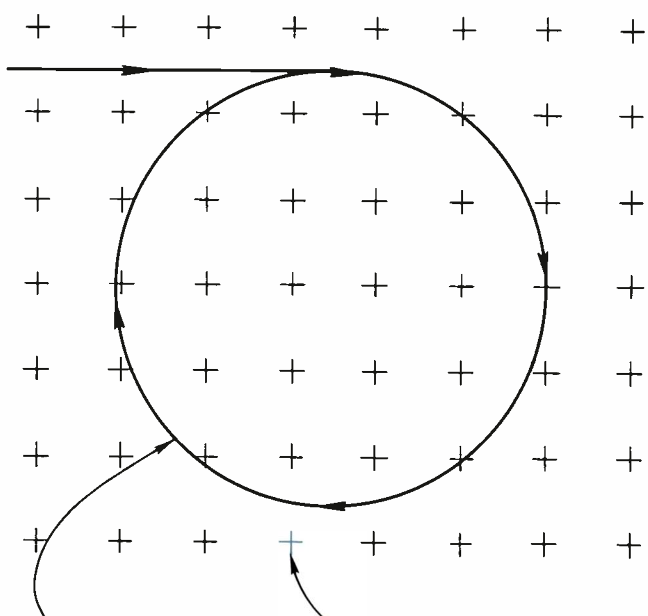


Figure 5A — Electron trajectories in a uniform magnetic field. Initial electron velocity is at right angle to magnetic field.

Note the different scales for the plate and grid currents on the left and right respectively. Figure 8 gives the grid and plate currents for the same tube without the magnet. While the plate currents in both diagrams are quite similar, the grid currents with the magnetic field are very much smaller. For instance at a plate voltage of 3 kV and a positive grid voltage of 1500 volts the plate current in both cases is approximately 150 A. The grid current without the magnet is about 60 amperes and with the magnet only 2.5 amperes.

The magnetic field strength is not critical and can, if chosen sufficiently high, vary over fairly wide limits without appreciably affecting the grid currents. This is shown in Figure 9 which gives the relationship between the plate and grid current and the magnetic field strength. These curves have been measured with an electromagnet using an experimental ML-LPT14. The stability of the magnetic field is easily held to the required limits with the use of permanent magnets, which are very reliable and have relatively unlimited life.

While the beaming action here is illustrated by measure-

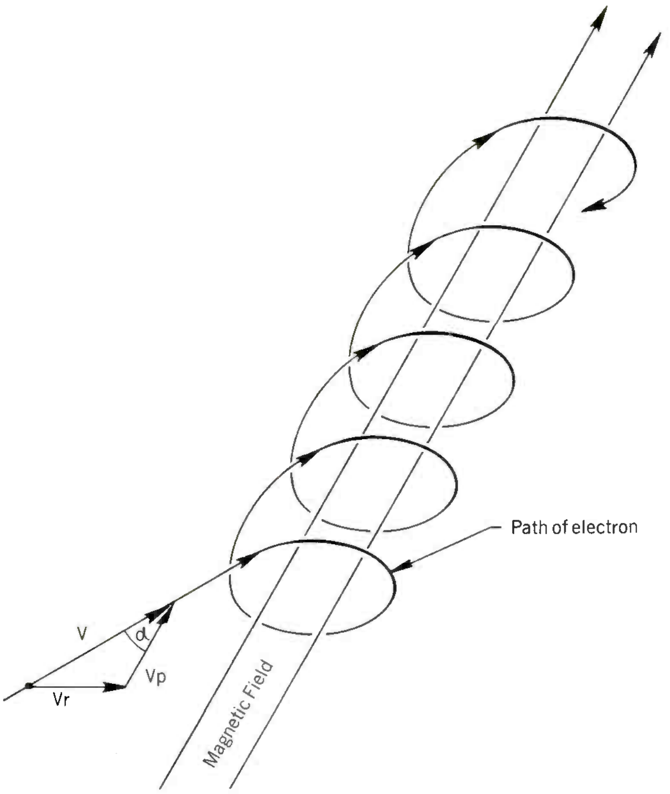


Figure 5B — Electron trajectories in a uniform magnetic field. Initial electron velocity is at an angle α to the magnetic field.

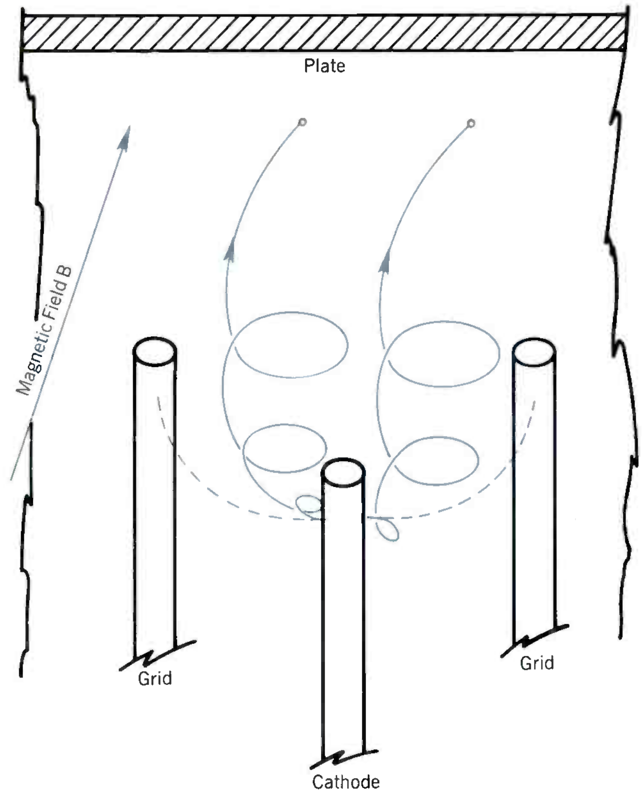


Figure 6 — Schematic of electron trajectories in a magnetically beamed tube.

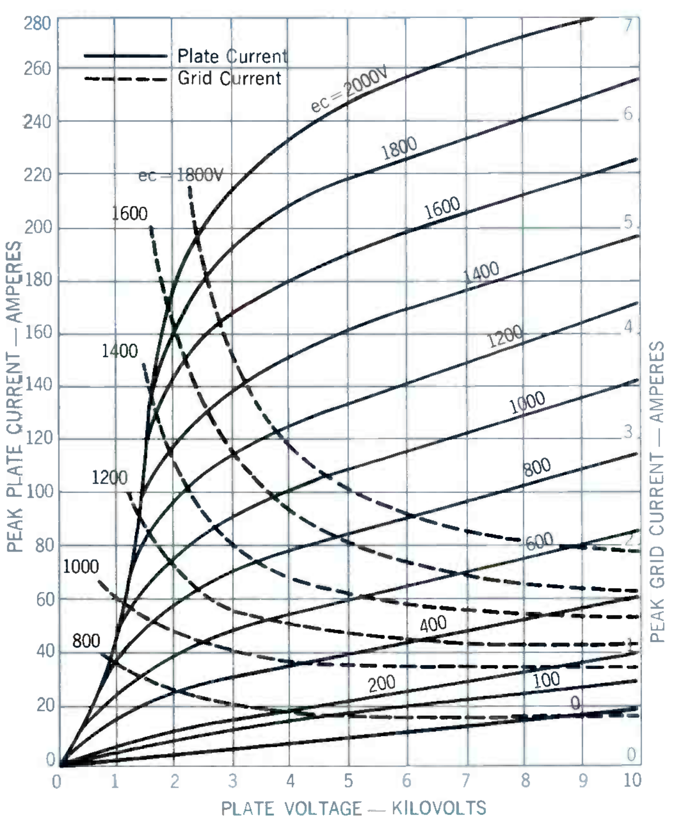


Figure 7 — Constant grid current characteristics of the ML-LPT14 with magnet of about 700 Gauss.

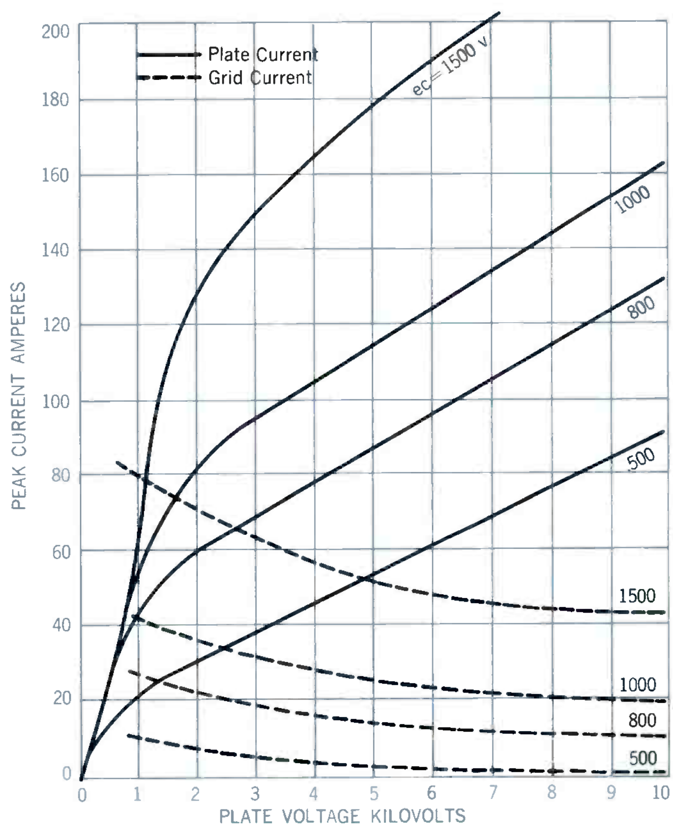


Figure 8 — Same as Figure 7, but without magnetic field.

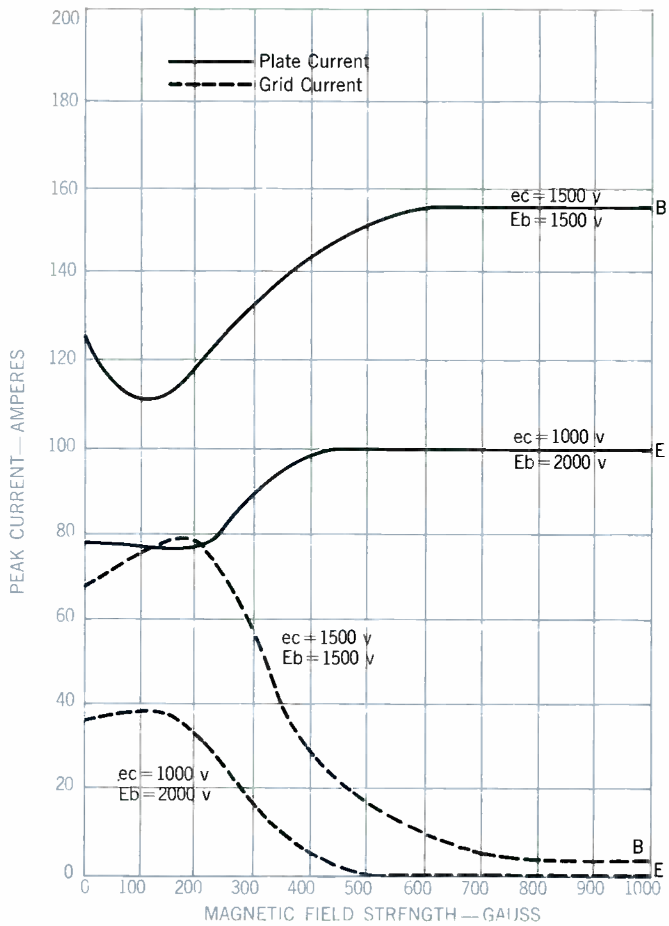
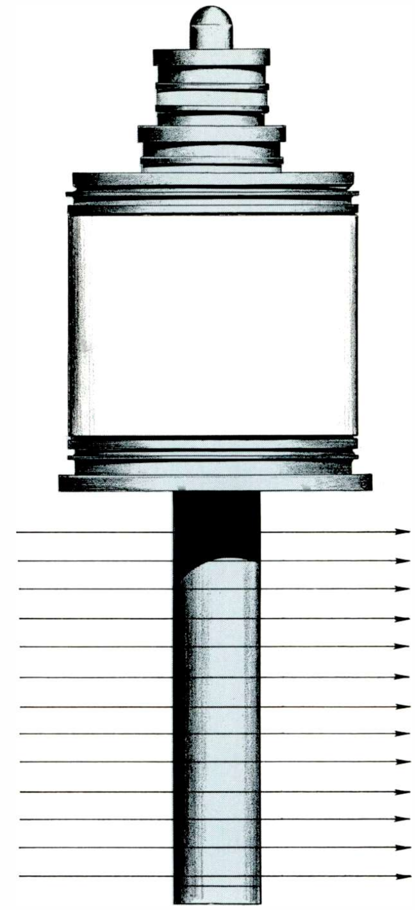


Figure 9 — ML-LPT14 plate and grid currents vs. different magnetic field strength.



ments made on the ML-LPT14, comparably excellent results have been obtained on a considerably larger tube, the ML-8549, which is described in an article starting on Page 30.

Comparison to Conventional Tubes

Figure 10 shows the constant grid voltage characteristics for the popular ML-6696 triode which has approximately the same filament power (2500 W) and practically the same cathode surface as the ML-LPT14 so that it can be used well for comparison purposes. Also, both tubes have about the same amplification factor of about 20. The plate current lines for both tubes are quite similar. For plate currents of the order of 100 A and plate voltages of a few kV the grid currents in the ML-6696 are typically about 25% of the plate currents as compared to about 3% for the ML-LPT14.

At higher plate currents the reduction in grid currents is even more pronounced. An important fact for obtaining high plate currents is that in the ML-LPT14 practically the entire cathode emission is available as a useful plate current whereas in the ML-6696 about 20% of it is intercepted by the grid.

Notes on Applications

In pulse modulator service the reduction in grid currents leads to a drastic reduction in drive power and a relatively higher plate current capability. Since the grid dissipation is also drastically reduced, magnetically beamed tubes can be utilized for considerably longer pulse durations or higher duties than conventional tubes. In many applications the reduced grid currents permit operation closer to the diode line so that the same plate voltage swing is obtained at a lower supply voltage. Incidentally, the voltage stability of magnetically beamed tubes is generally identical to that of conventional tubes and is primarily determined by electrical field gradients which are not affected by the magnetic field. The power limitation for magnetically beamed tubes in pulse modulator applications is set either by the permissible average plate dissipation or in case of long pulses by anode surface temperature peaks occurring during the pulse.

As a rf power amplifier or oscillator in Class C operation the ML-LPT14 is capable of generating readily an output of 200 kW. Figure 11 gives the constant current characteristics with a load line resulting in the following typical operation, in which the high power gain of 285 should be noted.

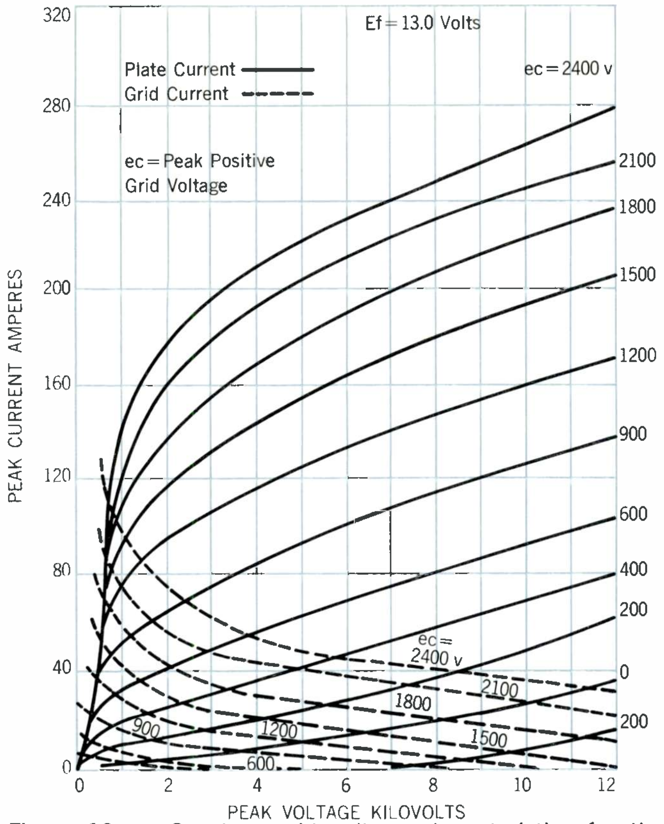


Figure 10 — Constant grid voltage characteristics for the ML-6696.

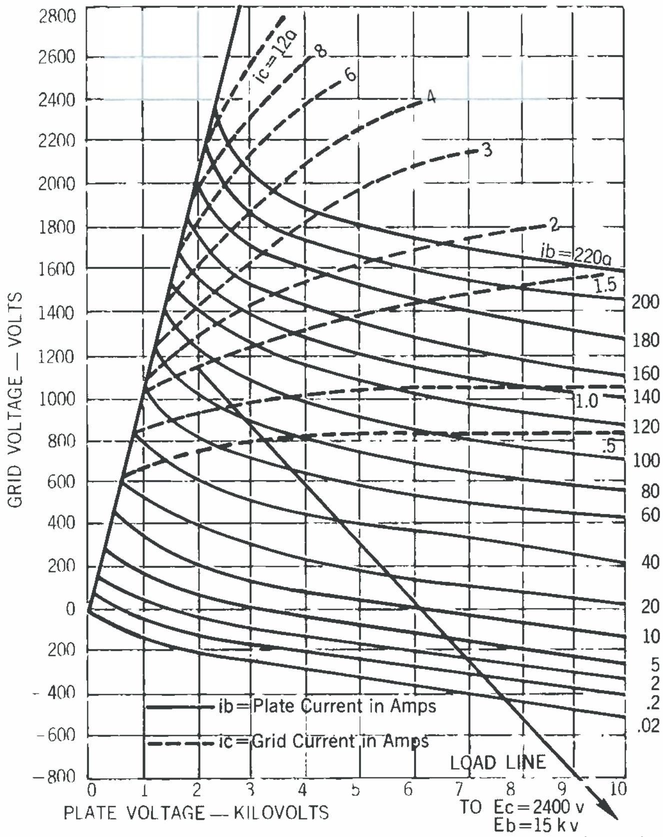


Figure 11 — Constant current characteristics for the ML-LPT14.

DC Plate Voltage	15 kV
DC Grid Voltage	—2400 V
Peak RF Plate Voltage	13 kV
Peak RF Grid Voltage	3500 V
DC Plate Current	17 A
DC Grid Current, Approximate	.2 A
RF Load Resistance	420 Ohms
Driving Power, Approximate	700 W
Grid Dissipation	220 W
Plate Dissipation	55 kW
Power Output	200 kW
Plate Efficiency	79 %
Power Gain	285

A comparable load line for the ML-6696 would give a power gain which is approximately 10 times smaller. The output power would be 180 kW and require a drive power of almost 6 kW. Practically, this operating condition is not permissible for the ML-6696 since it leads to a grid dissipation of 1700W which exceeds the maximum rating by 70%.

The ML-LPT14 has a tentative maximum grid dissipation rating of 500 Watts and a plate dissipation rating of 80 kW. In most applications as an rf or af generator power output will be again limited by the plate dissipation.

Conclusion

The foregoing illustrates that magnetic beaming in power triodes is very effective in reducing grid currents. It is expected that this beaming principle can be applied to multigrid power tubes and developmental work in this area is in progress at the Machlett Laboratories.

Acknowledgements

The concepts for the magnetic beaming were developed by Dr. H. Doolittle, Director of Technology of The Machlett Laboratories Inc., several years ago. The initial exploratory and developmental work was carried out under his guidance with the assistance of Messrs. B. Singer, A. L'Eplattenier, and L. Giers. Initial announcement was made at the Eighth Symposium on Hydrogen Thyratrons and Modulators in May, 1964[4].

The later development of the LPT-14 and other magnetically beamed tubes is the result of the efforts of many members of the staff of the Large Power Tube Operation and the various supporting departments.

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[2]Hoover, M. V., "Advances in Techniques and Applications of Very High Power Grid Controlled Tubes," *Proc. IRE*, Part B, Supplement 10, 1958.

[3]Spangenberg, K. R., *Vacuum Tubes*, McGraw-Hill Book Company, Inc., 1948, p. 111.

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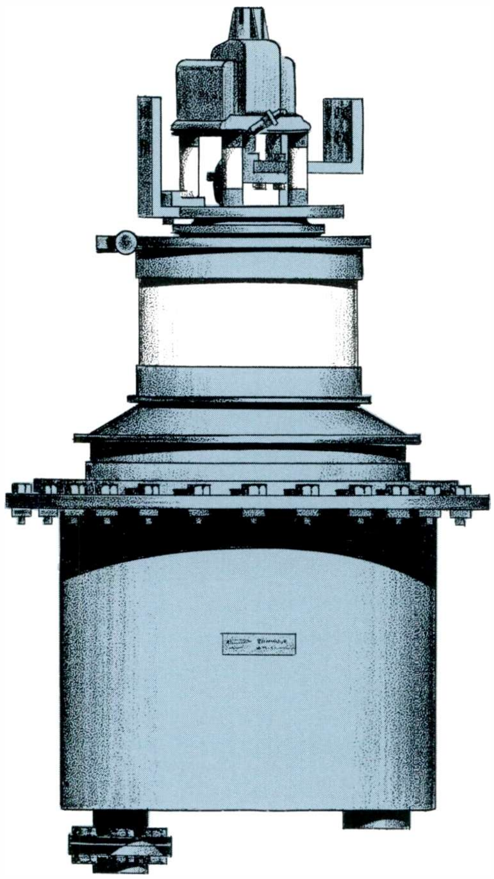

A Magnetically Beamed,

The use of the magnetic beaming principle in the ML-8549 super power triode has created a three-fold breakthrough in high power, high-power gain, and favorable tube efficiency. Magnetic beaming results in trajectories which cause the electrons emitted by the cathode to bypass the grid structures so that almost the entire emitted current reaches the anode, and thereby greatly minimize grid heating. The magnetic field is established by proper placement of a permanent magnet external to the active tube elements. (For a complete discussion of magnetic beaming see article in this issue on page 22.)

When used as a switch tube in a hard tube pulse modulator for radar or similar application, the ML-8549 can deliver more than 60 megawatts of pulse power with pulse lengths up to 10 milliseconds, a duty factor of 6% at a maximum plate voltage of 65 kV and plate efficiency in excess of 90%. Drive power to obtain 60 Mw power output is approximately 100 kw, i.e., a power gain of about 600.

In a current application of this tube, only five ML-8549 tubes in parellel supply a total peak power output of 300 megawatts, when driven by one single ML-8547 tube of about 500 kw output.[1]

When used as a pulsed rf amplifier, the ML-8549 should be capable of delivering 10 Mw at frequencies to 30 Mc. In CW operation as a Class C amplifier or oscillator, the ML-8549 is capable of providing more than 2 Mw output at a maximum plate voltage rating of 25 kV and a maximum frequency of 30 Mc. The anode of the tube is designed to dissipate 500 kW of power when cooled with a forced flow of water of about 100 gpm. The permanent magnet, which is an integrated part of the water jacket, is considered to be highly reliable and should last for the life of the equipment.

The ML-8549 was first announced at the "Hydrogen, Thyratron and Modulator Symposium" in May 1964[2] and subsequently reported in the July 27, 1964 issue of ELECTRONICS magazine.[3] This super power triode was also selected as one of the "100" most significant technical products developed in 1964 in a national I.R-100 competition sponsored by INDUSTRIAL RESEARCH magazine.

Design Considerations

Nearly all power tube structures to date use thoriated-tungsten wire cathodes in various forms which may be straight free hung, spring tensioned wired, or wire structures which form a mesh. Grid structures consist either of mesh structures or squirrel cage vertical structures with helical windings. In general, most grids are cooled by radia-

Super-Power Electron Tube—The ML-8549

by HELMUT LANGER, Senior Development Engineer

tion, although attempts have been made to apply liquid cooling of the grid bar when high grid dissipation and subsequent increase in grid temperature gave rise to thermal grid emission, and subsequent unstable operation. Aside from the mechanical problems involved in liquid cooling grid structures, and their relatively high cost, the advantages of increased grid dissipation capabilities are offset by decreasing the tube efficiency.

Present-day power triode tubes operate at plate current to grid current ratios of 3:1 to 5:1. For power tubes at low frequencies, the grid wire in the form of helical windings, or as a mesh, usually use wire diameters of 12 to 30 mils giving an optical screening faction of 10% to 20%.

In the design of VHF and UHF tubes, where the requirements of electron transit time dictate the use of extremely small (0.3 mils) wire, screening fractions of as high as 30% are encountered. However, fine wire structures which have certain advantages in improving electrical characteristics of the tubes, are not usually used in low frequency high power tubes because of the small thermal capacity per unit length of grid wire. At high power levels, and when subsequently large amounts of stored energy are involved, circuit or tube instabilities can result in internal tube arcing and cause catastrophic failures by dumping large amounts of energy into a small section of the grid. Use of protective circuitry may divert the larger amount of energy, but is not necessarily foolproof. Furthermore, use of very fine grid wires is only advantageous in improving electrical tube characteristics when combined with rather small grid-cathode distances for relatively higher frequency conditions. In very large tubes, establishing and maintaining very small electrode spacings over thousands of operation hours is obviously difficult and the price to be paid for it becomes excessive.

Another form of reducing grid drive power, and subsequent grid dissipation limitations, is found in shielded-grid triodes, which basically use electrostatic focusing of the electron beam. Typical shielded-grid tubes are ML-6544 and RCA-6949. Characteristic difficulties associated with these tubes involve accurate, but costly, mechanical positioning of the cathode strips between grid bars and high input capacitance.

As early as 1960, the practical feasibility of magnetic beaming in power tubes was considered at Machlett. Basic investigations commenced in 1962 when the principle of magnetic electron beaming was studied on smaller structures.[4]

The schematic of a magnetically beamed triode tube is shown in Figure 1. The permanent magnet assembly is located outside the tube envelope creating a field of several hundred gausses across the gap. Permanent magnets are considered highly reliable and have relatively unlimited life. Since emission is drawn from both sides of the cathode, the cathode wires are used at maximum emission efficiency — milliamperes per cathode watts. Plate current to grid current ratios are 50:1 to 100:1 as compared to 4:1 for conventional power triodes. In other words, the grid drive power to obtain a specified tube output is radically reduced and the power output from tubes of this new design is not limited by grid dissipation capabilities as is often the case for tubes of conventional design. The magnetically beamed tube design lends itself well for high power and high voltage operation. The use of large size grid bars (about .070″ to .080″ diameter), increases thermal capacity and limits the maximum rise in grid temperature during a pulse, as given by:

$$\Delta T = \frac{0.24\,P}{(s)\ (m)}\,\tau$$

where ΔT = temperature rise in °C
P = watts dissipated in the grid
τ = pulse length in seconds
s = specific heat of the grid material in cal/gm/°C
m = mass of the grid in grams

Slight spacing variations and alignment between grid bars and cathode wires in magnetically beamed tubes are much less critical than in electrostatically beamed power tubes.

The design of the anode consists of two concentric cylinders surrounding the grid-cathode structure: one cylinder of a larger outer diameter, and one cylinder of a smaller inner diameter. The permanent magnet becomes an integral part of the water jacket, air distributor or vapor-cooling jacket, depending on the mode of tube cooling used, i.e., water, air or vapor cooling.

Tube Design

The ML-8549 utilizes a cathode which consists of an array of 112 vertical, thoriated-tungsten wires placed sequentially on a bolt circle nearly 14 inches in diameter. The cathode wires are approximately 1 mm in diameter, are carburized and assembled in segments of 8 wires each. The cathode power at nominal operation is 7.6 volts and about 1840 amperes, i.e., very close to 14 kilowatts. The grid is composed of two parts: a cylindrical array of wires on a smaller diameter, such that each set of grid wires radially are midway between the cathode wires. The grid wires are approximately 2 mm in diameter. The design of the grid-cathode electrode mounting structure is of coaxial design. Figure 2 shows the grid-cathode structure of the complete tube. The grid-cathode structure is surrounded by two anode cylinders of different diameters which are coaxial to each other and the grid-cathode structure. In

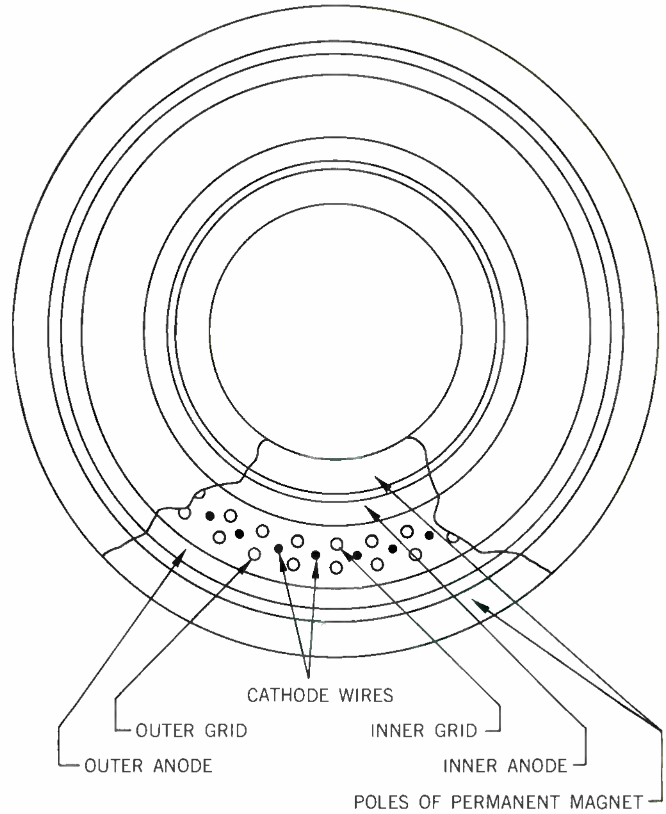

Figure 1 — Schematic of Magnetically Beamed Triode.

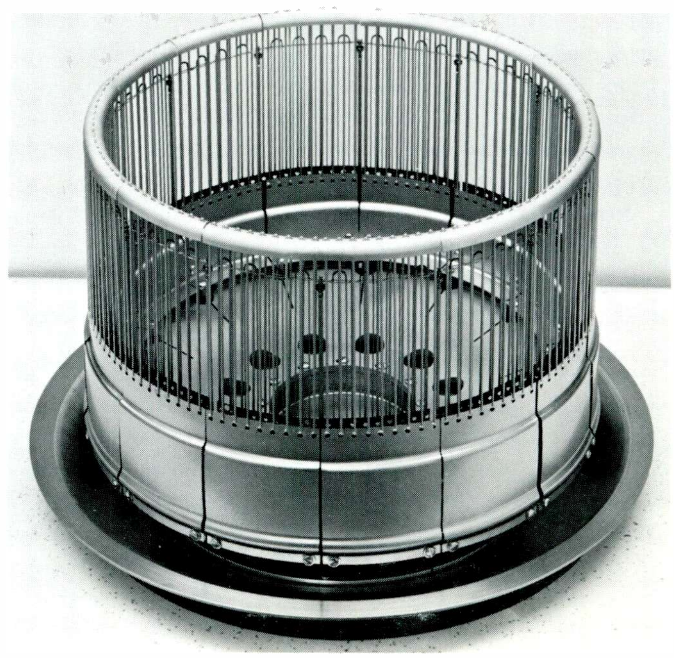

Figure 2 — Grid and Cathode Structure of ML-8549.

Figure 3, the complete assembly is shown prior to closing the tube by heliarc welding techniques. The insulating tube envelope is made from high purity aluminum oxide. It is dimensioned in length and diameter such that operating voltage of more than 65 kV can be obtained. The complete tube, mounted in the water jacket is shown in Figure 4.

The large size (large diameter) structural components of the tube required extensive stress analysis calculations prior to finalizing the tube design. This, of course, was required when one considers that the entire surface area of the tube is subjected to total forces of about 15 tons under atmospheric pressure. Added to this are the additional forces applied to the water-cooled anode structure.

High temperature processing and outgassing is done to a large extent under double vacuum conditions in the Machlett-designed tube exhaust facility for super-power tubes. Double vacuum processing procedures are dictated by reducing external forces when processing tube envelope structures at temperature above 600°C, and by greatly reducing gas diffusion from the external environment to the inside of the tube.

A 5-liter per second Vacion sputter pump is a permanent attachment to the tube; it is considered a requirement in tubes for super-high-power operation in order to assure an extremely low gas level in the tube over thousands of hours of operation.

The completed tube, Figure 4, is designed to operate vertically with the anode water jacket either up or down. The terminal section of the tube is designed to allow large, low-inductance connection to the grid and filament of the tube. The anode structure is provided with a large-diameter, heavy steel ring for mounting to the water jacket and for providing a means whereby the tube may be lifted or moved.

Electrical Processing

The ML-8549 undergoes extensive high-energy electrical testing prior to the final tests for cathode emission and electrical characteristics. The tube is aged and tested in the Machlett High-Voltage, High-Power Pulse-Modulator Test Set to plate voltages of 90 kV, cathode current emission to 1300 amperes and total peak power output levels of more than 80 Megawatts at plate efficiencies of more than 90%. All of these tests are done with the tube completely immersed in oil. Further testing is done under high-voltage conditions to 65 kV in circuits having high stored energy and tests under dc conditions resulting in plate dissipation levels up to 500 kV CW. Tests of 13.6 Mc as a Class C amplifier have been started. It is intended to go to an input of 1.2 Mw, which is the limit of existing rf test facilities at Machlett.

Static Electrical Drive Characteristics

Figure 5 shows the constant grid voltage characteristics of the ML-8549 to plate voltages of 10 kV. The constant

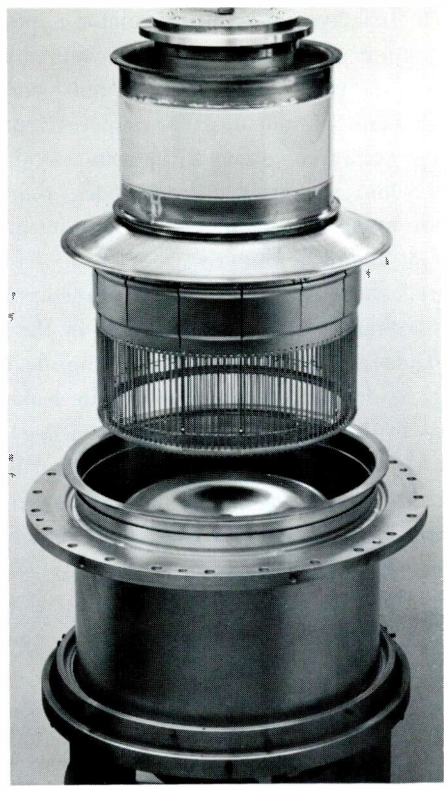

Figure 3 — Grid-Cathode Sub-assembly and Anode of ML-8549.

Figure 4 — ML-8549, Super-Power, Magnetically Beamed Triode Complete with Water Jacket.

plate current characteristics of this tube are shown in Figure 6. In a typical pulse modulator application requiring an output of 60 Mw at a plate voltage of 65 kV, the tube operating parameters may be a pulse output voltage of 60 kV, a plate current of 1000 amperes requiring a positive drive voltage of about 2750 volts (total drive voltage of 6750 volts) at a grid current of less than 20 amperes. There are many driver tubes available that provide outputs of 7 kV at about 20 amperes.

Figure 7 shows actual and recommended grid bias voltage vs plate voltage to 65 kV for cut-off in the interpulse interval. Data are based on a static amplification factor of about 17 under cut-off conditions. Plate leakage current at 65 kV is in the order of 2 to 3 ma at a negative grid bias voltage of 5000 volts. Plate leakage current here is defined as electrons arriving at the anode in the form of field emission from the grid structure, not thermal emission. Strapped resonance frequency values for the ML-8549 are in the grid plate system ≅ 56 Mc and in the grid-cathode system ≅ 64 Mc. These measurements were made with a grid dip meter and by connecting the electrodes over the shortest possible path with a conducting foil completely surrounding the insulators. The inter-electrode capacitances of the tube when measured directly at the appropriate terminals are:

Grid-Plate	290 pf
Cathode-Anode	27 pf
Cathode-Grid	745 pf

Operation of the ML-8549 at voltage levels of 65 kV, as is the case with all high voltage tubes, may produce x-ray radiation and appropriate shielding of the equipment must be provided.

Cooling Characteristics

The anode of the ML-8549 is designed to dissipate 500 kW of power when cooled with a forced flow of water in the order of 100 gallons per minute. At the full water flow of 100 gpm, the pressure drop across the tube water jacket amounts to about 6 psi. Figure 8 shows the cooling characteristics of the tube, while Figure 9 is a cross-section of the anode and water jacket illustrating the cooling system. The water flow pattern is such that equal amounts of water are forced through the outer and inner cooling passage, thereby assuring turbulent flow conditions in both passages. Maximum outlet water temperature is limited to 70°, maximum on the water jacket is limited to 40 psi. For filament stand-by conditions, the minimum water flow required is 20 gpm. It is recommended that the water cooling system be of the closed type utilizing distilled or de-ionized water with means for maintaining water purity at about 100 K ohm-cm at 25°C, eliminating, insofar as possible, sources of contamination such as copper oxides, oxygen, carbon dioxide, etc.

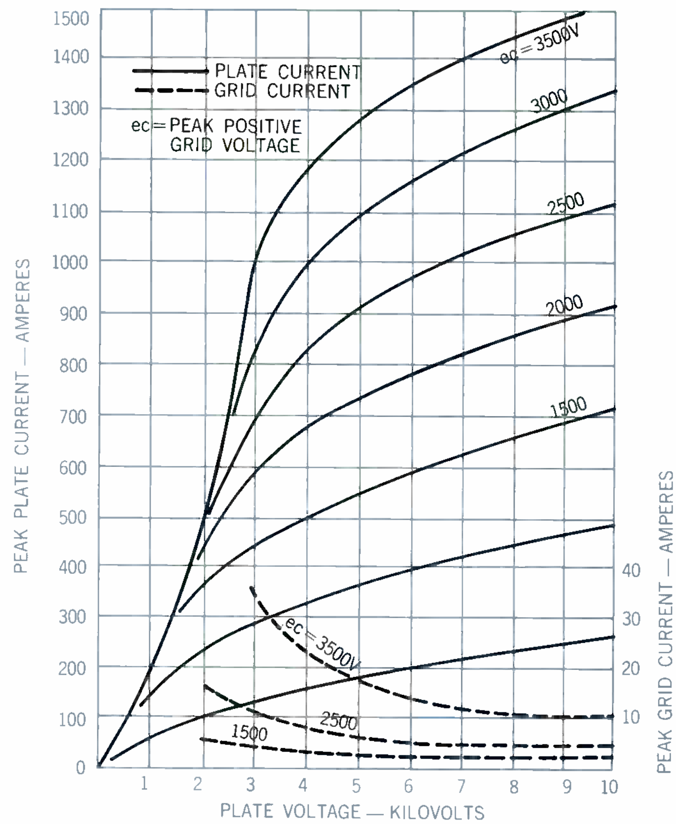

Figure 5 — ML-8549 Constant Grid Voltage Characteristics. (Tentative)

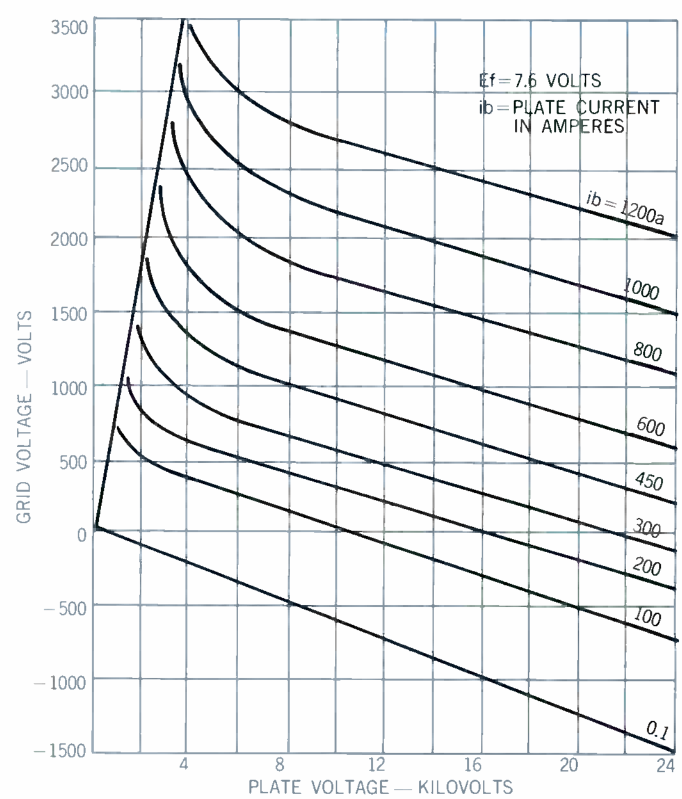

Figure 6 — ML-8549 Constant Plate Current Characteristics. (Tentative)

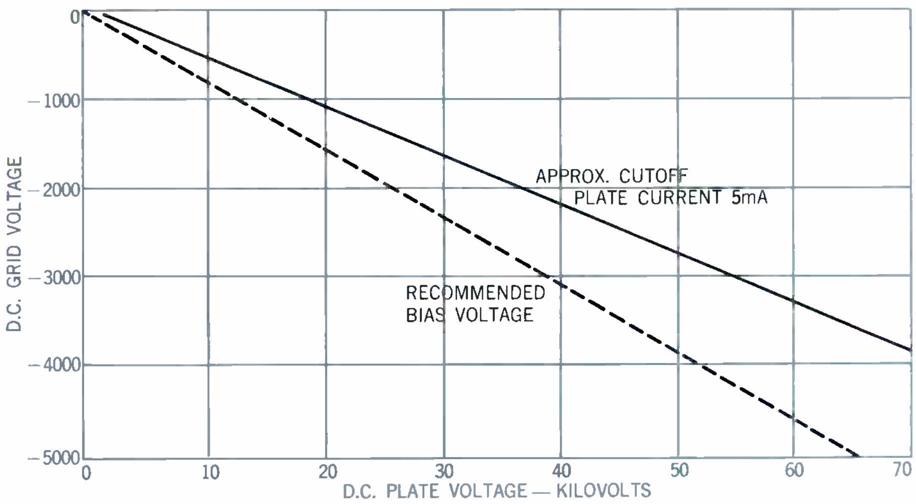

Figure 7 — ML-8549 Actual and Recommended Grid Bias Voltage for Cut-Off in Inter-Pulse Interval.

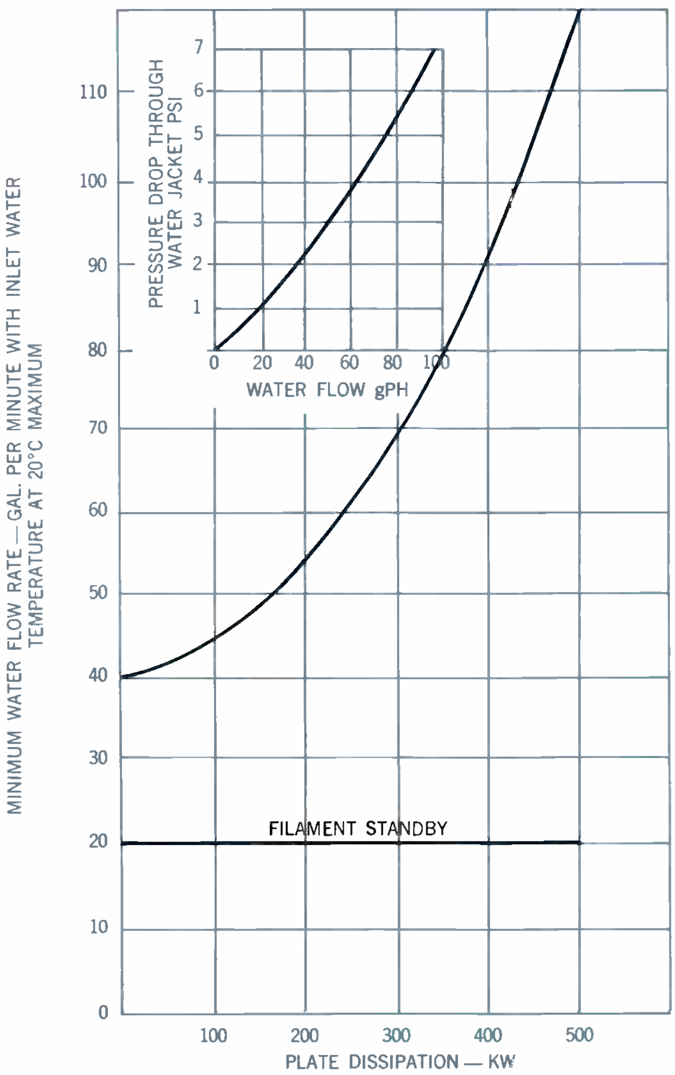

Figure 8 — ML-8549 Anode-Water Cooling Characteristics.

Tube Applications

High-power output and high-power gain make this tube particularly well suited for controlling the pulse modulation of large radar equipment and particle accelerators in the field of nuclear physics. Other applications are foreseen in the field of high-power communications, in industrial applications covering the field of induction or dielectric heating, and in CW or pulsed rf sources for accelerators. Tentative maximum ratings and typical operating conditions are summarized in Table I.

Presently, a complete high-power tube testing complex is being installed at Griffiss Air Force Base by the Continental Electronics Manufacturing Co.[5]. For output pulses of 60 kV and 5400 amps using hard tube modulator switches at this installation, 14 off-the-shelf conventional tubes would have been required to achieve the total pulse power output. But this would have been limited to an .01 duty due to the grid dissipation capabilities of the tubes involved. However, 5 ML-8549 tubes will supply 5400 amps at 60 kV at .06 duty. Low drive power requirement of the ML-8549 will permit the use of a single, relatively small triode to drive all 5 tubes.[1]

Since primary grid current is low, secondary emission effects, which sometimes result in pulse stretching in conventional triodes, can be easily avoided. The use of a swamping resistor in parallel with the tube input, which draws an additional 15 amps should give a high degree of stability and still permit a power gain of 300. Furthermore, the grid is capable of about 10 kW average dissipation. It is likely that very high power, with pulse widths as long as 0.1 seconds, can be switched using this tube.

In any type of high-power application, the use of crowbars or energy diverters is required. The use of a crowbar which will act in less than 10 microseconds to divert energy from a flash-arcing tube to a shunting circuit is of

TABLE I—ML-8549 Tentative Maximum Ratings and Typical Operating Conditions

Pulse Modulator or Pulse Amplifier

Maximum Ratings, Absolute Values		
DC Plate Voltage	65	kV▲
Peak Plate Voltage	70	kv▲
DC Grid Voltage	—5000	V
Peak Negative Grid Voltage	—6000	v
Pulse Cathode Current	1200	a
Grid Dissipation	9	kW
Plate Dissipation	500	kW
Pulse Duration	10	ms#
Duty Factor	.06	#

Typical Operation		
DC Plate Voltage	65	kV
DC Grid Voltage	—4000	V
Pulse Positive Grid Voltage	3000	v
Pulse Plate Current	1100	a
Pulse Grid Current	10	a
Pulse Driving Power	70	kw
Pulse Power Output	65	Mw
Pulse Plate Output Voltage	59	kv

Plate-Pulsed RF Power Amplifier and Oscillator — Class C

Maximum Ratings, Absolute Values		
Peak Plate Pulse Supply Voltage	40	kv▲
DC Grid Voltage	—4000	V
Pulse Cathode Current	1200	a
Grid Dissipation	9	kW
Plate Dissipation	500	kW
Pulse Duration	10	ms#
Duty Factor	.06	#

Typical Operation	Cathode Drive	Grid Drive	
Peak Plate Pulse Supply Voltage	38	38	kv
DC Grid Voltage	—2300	—2300	V
Peak RF Grid Voltage	5500	5500	v
Peak RF Plate Voltage	32	32	kv
Peak Plate Current from Pulse Supply	400	400	a
Peak RF Fundamental Plate Current	630	630	a
Peak Plate Dissipation	5.2	5.2	Mw
Plate Dissipation at .01 Duty	52	52	kW
Peak Driving Power	1750	33	kw
Peak Grid Dissipation	24	24	kw
RF Load Resistance	60	51	ohms
Peak Power Output	11.8‡	10	Mw

▲Maximum plate voltage ratings apply with the tube in air or immersed in oil.
#For applications requiring longer pulse duration or higher duty factors, consult the Machlett Engineering Department.

Plate-Modulated RF Power Amplifier Class C Telephony

Carrier conditions per tube for use with a maximum modulation factor of 1.0

Maximum Ratings, Absolute Values		
DC Plate Voltage	16	kV
DC Grid Voltage	—4000	V
DC Plate Current	100	A
Plate Input	1.6	MW
Plate Dissipation	330	kW

Typical Operation	Cathode Drive	Grid Drive	
DC Plate Voltage	15	15	kV
DC Grid Voltage	—2000	—2000	V
Peak RF Plate Voltage	13	13	kv
Peak RF Grid Voltage	3500	3500	v
DC Plate Current	90	90	A
Peak RF Fundamental Plate Current	162	162	a
RF Load Resistance	102	78	ohms
Driving Power	300	4	kW
Plate Dissipation	300	300	kW
Power Output	1.3‡	1.1	MW

RF Power Amplifier and Oscillator Class C Telegraphy

Key-down conditions per tube without amplitude modulation.†

Maximum Ratings, Absolute Values		
DC Plate Voltage	25	kV
DC Grid Voltage	—4000	V
DC Plate Current	150	A
Plate Input	3.0	MW
Plate Dissipation	500	kW

Typical Operation	Cathode Drive	Grid Drive	Grid Drive	
DC Plate Voltage	20	20	25	kV
DC Grid Voltage	—2600	—2600	—3100	V
Peak RF Grid Voltage	4400	4400	4900	v
Peak RF Plate Voltage	18000	18000	23000	v
DC Plate Current	110	110	115	A
Peak RF Fundamental Plate Current	200	200	220	a
RF Load Resistance	112	90	107	ohms
Plate Dissipation	460	460	450	kW
Grid Driving Power	450	9	10	kW
Grid Dissipation	2500	2500	2500	W
Power Output	2.3‡	1.8	2.5	MW

†Modulation essentially negative may be used if the positive peak of the envelope does not exceed 115% of the carrier conditions.
‡Includes power transferred from driver stage.

tremendous value in maintaining the high-voltage stability of high-power tubes and high-power equipment in general.

Tube Handling

Consult ML-8549 Data Sheet for outline showing the tube with water jacket and connectors. For anode down operation a simple 3-cable sling arrangement has been designed for lifting the tube, for mounting to the water jacket, and for installing the tube into equipment. If the tube is to be used in the anode-up position, a tube turn-over fixture is available to facilitate this task without major effort. A tube transportation and mounting dolly has been designed for moving the tube and for facilitating tube turnover within close proximity of the tube socket.

ML-8549 Application Notes, covering all aspects of shipping, uncrating, mounting, installation into equipment and tube conditioning, are available on special request.

The net weight of the tube is approximately 380 pounds. The weight of the water jacket and magnet is approximately 600 pounds.

Acknowledgments

The early research and proof of the applicability of magnetic beaming to power tubes was conducted by Dr. H. D. Doolittle, Manager of Machlett's Technology Division and B. Singer, Development Engineer. Product development was carried out by Dr. J. A. Randmer, Chief Engineer for Large Power Tubes, H. Langer, E. Peter, L. Giers, J. Fedorchuck, W. Bulger and a supporting staff of technicians under the overall supervision of C. Kirka, Manager of Machlett Large Power Tube Operation.

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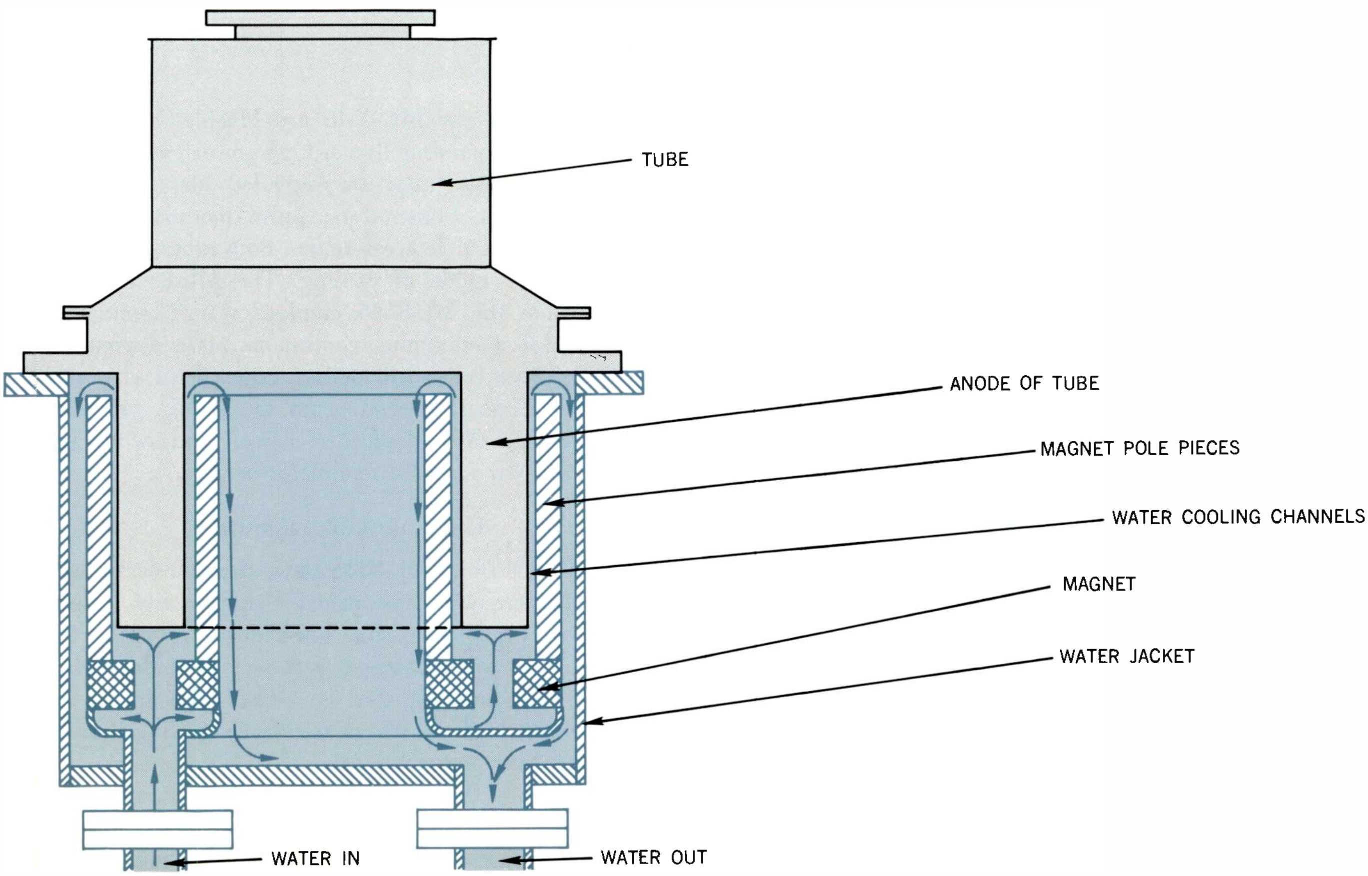
[4]Randmer, J. A., "Magnetic Beaming in Power Tubes", *Cathode Press*, Vol. 22, No. 2, 1965.

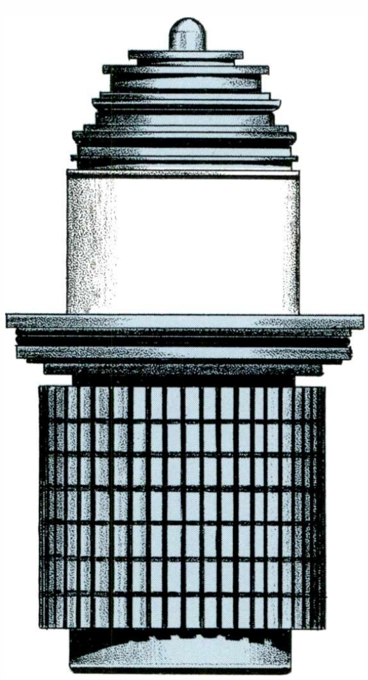
[5]Wiejek, A. J., "High Power Laboratory at Rome Air Development Center", a paper presented at the Eighth Symposium on Hydrogen Thyratron and Modulator at Fort Monmouth, N. J., May 1964.

Figure 9 — Schematic of Water Cooling Arrangement of ML-8549.



World's Highest Power Tetrodes—

by C. T. JOHNSON, Development Engineer
and DR. J. A. RANDMER, Chief Engineer,
Large Power Tubes

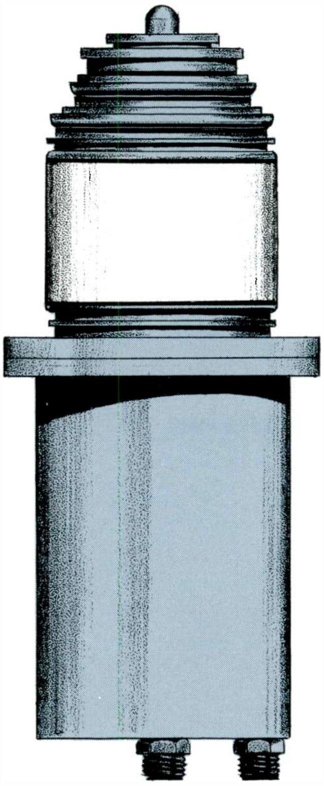


The ML-8545 and ML-8546 are Machlett's latest additions to its expanding line of high-power general-purpose tetrodes. These tubes are intended for use in superpower broadcast transmitters, pulse modulators, and rf generators for particle accelerators. Both tubes are identical, except for the mode of cooling. The ML-8545 is vapor cooled, while the ML-8546 employs water cooling. Both are rated for a maximum continuous plate dissipation of 150 kW. These tubes will deliver 300 kW of rf power in continuous Class C operation up to 50 Mc, provide approximately 1.5 Mw of pulse rf power, and switch in the order of 10 Mw in pulse modulator service.

Constructional Features

The ML-8545 and ML-8546 have alumina ceramic insulating members with cylindrical elements and terminals, thus providing low-loss and low-inductance paths for rf currents. The large-diameter ceramics provide high mechanical and dielectric strength. They also facilitate accurate control of the close interelectrode spacings necessary in modern high-perveance tubes.

The cathode shown in Figure 1 is composed of 36 strands of thoriated tungsten, and is capable of providing 300 amperes of pulse cathode current at rated filament



ML-8545 and ML-8546

voltage. The perveance in grid controlled tubes varies approximately as the square of the reciprocal of the grid-cathode spacing. Therefore, it is evident that this dimension must be kept as small as possible for good power gain, especially in grounded grid operation. In order to achieve a small spacing (approximately .060″) in a relatively large structure, as is involved in these tubes, and to maintain it at the high operating temperatures normally experienced in tubes, a new filament suspension system has been developed. Each strand is held in place by a rigid structure at one end and a novel filament support and tensioning system at the other end. This arrangement provides complete mechanical isolation of adjacent filaments so that no stresses develop as a result of nonuniform expansion. In a large tube with such close spacings as are required in the ML-8545/46, the new method of holding the filaments provides several advantages. It provides good control over the cathode-grid spacing so that variations in characteristics from tube to tube are minimized. The absence of filament distortion prolongs the constancy of tube characteristics and therefore extends tube life. Ease of assembly results in economies in manufacturing which are passed on to the user. Fairly heavy filament wires were selected in order to provide the long life expected of Machlett tubes.

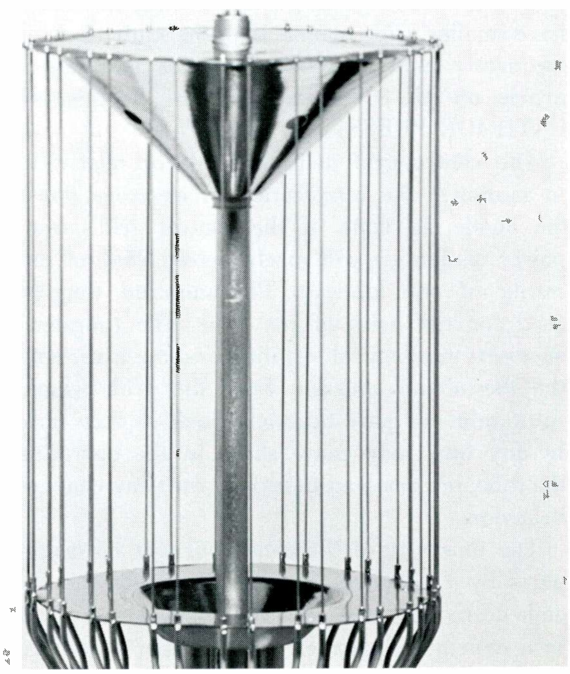


Figure 1 — Cathode structure, ML-8545 and ML-8546.

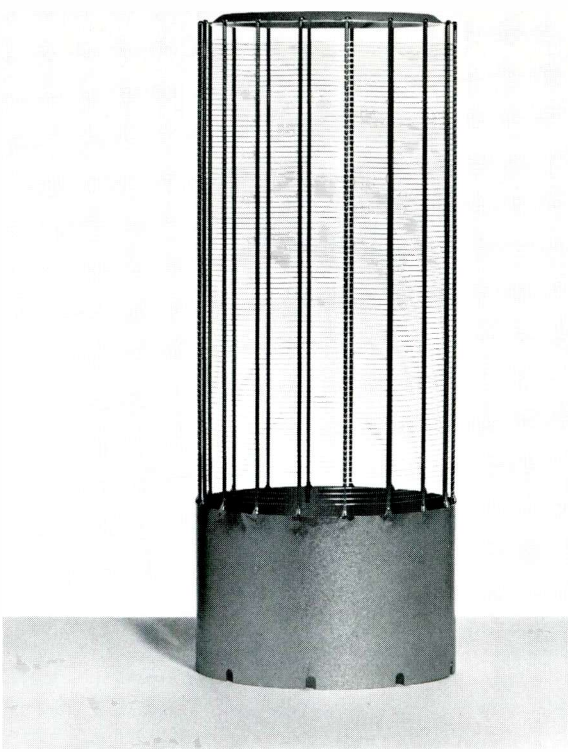


Figure 2A — Control grid showing helix made of fine wire.

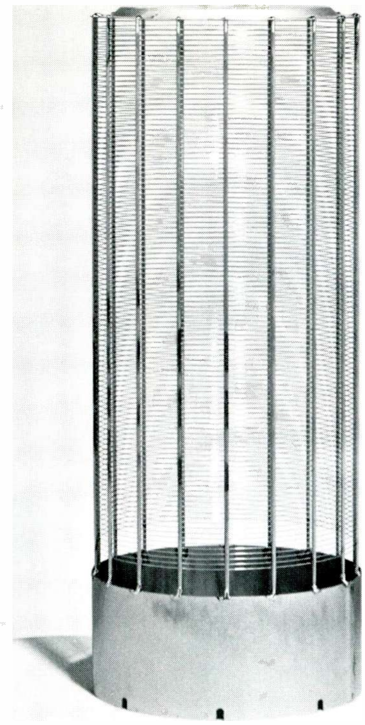


Figure 2B — Screen grid with heavier helix but with pitch same as Control Grid.

The control grid (Figure 2A) and screen grid (Figure 2B) are of helical design with heavy vertical support stays. During the design of the tube, it was determined that for the selected filament design such grid structures would have smaller grid currents than the squirrel-cage type grids frequently used in smaller tetrodes (for latter grids see article on ML-8170 and ML-8281 in this issue of the CATHODE PRESS).

The control-grid helix is made of relatively fine wire to minimize the interception of electrons flowing toward the anode. In spite of the control grid's fine structure, power dissipation will rarely exceed 75% of its maximum rating of one kilowatt. Platinum-clad tungsten wire is used for the helix of the grid. The tungsten gives the necessary mechanical stability, and the platinum suppresses the thermionic emission from the grid, which could be substantial for pure tungsten. Such primary grid emission in any tube may cause shifts in the operating point of the tube, or even lead to serious runaway changes in circuit behavior.

The fine wire of the control grid is fastened to its supports by a swaging method. This involves mechanically embedding the wire into the support rods, which results in a structure of greater strength than grids made by spot-welding techniques. Joints between wire and supports are not brittle, and there is no tendency for joints to separate and cause arcing during rf operation. Furthermore, the embedding improves heat transfer to the heavy vertical support rods, which improves grid dissipation capabilities. The grid is mounted on a molybdenum cylinder, which is fastened with screws to the terminal assembly. The top of the grid is accurately positioned with respect to the filament assembly by an insulating member, which prevents relative radial motion between the two elements.

This insulating member also guides the screen grid, which is similar in construction to the control grid. The screen grid has the same pitch as the control grid and is carefully aligned directly behind it in order to promote beam-forming, and thus, reduce screen grid currents (see Figure 3). The maximum permissible screen grid dissipation is usually the limiting factor for the power output of tetrodes. Therefore, the screen grid is made of heavier wire, so as to give a larger radiating area. Because of the aforementioned beaming effect between the two grids, a larger wire diameter is permissible without resulting in excessive screen grid currents. The maximum permissible screen grid dissipation is 3 kW. In order to handle this relatively large dissipation without distortion due to thermal effects, tungsten wire is used for the helix of the screen grid. This helix is also platinum-clad in order to suppress thermionic emission. Platinum is, of course, one of the best high-temperature, high-work-function materials known for use on grid surfaces for tubes having thoriated-tungsten filaments.

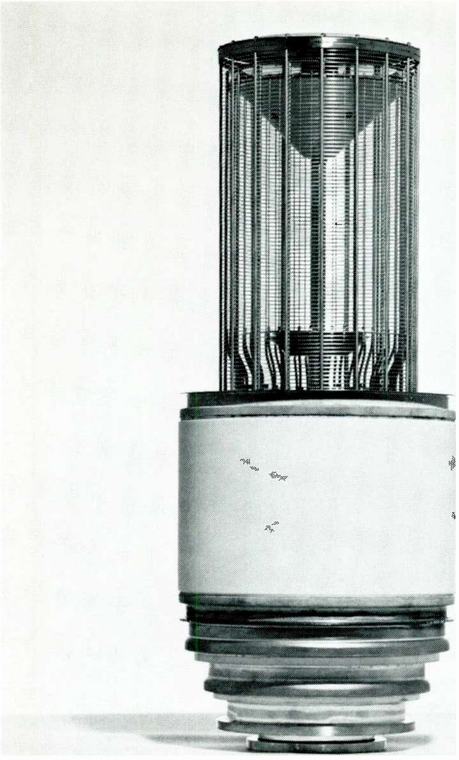


Figure 3 — Tube showing cathode structure with both grids mounted. Also shown is screen anode insulator.

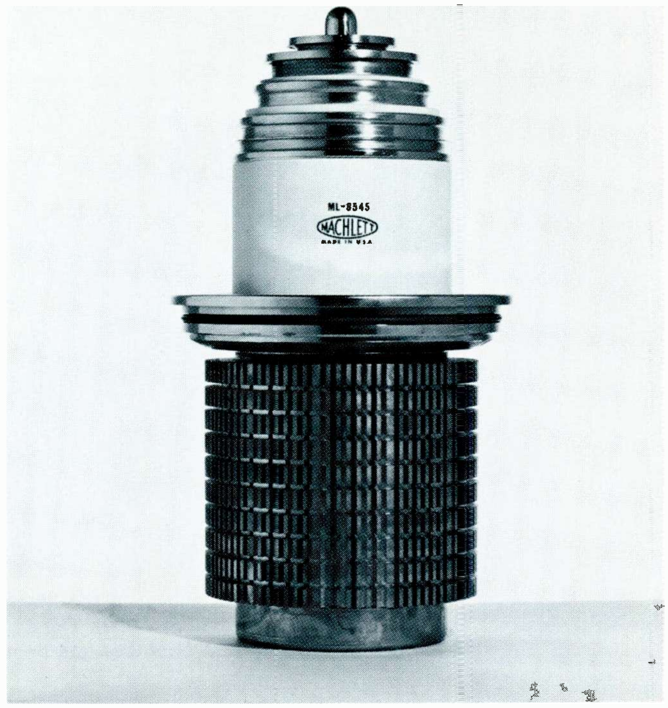


Figure 4A — Complete ML-8545 showing flange for mounting in vapor jacket.

The ML-8545 and ML-8546 anodes are made of pure copper, which is forged to the approximate shape and then machined to final dimensions. Both anodes have heavy walls in order to withstand high momentary overloads. The one-piece construction of the ML-8545 anode gives optimum heat conduction through the metal to the water, as compared to anodes utilizing brazed-on cooling ribs. The deep grooves on the exterior increase the area in contact with the water and provide the necessary heat transfer efficiency. This anode can be seen in Figure 4A as a part of the complete tube. The dissipation rating for the ML-8545 anode has been set well below the calefaction level so that substantial overloads can be handled with no difficulty. Calefaction is a condition wherein so much vapor is created that very little water is in contact with the anode. Because vapor is a poor conductor of heat, the temperature of the anode rises rapidly, and the tube is destroyed unless power is removed very quickly. (See references 1 and 2.)

The anode of the ML-8546, shown in Figure 4B, is not visible as it is surrounded by an integral water jacket.

Processing Features

Tungsten, thorium, molybdenum, nickel, iron, chrome, copper, oxygen, carbon, silver, platinum, aluminum, cobalt, rhodium, gold, zirconium, and manganese are the elements that go into the construction of the ML-8545 and ML-8546. The compounds, alloys or elements used must be very pure

Figure 4B — Complete ML-8546 showing integral water jacket.

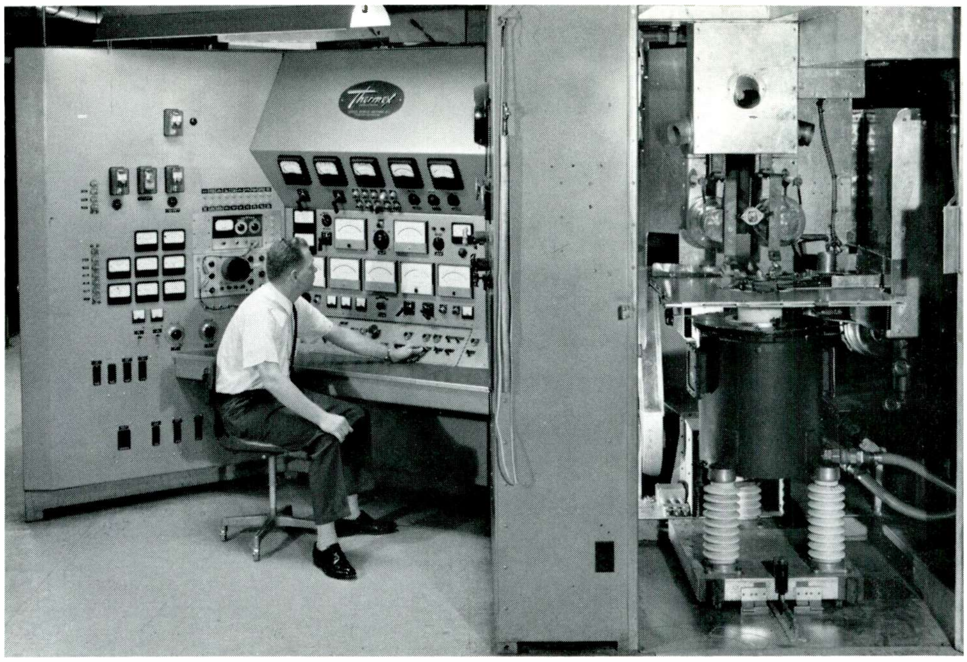


Figure 5 — ML-8545 is shown in the Machlett 1.2 Mw Test Set. Screen anode insulator is just visible above the Vapor-Jacket Condenser Cooling Unit. For pictorial purposes, here, the interlock door to test chamber has been left open.

— in fact, as pure as the state-of-the-art of the industry permits. In spite of all the precautions taken, most of the materials are not pure enough in the purchased state, and this, of course, emphasizes the importance of tube processing. Even if all materials were of the preferred purity, there would still be the problem of surface contamination, and adsorbed, absorbed and occluded gases. The more complete the elimination of impurities and gasses, the longer the life of the tube.

Before final assembly, nearly all parts are fired in a hydrogen atmosphere and subsequently in a vacuum to make the exhaust procedure more effective and to help to eliminate substances which could be harmful during exhaust. The first stage of exhaust involves baking the entire tube at dull-red heat (1000°F) for several hours. Then all elements inside the tube and the anode are simultaneously operated well above temperatures occurring in later use for more than 10 hours. During this period, an ion-getter pump is used for exhaust purposes, and the final pressure reading is in the range of 10^{-8} millimeters of mercury. After pinch-off, further exhausting is carried out with a small ion-getter appendage pump. While this pump is operating, high dc voltage is applied to the anode in gradually increasing amounts to a 70 kV level. This voltage is maintained until internal arc-overs have dropped below a certain low level. The ion-getter pump will also show a much lower pressure reading at this point. After this high-voltage aging, the appendage pump is usually removed. However, if gas levels are relatively high, tubes can be pumped for many hours when necessary, thus helping to assure high-voltage stability and long life.

Testing

The final step in the assurance of quality is thorough testing. Each tube is subjected to at least twenty different tests to determine whether its characteristics fall within the specified limits. Some of these tests check interelectrode capacitances, amplification factor, plate, grid and screen characteristic curves, control and screen grid primary emission, and gas current at full plate dissipation. The most elaborate test is for the ability of the tube to perform at above-rated voltage and power levels as an rf generator. This test is made in the Machlett 1.2 Mw rf test unit at 13.6 Mc. (See Reference 3 for further description of test set.) Figure 5 shows an ML-8545 tube mounted in this test equipment.

The 1.2 Mw Test Set was originally designed for testing high-power triodes and has now been modified to accommodate large tetrodes. At present the tubes are operated in this equipment at an output level exceeding 300 kW at a plate voltage of 20 kV. In order to assure high-voltage stability, the tubes are also operated at a plate voltage of 25 kV at reduced power levels, and must perform at this voltage for at least half-an-hour without interruptions, such

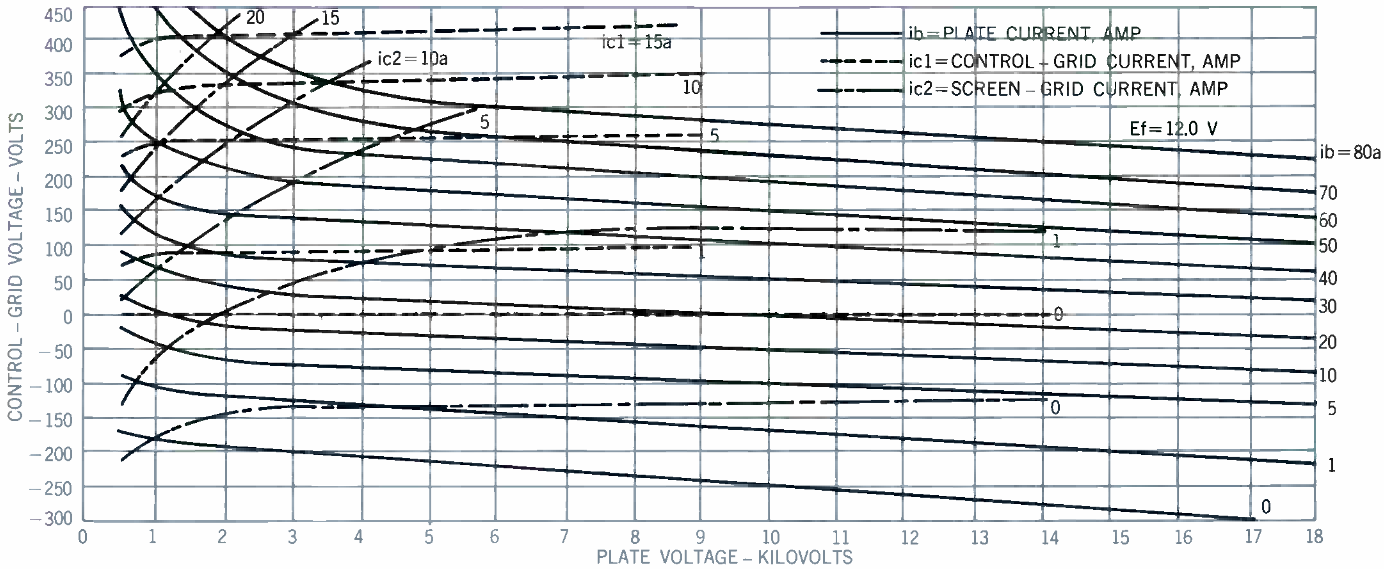


Figure 6 — Constant Current Characteristics showing screen-grid potential at 750 volts.

as kick-outs before completion of rf testing. After this test, cathode peak emission is measured in order to be sure that it was not adversely affected by rf operation.

Tube Characteristics

Plate Characteristic Curves

In contrast to a triode, tetrodes have many sets of characteristic curves, each corresponding to a given screen voltage. Figures 6 and 7 show constant current curves for screen potentials of 750 volts and 1500 volts, respectively. Notice that for plate potentials above about 5 kV, the spacing between corresponding constant plate current lines is practically the same for either set. This will be true for any screen voltage in the region where the constant current lines tend to be flat. A realization of this fact helps one to understand the effect of the screen on plate characteristics. A brief explanation can be found in the following familiar equation,

$$i_p \approx K\left(e_{g1} + \frac{E_{g2}}{\mu_{g1g2}} + \frac{e_p}{\mu_{g1p}}\right)^{3/2}$$

(See reference 4.)

where i_p = plate current
K = perveance, a constant determined by the tube's active electrode dimensions
e_{g1} = control-grid voltage
E_{g2} = screen-grid voltage
e_p = plate voltage
μ_{g1g2} = control-grid to screen-grid amplification factor

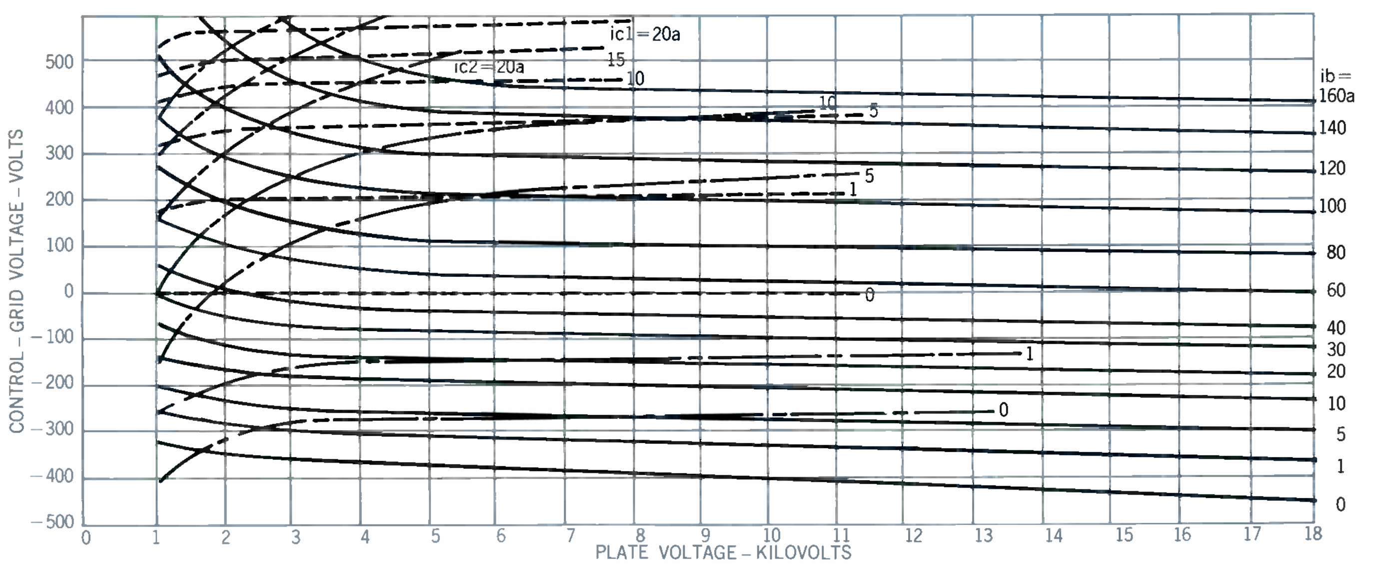


Figure 7 — Constant Current Characteristics showing screen-grid potential at 1500 volts.

μ_{g1p} = control-grid to plate amplification factor.

From this equation it can readily be seen that for any given plate current, the sum of the voltage terms is a constant. If the screen voltage is raised by $\triangle E_{g2}$, the control-grid voltage need only be lowered by $\frac{\triangle E_{g2}}{\mu_{g1\,g2}}$ to get the original plate current. (This is the basis for defining $\mu_{g1\,g2}$.) Therefore, the result of raising screen voltage is merely to lower the entire family of constant-current lines by equal amounts along the grid-voltage coordinate. Since providing further sets of curves for many different screen voltages would be unwieldy here, the curves in Fig. 8 are offered as a means of showing the approximate plate currents available over practically the entire range of screen voltages. Data here is based on actual measurements. For any given screen voltage on the abscissa, the anode voltage is twice that value. Other voltage combinations are possible as long as the peak cathode current does not exceed 400 amperes.

Control Grid and Screen Grid Currents

Both control and screen grid currents are shown along with plate currents in Figures 6 and 7. Further sets of curves at higher or lower screen voltages can be provided for equipment designers.

Filament Operating Conditions and Peak Cathode Current Ratings

The nominal filament operating conditions are at 12 volts and 400 amperes. As customary for thoriated-tungsten cathodes, a voltage variation of ±5% is permitted for normal operation. However, closer regulation — to ±1%, with the use of regulating transformers — will extend filament life. This is illustrated by the fact that the filament life expectancy is cut in half if the filament voltage remains continuously at the +5% upper limit.

The tube is rated for a peak cathode current of 300A at nominal filament conditions. Currents of 400A may be drawn if the filament voltage is increased to 12.5 V. Several thousand hours of tube life are assured even at this elevated voltage.

Plate Voltage Ratings

At present the tubes are rated for a maximum plate dc voltage of 18 kV for Class C telegraphy and Class AB audio or linear rf amplifier service. A maximum plate voltage of 13 kV applies for the plate modulated case. For rf pulse generation the dc plate pulse voltage should not exceed 30 kV, whereas a maximum dc plate voltage rating of 40 kV and a peak dc plate voltage rating of 50 kV has been set for applications in pulse modulator service. These ratings are relatively conservative and should give the necessary safety margin for satisfactory operation.

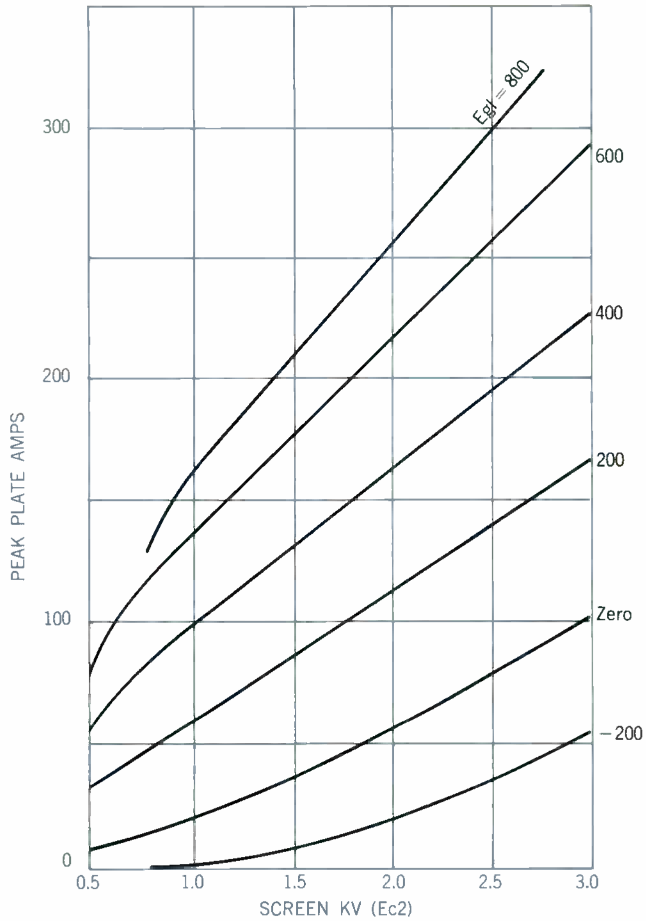


Figure 8 — Curves showing available plate current over a continuous, wide range of screen voltages and for discrete control-grid voltages.

Strapped Resonant Frequencies

For this measurement aluminum foil was wrapped around the insulators to form a conducting cylinder connecting the appropriate terminals. A grid-dip meter was then coupled through a small hole in the foil, and the following strapped resonant frequencies were obtained:

Cathode to Control Grid	96 Mc
Control Grid to Screen Grid	100 Mc
Screen Grid to Plate	130 Mc

Interelectrode Capacitances

The capacitances were measured without any socket connectors or shields and typical values for grounded-cathode operation are:

Input	640 pf
Output	112 pf
Feedback	6.5 pf

and for grounded-grid operation:

Input	235 pf
Output	117 pf
Feedback	2 pf

Tube Protection

In high-power installations using tubes such as the ML-8545 and ML-8546, special precautions must be taken to limit fault currents in the tube. If flash-arc energies are not limited, the voltage holdoff capability of the tube may be easily affected or the tube damaged permanently. Dump-tube thyratron circuits provide the best method of diverting the large amounts of energy involved. For further information on protection circuits. (See References 5 and 6.)

Tube Accessories

The terminal connectors provided by Machlett are suitable for most applications. The filament, control-grid, and screen-grid connectors are shown in increasing order of size in Figure 9.

Figure 9 — Terminal connectors: two cathode (filament) connectors, foreground; control-grid, top left; screen-grid, top right.

Jackets for either vapor-up or vapor-down cooling systems and other vapor cooling accessories have also been designed for use with the ML-8545. Figure 10 shows the ML-8545 mounted in a Machlett vapor-down jacket. The ML-8546 has an integral water jacket which simplifies exchange of tubes in large transmitters. Tube storage and transportation dollies are also available for proper handling and for convenience at equipment sites. Complete data on all accessories are available for equipment designers.

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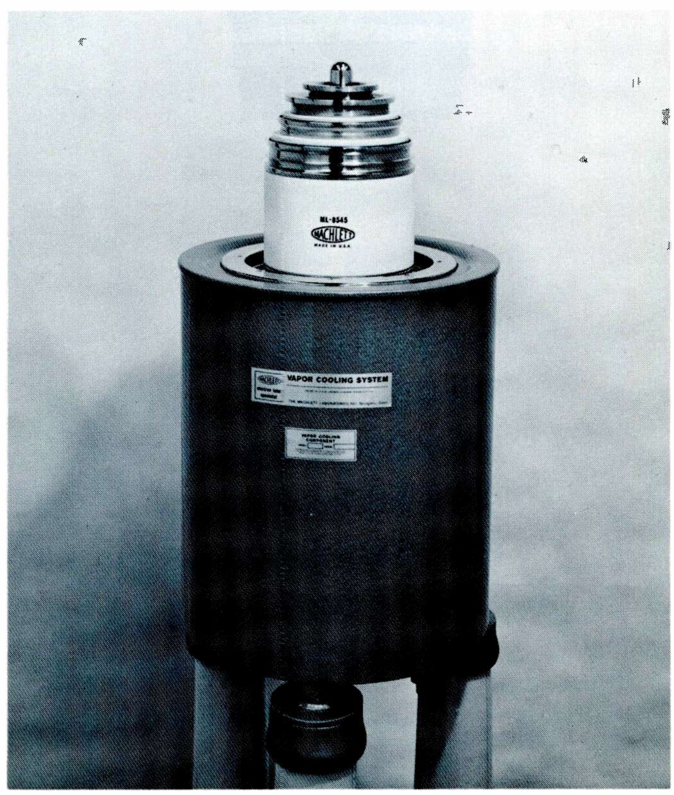
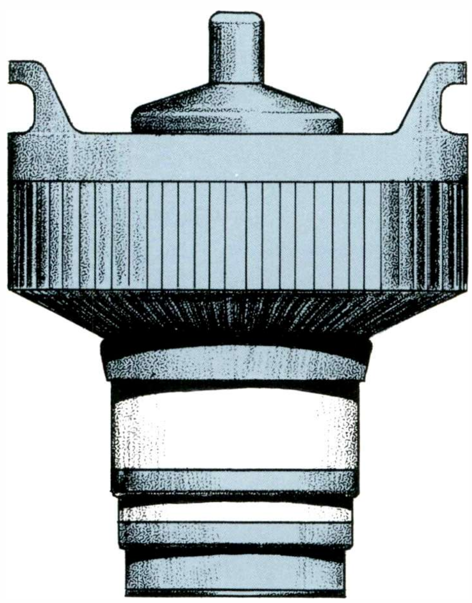
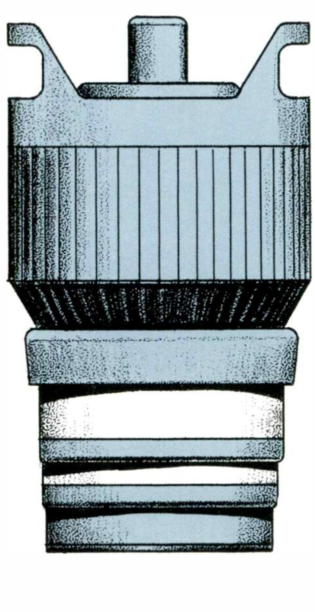


Figure 10 — ML-8545 shown mounted in a Vapor-Down Jacket.

The ML-8170/4CX5000A and

by A. ECKHAUS, Development Engineer
and DR. J. A. RANDMER, Chief Engineer,
Large Power Tubes





In recent years the preference for power tetrodes for use in various types of transmitters over a wide power spectrum has grown more pronounced. This has been, to a large extent, due to two superior characteristics of tetrodes as compared to triodes. First, for comparable power outputs, tetrodes require relatively low driving power since their power amplification is higher than triodes. This can reduce the number of driving stages or, at least, the power levels of intermediate stages. It can also result in a better overall power efficiency since less power consuming components are involved between the exciter and the power amplifier. Secondly, the feedback capacity in tetrodes is much smaller than in triodes. This can then either eliminate the need for neutralization at lower frequencies or reduce its extent by simplifying the required circuitry.

The Machlett Laboratories has been a long-time supplier of power tetrodes having originated the ceramic ML-7007[1], which is widely used in VHF television and other more specialized transmitters. It has developed very high gain tetrodes for high-voltage regulation and switching (ML-7248, ML-7249) and has more recently announced the ML-8545 and ML-8546, which are the world's highest power tetrodes (see article in this issue of CATHODE PRESS). Most recently, Machlett Laboratories has augmented their Large Power Tube product line with a complete series of tetrodes of popular contemporary design. The ML-8170/4CX5000A and ML-8281/4CX15000A forced-air cooled ceramic tetrodes are the primary tubes offered as a base for a complete line of air, water and vapor-cooled tubes, ranging from 5 to 35 kW plate dissipation. The air-cooled ML-8171/4CX10000D, which is intermediate in plate dissipation at 10 kW between the 5 kW ML-8170/4CX5000A and 15 kW ML-8281/4CX15000A, is also currently in manufacture. Introduction of the vapor and water-cooled versions will be complete within several months.

This article is intended to give the reader an insight into the construction, processing and testing of these tubes. It is to be noted that all descriptions of terminal structures,

ML-8281/4CX15000A Power Tetrodes and Their Variants

grid and filament assemblies of the ML-8170/4CX5000A and ML-8281/4CX15000A are applicable to the ML-8171/-4CX10000D and subsequent water and vapor-cooled versions, since their design features differ only in the anode, radiators, or mode of cooling.

Structure

Most contemporary power tetrodes of American and European design are of very similar, basic construction. The cathode and the grids are supported by concentric cylinders and cones which extend from the terminal assembly. The latter is usually formed by a stack-up of concentric ceramics and metal electrode terminals. This design provides the well-known "coaxial tube" properties of low inductance, high rf current-carrying capacity and mechanical sturdiness. The latter is important for maintaining the small cathode and grid spacings required in high-gain tetrodes. This type of construction has been used in tetrodes which, depending on the detailed geometry of individual types, are capable of generating power at frequencies over 1000 Mc.

Machlett Laboratories has retained this basic structure in the ML-8281 and has adopted it for the ML-8170, as well as their respective variants. A cut-away of the Machlett ML-8170 terminal is shown in Figure 1. (The ML-8281 terminal is essentially of the same design utilizing many common parts.) The terminal assembly contains all ceramic insulators and supporting structures. Assembly complexity is minimized since all parts are stacked up on a fixture and are furnace-brazed simultaneously. Element concentricity is accurately held by fixtures, which also transmit pressure to the ceramic seal joints.

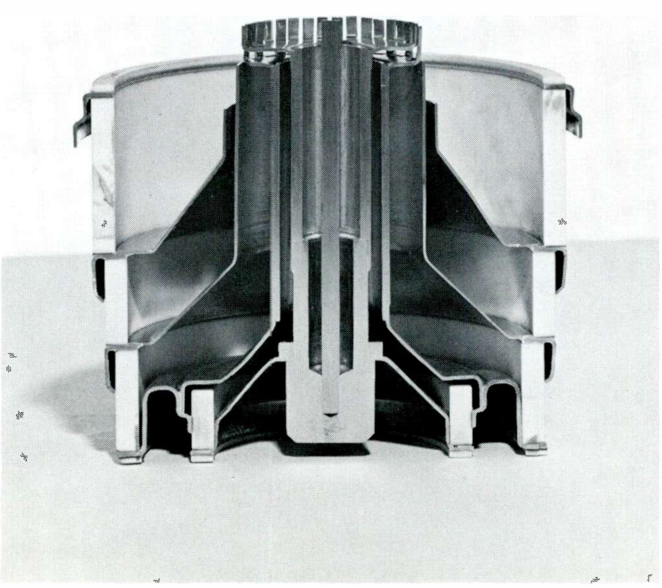
The main type of ceramic seal used is a "butt" seal, which in all cases is backed up by ceramic on both sides. This technique permits use of copper terminals, even though the thermal expansion properties of copper and ceramic differ. Repeated high temperature cycling of these seals has shown them to be at least as reliable as the standard Kovar compression seal in use on most of the other Machlett ceramic power tubes. The ceramics themselves are of the high-strength, high-alumina-content type.

A unique structural feature of the ML-8170 and ML-8281 is a rigid, copper-plated Kovar annulus between the grid and filament ceramic. Kovar has been selected here in order to obtain a stronger member between the filament and the grid sections of the terminal. This precludes shifting of internal elements by external pressure on the filament contact terminals.

Supporting elements within the ceramic envelope consist of rigid, nickel cones for the grids and nickel "fingers" for the filaments. The molybdenum center mast is brazed within a copper bushing at the bottom of the terminal and serves as a reference axis for brazing all supports concentrically.

Figure 2 shows the ML-8281 terminal assembly with filaments welded in place. The .014-inch diameter carburized thoriated-tungsten filament wires are held under tension by a compression spring located in the relatively

Figure 1 — Cut-away View of the ML-8170 Terminal Assembly.



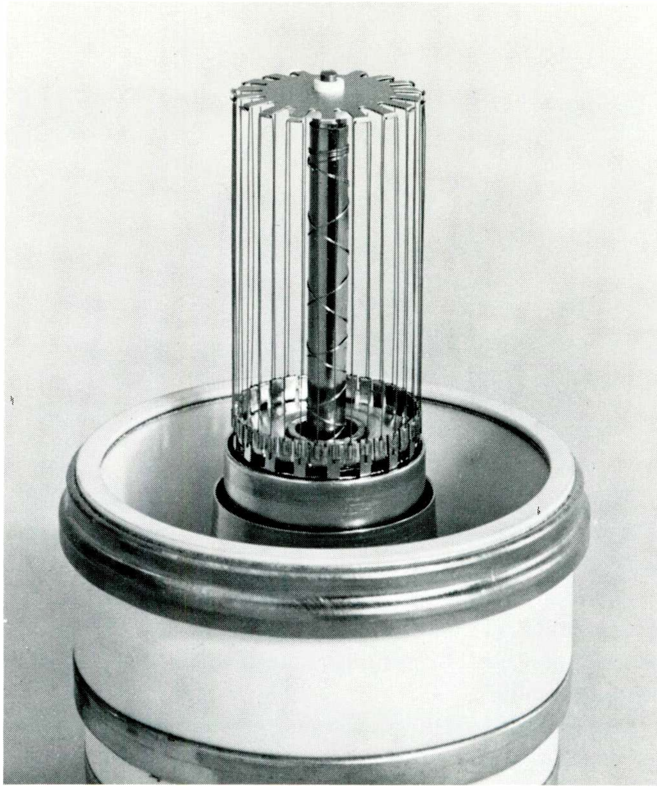
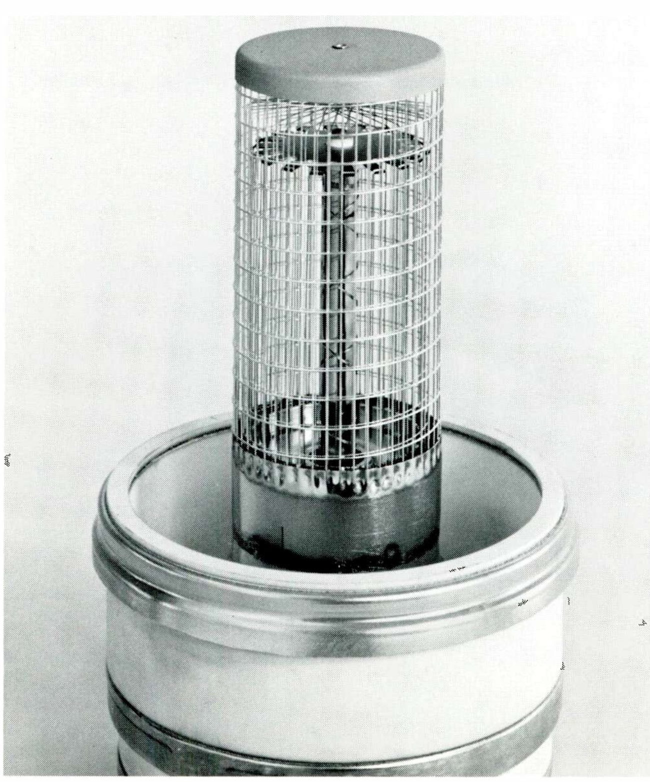


Figure 2 — ML-8281 Filament Assembly.

Figure 3 — ML-8170 Showing Mounted Control and Screen Grids.



cool recess at the bottom of the center mast. The spring force is transmitted to the filaments through a molybdenum push tube surrounding the center mast and through a molybdenum top spider, which rides on the push tube. Spring loading is sufficient to keep filaments under tension during operation, which results in filament expansion and subsequent partial relaxation of spring compression. The ML-8281 filament assembly incorporates a tie-wire on the center mast that holds a piece of zirconium sheet about the center mast, which functions as the getter in the completed tube. The ML-8170 filament assembly is similarly constructed.

The grids are mounted and welded directly to their conical nickel supports (see Figure 3). No mounting screws are used, so that uniform distribution of rf current is achieved and the possibility of localized overheating is eliminated. In addition, the ML-8281 grids are centralized at their tops by a ceramic bushing which rides on the center mast. This configuration not only accurately assures element concentricity, but is a ruggedizing feature in that grid deflection is minimized under shock and vibration conditions.

The grid structures for the ML-8170 and ML-8281 are shown in Figure 4. They are of the general cage type in which the vertical straight wires provide most of the grid control, with the helix used mainly for structural support. The basic grid wire is molybdenum except for the screen grid in the ML-8281 which is platinum-clad tungsten. The control grid in the ML-8281 is platinum-clad molybdenum. The ML-8170 grids have a more complex surface composition, of which one of the main ingredients is platinum. These special coatings, together with the subsequent processing, are necessary in order to minimize primary and secondary electron emission of the grids. The control and screen grid in both tubes are carefully aligned so that the vertical control wires of both grids are lined up exactly in radial direction. Also, the helixes of the two grids are aligned. This alignment promotes electron beaming and reduces screen currents at high positive drive voltages.

Anode and Radiator Assemblies

Radiator fins on the air-cooled ML-8170 and ML-8281 are directly furnace brazed to the anode at the same time as the other anode components are brazed. The principle reason for hard-brazing radiator fins is to insure efficient heat transfer from the anode through the fins and higher temperature operation of the anode itself. High temperature brazing material also prevents loss of the solder bond under short-period overloading such as may be encountered during tune-up procedures. The ML-8170 and ML-8281 anode-radiator assemblies are shown in Figure 5.

Final Tube Assembly

To complete the assembly of a tube, the anode and radiator assembly (Figure 5, ML-8170) is heliarc welded

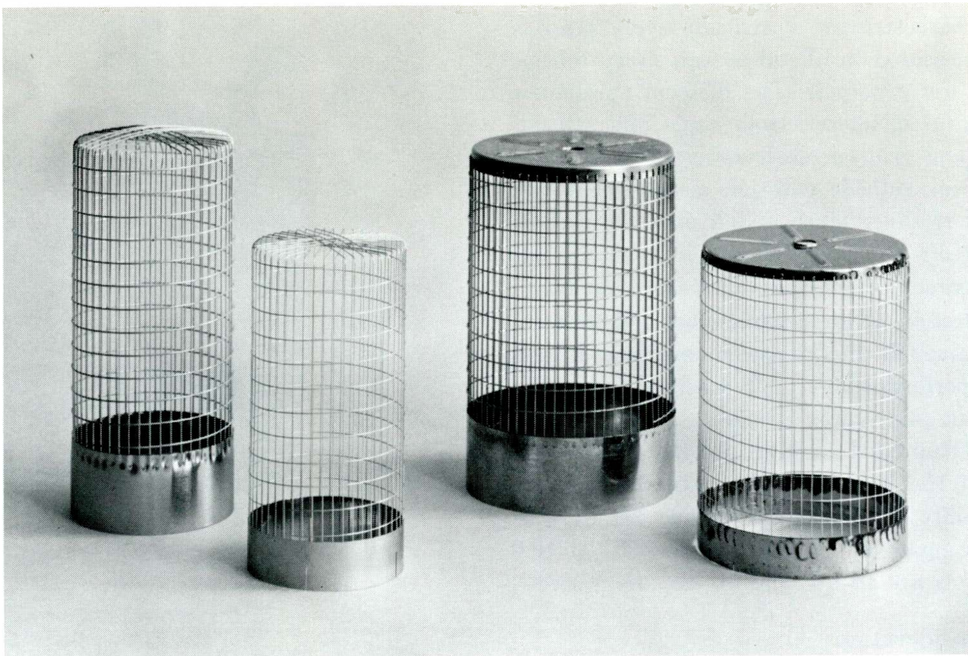


Figure 4 — ML-8170 and ML-8281 Grid Structures.

to the grid-filament assembly (Figure 4). This heliarc weld is made on the edge of the anode collar (see Figure 6, just below the radiator encircling the ceramic) and the anode ceramic collar (see Figure 1, top outermost metal ring). Both these collars are relatively thin in order to provide proper flexibility for differences in thermal expansion between the anode and the anode ceramic. So as to avoid possible damage to the seal or the thin anode collar, no electrical connection should be made, as a general rule, on the anode collar in the socket. Excessive contact pressure or local heating or arcing due to poor electrical connections may result in such damage.

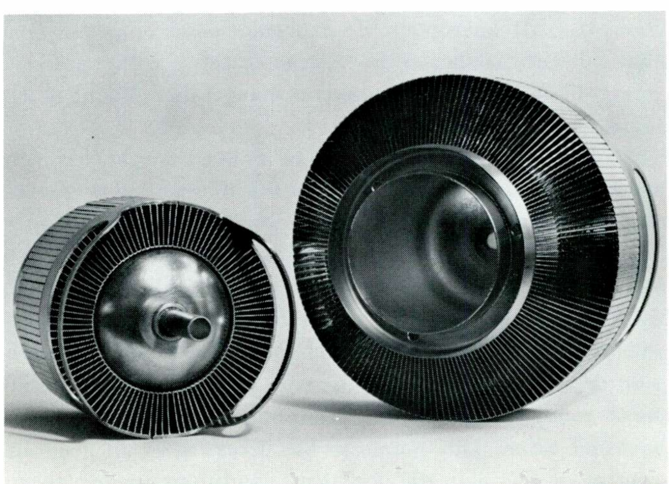
Processing

Prior to assembly, all parts receive the thorough, specialized treatment necessary for high-power tubes. Sandblasting, chemical and ultrasonic cleaning, hydrogen and high-vacuum degassing and inspection for surface cleanliness are typical. During the exhaust procedure, the tubes are subjected to temperatures far in excess of what they would ever encounter in service. For instance, the entire assembly is first baked for several hours at approximately 550°C. Later the anode is heated and maintained at a visibly dull-red color which corresponds to a temperature of approximately 600°C for several hours. Grid degassing is carried out at dissipation levels exceeding the normal ratings by a factor of 2 to 3. At the time of "pinch-off", residual tube pressure is less than 10^{-7} mm of Mercury. Once the tube is sealed off from the vacuum system, the zirconium getter absorbs in normal operation any further slow release of residual occluded gases and gases entering into the tube by slow diffusion. The latter two phenomena are present in all power tubes and do not interfere with tube operation as long as they are not accelerated by exceeding the normal dissipation ratings established for the tube. After pinch-off, the exterior of the tube is cleaned and silver plated.

Testing

Since the production of the ML-8170 and ML-8281 is in the build-up phase, the test program for these tubes is considerably more intense than for well-established types. All tube assemblies and component parts are carefully checked dimensionally and for other aspects to insure uni-

Figure 5 — ML-8170 and ML-8281 Anode and Radiator Assemblies.



formity of tube characteristics. Practically every possible characteristic is measured in all tubes. and every tube is operated in an rf test generator. The filament parameters are accurately measured. interelectrode capacitances determined, and plate and grid current characteristics checked at many points. Peak cathode emission measurements are made, gas current readings taken at full plate dissipation, and rated cooling air flow and thermionic grid currents determined at maximum rated grid dissipation inputs.

A further verification of these parameters and their interrelations is obtained in the rf power amplification test. Each tube has to perform stably for a specified test period under certain input and output conditions. An rf test is made on a crystal-controlled amplifier having a maximum input capability of 15 kV and 6 A. Emphasis is placed on good voltage stability during this test. The ML-8170 is tested at 7.5 kVdc plate voltage and the ML-8281 at 10.0 kVdc. Power outputs are 16 kW and 36 kW. respectively.

Cathode Life Considerations

In power tubes having thoriated-tungsten filaments, the life expectancy of the cathode is primarily determined by the depletion of the tungsten-carbide layer of the filaments. The formation of this carbide layer on the tungsten filament, termed carburization, is accomplished after filament assembly under carefully controlled conditions, giving an outer carburized layer having an area of about 30% of the wire cross-section. For long cathode life, a heavier layer would be desirable but this would lead to extremely fragile filaments, since tungsten-carbide is a relatively brittle compound. The characteristics and the geometry of the ML-8170 and ML-8281 require many fine filament wires, .010″ and about .014″ in diameter, respectively (see Figure 2). For an equal percentage of area carburization, the carbide layer on thin wires is less than on heavier wires. The cathode life is directly proportional to the thickness of the carbide layer at a given temperature[2]. Accordingly, at the same operating temperature, the life expectancy of small diameter filament wires is less than for cathodes made of heavier wire. This does not mean that the ML-8170 and ML-8281 have poor life expectancies. It simply means that tube life is shorter in relation to tubes with relatively heavy filament wires, as used in many other Machlett designs.

In this connection it should be noted that the filament operating voltage which controls the filament temperature and, hence, the rate of decarburization, has a very pronounced effect on the cathode life expectancy. As a rule of thumb, the life expectancy doubles if the filament voltage is decreased by 5% and is cut in half if the filament is operated 5% above the nominal value. The change in emission capability is just opposite, e.g.. a 5% reduction in filament voltage decreases the peak emission to about half its nominal value. This points to the necessity of an accurate control of the filament operating conditions in any thoriated-tungsten tube. It also shows that with good filament regulation. say to ±1%, which can be readily attained, and a reduction of the filament voltage by one or two percent, a very substantial extension of filament life can be achieved. Larger filament voltage deratings should. of course, be made only if the required peak currents are relatively low and after due consultation with the tube manufacturer.

Figure 6 — Completed ML-8170/4CX5000A.

Application Data

Maximum Ratings, typical operating conditions, cooling information and other pertinent application data are covered in the tube data sheets for the ML-8170 and ML-8281. The Machlett versions of these tetrodes have been carefully designed to achieve maximum interchangeability with other 8170's and 8281's. Plate current levels, capacities, interelectrode strapped resonant frequencies. filament characteristics, maximum ratings and pertinent dimensions are all essentially identical to competitive tubes.

ML-8170 and ML-8281 Variants

A basic ML-8170 with a larger radiator, capable of handling a dissipation of 10 kW. is already being phased into production. This tube can be seen in Figure 8 and has the type designation ML-8171/4CX10000D. Because of the larger radiator, it can provide larger power outputs in linear amplification. both in rf and af service, since in this class of service. relatively large plate dissipation capabilities are required. For equal plate dissipations, the ML-8171 requires less air flow and a considerably lower air pressure than the ML-8170, and can therefore be used instead of the ML-8170 in applications having restrictions

Figure 7 — Completed ML-8281/4CX15000A.

Figure 8 — Completed ML-8171/4CX10000D.

on air flow or in-and-out going air temperatures.

Figure 9 shows another adaptation of the basic ML-8170 — the developmental type number of this tube is ML-LPT11. This tube has an anode designed to be cooled by vaporization of water. It features an integral vapor jacket (see completed tube, Figure 10) and is intended for use in vapor-up cooling systems[3]. The plate dissipation capability of the ML-LPT11 is 10 kW. The integral jacket design results in a plate capacity to the surrounding equipment which is very close to that of an air-cooled ML-8170 or ML-8171. This vapor-cooled version is of considerable advantage for installations in which the high noise level of air cooling is objectionable.

Other variants of the basic ML-8170 and ML-8281 can be made readily available with relatively short lead times. Vapor-cooled versions of the ML-8281 are under development and water-cooled versions pose only a straight-forward design task.

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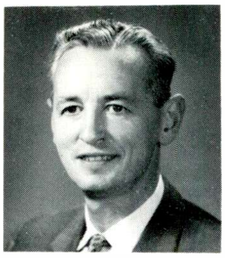
Figure 9 — ML-LPT11 Vapor-Cooled Tetrode Showing Anode Without Integral Vapor Jacket.

Figure 10 — ML-LPT11 Vapor-Cooled Tetrode Complete with Integral Vapor Jacket.

About the Authors



DR. JACOB A. RANDMER

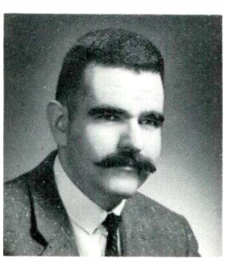
Dr. Randmer is Chief Engineer of The Machlett Large Power Tube Operation and is responsible for the development and production engineering of the operation. He received his Electrical Engineering degree from the Institute of Technology in Berlin and a Doctor of Engineering degree from the Institute of Technology in Munich. He was staff member at both institutes and was primarily engaged in research on cathode ray tubes, vacuum techniques and related areas, such as secondary emission, electron optics, and thin film deposition. Dr. Randmer is a senior member of IEEE and holds three U.S. patents in his field.

HELMUT LANGER

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

C. T. JOHNSON

Mr. Johnson, who was responsible for designing and building the ML-8545 and 8546 prototypes, is a Senior Development Engineer for the Machlett Large Power Tube Line. Before joining The Machlett Laboratories, Inc., in 1964, he was associated with the Radio Corporation of America, where he worked on the development of medium-power UHF tetrodes and pulse modulator tubes. Mr. Johnson received his B.S. in E.E. from Georgia Institute of Technology and he's presently working on his M.S. in E.E. at Brooklyn Polytechnic Institute.



ALLAN ECKHAUS

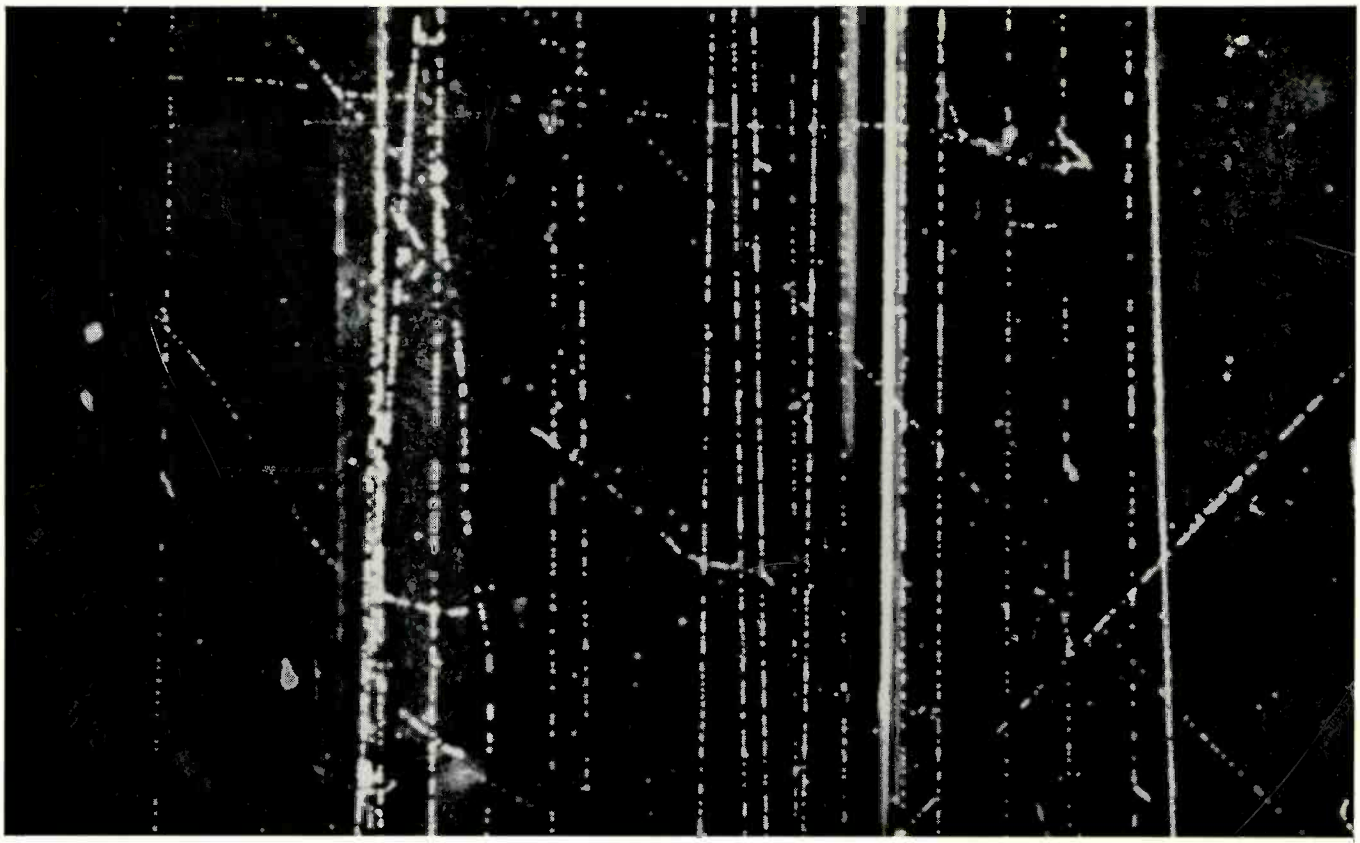
Allan Eckhaus, who received his B.S.M.E. from the Massachusetts Institute of Technology, has been a development engineer with Machlett since 1963. Prior to joining the Large Power Tube Operation, Mr. Eckhaus worked in development and production of traveling wave tubes at Sperry Gyroscope Co., and receiving tubes at Sonotone Corp. He is currently engaged in design and development of Machlett's new line of power tetrodes.

NEW MACHLETT DEVELOPMENT . . . ML-8618

The ML-8618 is a magnetically beamed, high-power, general-purpose, water-cooled triode. When operated as a class C amplifier or oscillator, the tube is capable of a continuous output in excess of 225 kW with only 200 W driving power. When used as a switch tube in hard-tube pulse modulators for radar, particle accelerators, or similar applications, it can deliver more than 8 Mw pulse output with pulse widths up to 10,000 microseconds at a duty factor of .06.

The water-cooled anode of the ML-8618 is capable of dissipating up to 80 kW. The tube can be operated in air at maximum plate voltage ratings. Maximum ratings apply at frequencies up to 30 Mc. Useful power output can be obtained at higher frequencies with a reduction in plate voltage.

High Energy Physics and Machlett High Power Electron Tubes



High energy physics, as represented by this "hydrogen bubble chamber" photo and Machlett's high power electron tubes, have had a long association in the nation's foremost Particle Accelerators—helping to accelerate protons from the early cyclotron (22 million electron volts) to the modern synchrotron (33 billion electron volts). Reasons for this long association lie in the performance reliability of Machlett tubes, and reflect continued confidence in the capability of the Machlett organization. Whether you require high power/high voltage triodes or tetrodes, UHF planar triodes, X-ray tubes, vidicons, or you need assistance in research or design development, write: The Machlett Laboratories, Inc., Springdale, Conn. 06879. An Affiliate of Raytheon Company.

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