RESEARCH ON

MICROWAVE WINDOW MULTIPACTOR AND ITS INHIBITION

REPORT NUMBER 1

CONTRACT NUMBER DA36-039-SC-90818
DEPARTMENT OF THE ARMY
TASK NUMBER OST 76-10-318-28-03

FIRST QUARTERLY PROGRESS REPORT
1 July 1962 through 30 September 1962

U. S. ARMY ELECTRONICS RESEARCH AND DEVELOPMENT LABORATORY
FORT MONMOUTH, NEW JERSEY

EITEL-McCULLOUGH, INC.
San Carlos, California

(6) RESEARCH ON
MICROWAVE WINDOW MULTIPACTOR
AND ITS INHIBITION.

REPORT NUMBER 1

(12) CONTRACT [redacted] DA36-039-SC-90818
~~DEPARTMENT OF THE ARMY~~
~~TASK NUMBER OST 76-10-318-28-03~~
(13) N/A

~~FIRST~~ QUARTERLY PROGRESS REP[redacted]T. no. 1
1 July [redacted]-30 Sep[redacted]62

Object of Research: (1) Attain a more complete theoretical understanding of microwave tube window multipactor, its initiation and sustainment, and the tube performance limitations it imposes; (2) Investigate techniques to inhibit multipactor without degrading tube performance.

~~Prepared~~ by: Oskar Heil and
Oskar Heil

Donald Preist

(9) 30 Sep 62, (10) 47p. incl. illus.
(11) N/A

This research is a part of Project DEFENDER, sponsored by the Advanced Research Projects Agency, Department of Defense, under ARPA Order Number 318-62, Project Code Number 7300, and is conducted under the technical guidance of the U. S. Army Electronics Research and Development Laboratory, Fort Monmouth, New Jersey.

TABLE OF CONTENTS

1. PURPOSE

The broad purpose of the study is to provide a deeper understanding of multipactor effects at waveguide windows used with high power microwave tubes which will lead to practical methods for preventing or eliminating multipactor, thereby raising the power handling capacity of windows. Throughout the investigation emphasis will be placed on a scientific approach and understanding of the phenomena involved so that solutions may be obtained in the most general terms and can therefore be expected to be applicable over a wide range of conditions.

At present, the method of eliminating multipactors is the application of an evaporated film of titanium in order to reduce the secondary emission coefficient of the window and adjacent surfaces, using techniques which have already been developed to a certain point as a result of the company-sponsored research at Eitel-McCullough on cylindrical windows prior to the inception of the present contract. This work has been summarized in two published articles[1]. In the course of this work klystrons were made with coated output windows and adjacent metal parts. These windows without coatings exhibited severe multipactor, and with coatings exhibited no multipactor. We believe this is the first time this has been done. At the time of the inception of the contract it had not been done anywhere else, to our knowledge. It seems reasonable to suppose that these techniques would be equally effective if applied to waveguide windows at which multipactor discharges are occurring. Another possible method would be that originally proposed by O. Heil in 1960 which is the direct application of titanium suboxides, rather than titanium metal.

An alternate method of eliminating multipactor is provided by phase or space defocusing of the electron cloud near the window. If the electric fields in the window region are properly shaped, or if the window configuration is suitably designed, the secondary electrons produced will not be entrapped in a resonant field. This method does not, in principle, require a reduced secondary emission coefficient at the window surface. However, these two approaches are mutually beneficial, and together should provide a very effective means of suppressing multipactor.

Because these approaches are quite different in application, the work has been divided into the following two tasks, with separate investigators:

---

[1] "On the Heating of Output Windows of Microwave Tubes by Electron Bombardment," by D. H. Preist and R. C. Talcott, IRE Trans. PGED Vol. ED-8 No. 4, July 1961, and "The Effects of Titanium Films on Secondary Electron Emission Phenomena in Resonant Cavities and at Dielectric Surfaces," by R. C. Talcott, IRE Trans. on Electron Devices, Vol. ED-9, No. 5, Sept. 1962, pp 405-410.

TASK A: An Experimental Study of Electron Bombardment Phenomena at the Output RF Windows of High Power Microwave Tubes.

Phase 1. Experimental and analytical study of multipactor effects at waveguide windows under high power conditions.

Phase 2. Development and application of evaporation coatings and techniques applied to the window and surrounding metal parts in order to reduce secondary emission coefficient to less than unity.

TASK B: Study of the Inner-Window Surface and Configurations Affecting Power Handling Capabilities of High Power Microwave Tubes.

Phase 1. Analysis of various means of obtaining space and phase defocusing of electrons by shaping the fields and window surfaces.

Phase 2. Study of materials and coatings in conjunction with shaped fields to develop windows capable of handling higher powers without multipactor.

2. ABSTRACT

TASK A: An Experimental Study of Electron Bombardment Phenomena at the Output RF Windows of High Power Microwave Tubes

This ~~first quarterly~~ report on the study and elimination of multipactor discharges at waveguide windows of high power microwave tubes ~~reports mentions~~ describes progress on the two major phases, which are:

(1) ~~A~~n analytical and experimental study of multipactor effects at waveguide windows using a frequency of 2850 mc ~~Megacycles~~ under both CW and pulse conditions, and

(2) ~~T~~he development and application of evaporative coatings and techniques to waveguide windows and the testing of these coated windows under multipactor conditions to evaluate the effects of the coatings in preventing multipactor.

So far, progress on Phase 1 has consisted of obtaining, setting up and checking out the ~~RF~~ equipment required

to provide necessary power and instrumentation and also the design and partial fabrication of the window box itself. On Phase 2, progress has been confined to a study of various methods of improving the control of evaporative coatings and to devising methods of applying such coatings to waveguide windows.

was made on

[redacted] ~~Study of the Inner-Window Surface and Configurations Affecting Power Handling Capabilities of High Power Microwave Tubes.~~

The gliding type multipactor with practically no phase restrictions is discussed. Methods of reducing or preventing multipactors are described. These are concerned with the lowering of the rate of secondary emission and by phase and space de-focusing. Special emphasis is given to the electron accelerating forces resulting from field inhomogeneities including those of standing waves. Two methods for instantaneous multipactor detection are given. Expected effects from a grooved window surface are discussed. Titanium monoxide sputtering experiments using Hg ions to get low secondary emission coatings are discussed, and their results are described.

3. PUBLICATIONS, LECTURES, REPORTS, AND CONFERENCES

TASK A:

3.1 Publications

"The Effects of Titanium Films on Secondary Emission Phenomena in Resonant Cavities and at Dielectric Surfaces," by Ruth Carlson Talcott, Trans. IRE, PGED, Vol. ED-9, September 1962.

3.2 Lectures

"Multipactor Motions in Microwave Tubes," by D. H. Preist, paper read at the International Congress on Microwave Tubes, the Hague, Holland, September 1962.

3.3 Conferences Held

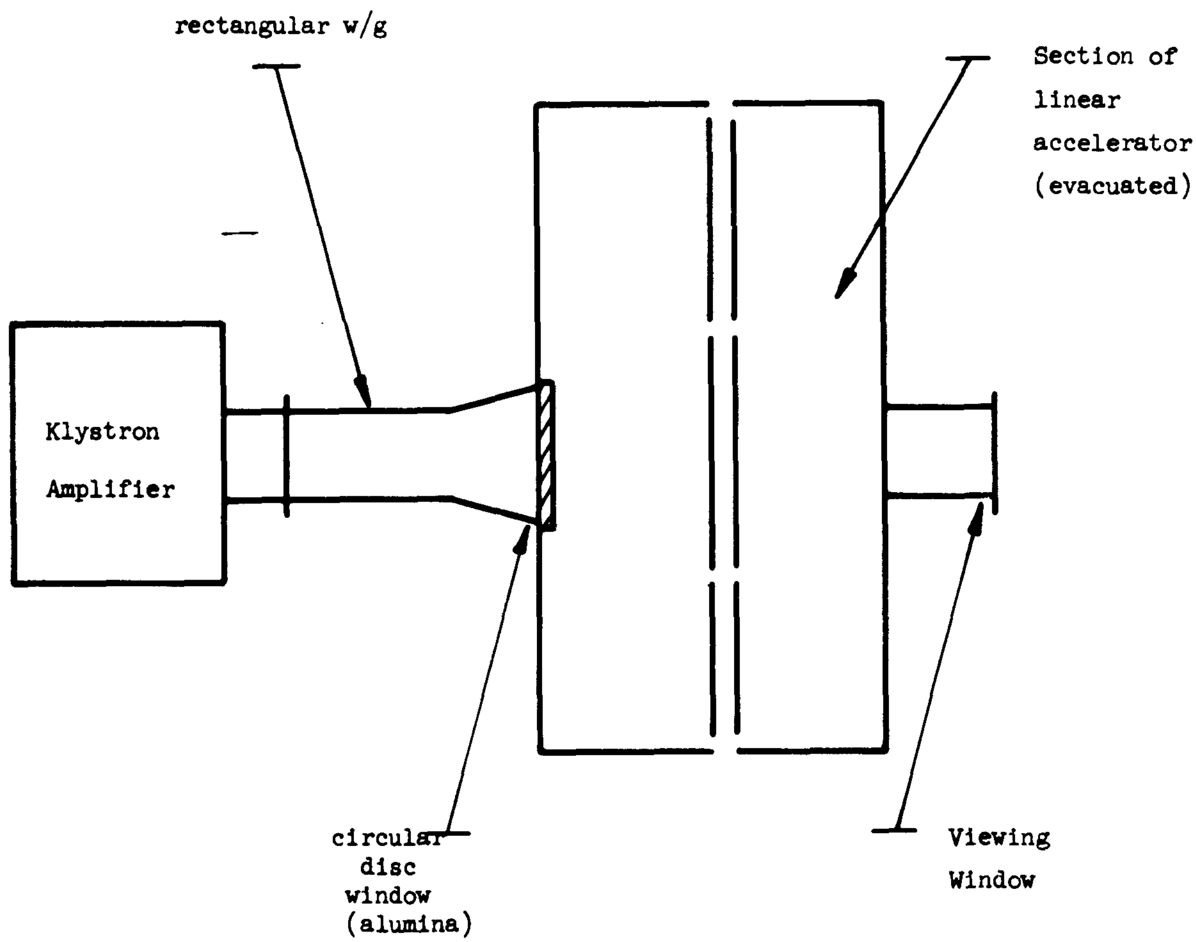
1. At Stanford University, August 30, 1962. Those present: Don Preist, Ruth C. Talcott, John Soderstrum, from Eimac and John Jasberg and Dr. Pedro Szenti of Stanford.

   The Stanford experiments on windows at S-band in cavity resonators were described and discussed.

These experiments were done with a higher window RF electric field strength than in the past on account of the lower loss of the cavity resonator than that of the ring resonator. They have shown repeatable damage to windows which appears as an internal physical change to the window material in the form of black dots or streaks. The power level at which this damage is observed appears to be a function of the gas pressure and becomes higher as the pressure is reduced. This work has been done with O-ring seals and a vacuum between 10^{-4} and 2×10^{-5} Torr but more work is planned with brazed joints and a better vacuum. The possibility that the damage could be caused by multipactor discharges was discussed but it was concluded that there was insufficient evidence to prove the existence of multipactor.

2. <u>At The Haque, Holland between Preist of Eimac and Dr. G. Schaffer of the Hamburg Linear Accelerator Project (DESY), September 7, 1962</u>.

Dr. Schaffer has some very interesting color photographs of discharges on the vacuum side of a window feeding a linear accelerator cavity at a frequency around 500 megacycles. The arrangement is shown in Figure 1, from which it can be seen that the window is a round disc waveguide window. When the power level was raised high enough (well beyond the designed level for the accelerator) bright spots began to appear and streaks of light on the vacuum side. When it was raised further, the window would crack. This was repeated several times. Examination of the window showed that the bright spots and streaks were associated with permanent damage to the interior of the window surface very similar to that observed at Stanford. Once again it was noted that the gas pressure on the output (vacuum) side of the window had an important bearing on the power level at which failure would occur. A calculation showed that the damage occurred at just above the critical field strength which we have previously shown to exist for a single surface multipactor (1), and it was agreed that in this case there were reasonable grounds for thinking that the damage resulted from a single surface multipactor discharge similar to the ones we have found at Eimac in the past.



Schematic Diagram of Dr. Schaffer's Set-Up
at Hamburg (DESY)

Fig. 1

3. At EMI, Hayes, Middlesex, England between Preist of Eimac and Dr. Kreuchen, Mr. Dixon and Mr. Barnes of EMI, September 12, 1962.

Their work with quartz-tipped glass conical waveguide windows was discussed. This work had been described in a paper by Mr. M. J. Smith of EMI at the Microwave Tube Congress at The Hague, Holland, September 5, 1962. Briefly, these windows appear to be capable of passing several megawatts and at least 50 kilowatts of average power at S-band in ring resonators. They exhibit evidence of single surface multipactor of the kind described in reference (1) at times, but this multipactor is not destructive and disappears when the power level is raised. EMI believe that this is due to the fact that at the higher power levels the electron velocities are such that δ for quartz would be less than unity, preventing multiplication of secondary electrons. Also, the shape of the window and its surrounding transition between circular and rectangular waveguide is such as to produce a force sweeping electrons out of the window and, therefore, also limiting multipactor action.

The method of analysis of the single surface multipactor given in reference (1) has been used by EMI, and they find it adequate to explain quantitatively the effects they observe. They have calculated the magnitude of the electric field gradient force at the window, and show that this force will drive secondary electrons emitted from the window back to the window as required to sustain the multipactor[2].

TASK B:

Conferences Attended by Oskar Heil

The American Physical Society Conference in Seattle, Washington, was attended. A paper presented by H. Seiwatz and C. M. Groom on the nondestructive breakdown on dielectrics led to the idea for window protection as described in the text.

---

[2] EMI "Progress Report No. 2 on Research Proj. RP 5-9 - E.M.I. Research Labs. Ltd. (Gr. Brit.), November 1961," by M. J. Smith and A. Bamford.

BOTH TASKS:

Conferences Held

1. At Eitel-McCullough, San Carlos, California with Lt. Col. W. B. Lindsay of ARPA, August 23, 1962.

   The general philosophy, purposes and orientation of the program were discussed and plans reviewed.

2. At Eitel-McCullough, San Carlos, California with Mr. Louis Heynick of the U. S. Army Electronics Research and Development Laboratory, July 2 and July 19, 1962.

   Plans and progress were reviewed.

4. TASK A

AN EXPERIMENTAL STUDY OF ELECTRON BOMBARDMENT PHENOMENA AT THE OUTPUT RF WINDOWS OF HIGH POWER MICROWAVE TUBES.

Prepared by

Donald H. Preist

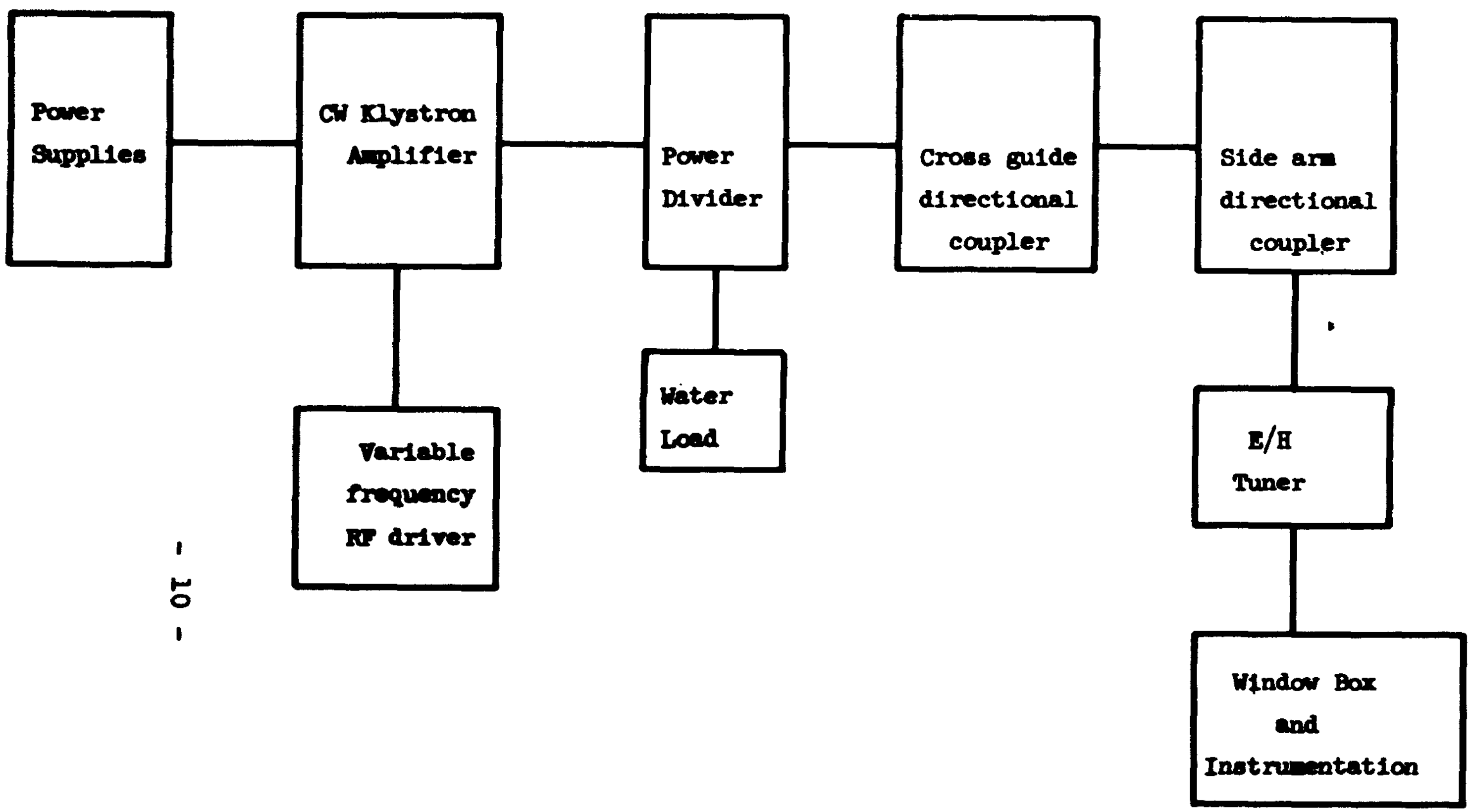
4.1 FACTUAL DATA. PROGRESS TO DATE

4.1.1 Design of Window Box and RF Plumbing Run and Acquisition or Fabrication of These Items

This arrangement is shown schematically in Figure 2. The RF driver will be either an Eimac 4KM70SK CW klystron rated at 20 KW CW output or an Eimac X632G pulse klystron rated at 10 megawatts peak and 10 kilowatts average power output. The frequency in both cases will be 2850 Mc. Following the driver is the power divider and waterload, which will ensure that the klystron is loaded adequately during all adjustments of frequency, etc., which might otherwise produce a large and damaging electric field strength at the klystron output window. Following this are two directional couplers in series to give simultaneous measurements of forward and backward power at high power levels.

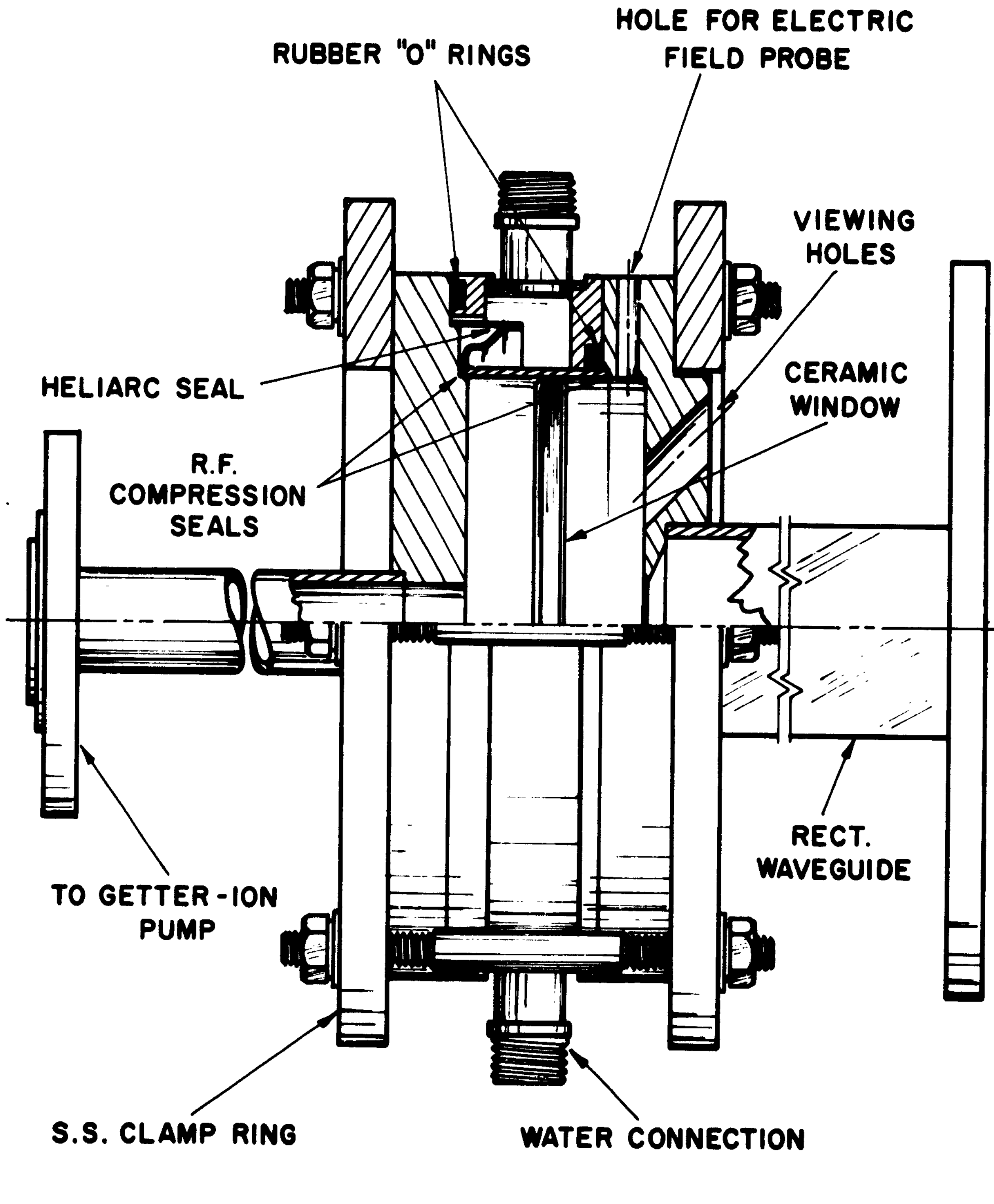
The window box itself, which is shown in detail in Figure 3, will be, for the first experiment, a resonant cylindrical cavity containing the ceramic window and operating in the $TE_{1,1,1}$ mode. Power will be fed through a circular coupling iris which is adjusted to be overcoupled in the condition where only dielectric losses and copper losses are present, and to be somewhere near a match if and when multipactor discharges occur. The window box is demountable and water-cooled, and equipped with a hole for insertion of an electric field probe. Also, there are holes in the end face on the air side of the window for viewing and for insertion of contact pyrometers for measuring window temperature immediately after turning off the power. The window box is designed so that the window and the minimum number of other parts attached to the window are expendable in case of failure. The only vacuum seals are the braze between the window and the surrounding copper cylinder and a braze between this cylinder and the sealing ring, and a final heliarc take-apart joint between the two sealing rings. The RF current will flow through compression seals made by squeezing the thinned edges of the copper cylinder against the end flanges by means of the bolts shown in the figure. The cavity is equipped with a connection to a getter-ion pump gauge.

A subsequent model of the window box will be fitted with a viewing window through which the vacuum side



Block Diagram of Test Setup

Fig. 2



"WINDOW BOX" ASSEMBLY

Fig. 3

of the window may be observed during operation. This should be of particular interest during the pulse tests.

Parts for the window box are being fabricated and are expected to be assembled shortly.

There has been considerable delay in obtaining some of the components in the RF plumbing run in Figure 2. However, all these parts should be available early in the next quarter.

4.1.2 Fabrication and Testing of Driver Klystron

A 4KM70SK klystron has been manufactured and tested in our High Power Microwave Division. Special attention has been paid to operation of the tube around 2850 megacycles, which is the frequency we propose to use for testing windows. In particular, a thorough examination of the ghost-mode pattern of the klystron window has been made to ensure that we will not damage it by operating at ghost-mode frequencies, if these exist. In the course of these tests the whole equipment, including power supplies, driver, etc., has been set up and checked out to ensure reliable and, hopefully, trouble-free operation during the testing of windows. It is expected that these tests will be finished early in the next quarter.

4.1.3 Work on Control of Evaporated Coatings on Windows

During this program we propose to use evaporated titanium coatings on both the window and surrounding metal parts as a means of controlling or inhibiting multipactor discharges when these are found to exist without such coatings. This approach has been found to be very successful in previous Eimac-sponsored work carried on before the inception of the present contract and has been rather completely described in a recently published article[3]. Briefly, the method is to evaporate titanium metal from a hot filament onto the target in a bell jar in a good vacuum. The purpose of this is to obtain, if possible, a pure titanium surface having the secondary emission characteristic of titanium, particularly the low value of δ_{max}. The previous work showed that this

[3] "The Effects of Titanium Films on Secondary Electron Emission Phenomena in Resonant Cavities and at Dielectric Surfaces," by Ruth Carlson Talcott, Trans. IRE PGED, Vol. ED-9 No. 5, September 1962.

could be achieved, apparently in a reproducible manner, both on metal surfaces and ceramic surfaces. The thickness of the films used on the ceramic was on the order of 100 angstrom units and at the frequency used (650 megacycles), this thickness of film gave only a small and insignificant increase in the apparent dielectric losses of the windows. Such coated surfaces could be baked out in vacuum in normal fashion without deterioration and have been successfully used in a number of high power CW klystrons having cylindrical ceramic windows inside the output cavities. This work and its results have also been described in reference (1). It is reasonable to suppose that similar coatings will have similar beneficial results when applied to waveguide windows suffering from multipactor effects.

A study has been made of various possible methods of improving the control of coatings. In the previous work we were concerned with cylindrical windows which have the advantage of two parallel ends, which simplifies the measurement of the coating resistances. This measurement of the coating resistance can be made during and after the coating process and can be used as a means of controlling the thickness of the coatings. With round disc windows we are, of course, unable to used this method. In addition, we were not satisfied with the method as it required somewhat undue skill on the part of the operator.

We have considered the use of three basic methods of control, which may be described as:

1. Metering the amount of material evaporated.

2. Control by optical measurements on a coating deposited on a transparent material simultaneously with the window.

3. Control by secondary emission measurement during coating.

The first method, while simple in concept, is very difficult to carry out in practice because we are dealing with exceedingly small amounts of deposited material. It should be remembered that the required thickness of material on the window dielectric surface is on the order of 100 Å only.

Such films are nearly transparent and are also too thin to give interference or color patterns.

The second method, using optical absorption or reflection, has some advantages and several disadvantages; one is that a separate glass target has to be used in the evaporating set-up and the evaporating filament must be designed to coat both this and the window. Optical measurements have to be made of the transmission or reflection of light from the glass target during the coating process. Once again, because the films are so thin, it would be difficult to make the measurements, and the films are sensitive to such things as the rate of evaporation and the quality of the vacuum.

The third method appears to be the most promising at present. This method is essentially to measure the value of δ, the secondary emission coefficient of the surface during the evaporation process so that the operator can tell when δ has fallen below unity on account of the coating. A pulse technique is essential to prevent significant static charges being built up by the electron beam, which is necessary to measure δ, and to prevent the cracking of hydrocarbons at the window with a resultant carbonaceous deposit. We are planning to pursue this approach experimentally during the next period.

Having established a satisfactory method of control, we plan to apply titanium coatings to the windows to be tested in the window box shown in Figure 3 to determine their effect on multipactors. We do not propose to limit our studies to titanium alone, but will be in a position to try other elements which appear to be favorable as a result of analytical study.

4.2 CONCLUSIONS

At this stage no conclusions have been reached about either of the phases of this task.

4.3 PROGRAM FOR NEXT INTERVAL

During this period we expect to test under CW conditions a sufficient number of windows to determine the conditions under which multipactor occurs and to make significant quantitiative measurements on the power loss in the multipactor discharge as a function of window electric field strength.

On coating control, we plan to continue with experiments based on the secondary emission measurement technique described earlier, and if this is successful, we shall attempt to apply evaporative coatings to round disc windows and test these windows in the window box described herein.

5. **TASK B**

STUDY OF THE INNER-WINDOW SURFACE AND CONFIGURATIONS AFFECTING POWER HANDLING CAPABILITIES OF HIGH POWER MICROWAVE TUBES.

Prepared by

Oskar Heil

Oskar Heil

5.1 FACTUAL DATA. PROGRESS TO DATE.

5.1.1 Introduction

There exists the possibility that many high power window failures by cracking or arcing within the material originate from a surface multipactor. In the case of cracking, it is the heating by the multipactor which causes thermal stress leading to fracture. In the case of arcing, the heating produces gas and the resulting ion space charge compensation increases multipactoring, leading locally to a runaway condition ending in internal window arcing. However, there is also the possibility that arcing is independent from multipactoring and is caused within the window material itself. In this case arcing may be favored by the window heating caused by multipactoring.

The aim of this study is to fully understand the effects of field configurations and materials on multipactor to control and prevent it.

5.1.2 Multipactors

The multipactor appears in many varieties: the double surface and the single surface, the low order and the higher order multipactor (according to the number of cycles between impacts), on conducting or insulating surfaces. For insulating materials the electric field need not be perpendicular to the surface, but can have any angle, even to the extent of being parallel to the surface. A multipactor occurring when the electric field is not normal to the plane of the window is known as a "gliding" multipactor. This gliding type of multipactor can exist between two surfaces or on a single surface. All single surface multipactors, the gliding type as well as the perpendicular, require a force driving the electrons back to the surface. This force can come from an electric field, or a magnetic field, or can be a force resulting from field inhomogeneities. This restoring force can be rather weak for the gliding multipactor, but must be of the same magnitude as the ac field in the perpendicular multipactor.

The gliding multipactor is the most common and easiest to start on windows for the following reasons:

1. Since the electric field of an electromagnetic wave stands perpendicular to the direction of energy propagation, and since this is also the direction of the usual waveguide window surface, the gliding multipactor is most common on window surface.

2. The gliding multipactor is the most stable and persistent multipactor because it has practically no phase restriction for the multiplying impact of electrons. It is always possible to have a free acceleration of emitted secondary electrons from the ac field no matter in which direction the electric field points. This is not so on a surface perpendicular to the electric field where half of the electrons are intercepted by the surface before gaining energy for multiplication, because half of the time the field points towards the surface.

3. The restoring force, the force driving the electrons back to the surface, is not critical and can have a wide range of values because the phase of arrival on the surface is unimportant. Only a force which is too strong and leaves the electron no time to pick up energy of the ac field would kill the multipactor.

4. Sliding incidence of the electrons on the surface increases the rate of secondaries and moves the voltage of the second crossover-point to higher values. On high power pulses the electrons oscillating in front of the window reach velocities higher than the second crossover, and by increasing the voltage of the second crossover, due to grazing incidence, the multipactor is more likely to occur.

5.1.3 Reduction and Prevention of Multipactors

There are three ways to reduce or prevent multipactors:

1. Lower the secondary emission coefficient of the surfaces (coating) as described below.

2. Space defocusing of electrons, described below.

3. Phase defocusing of electrons as described in 5.1.7.

1. Secondary emission coefficients of insulating materials as a rule are higher than those of conductors. An explanation for this can be found in the microfield of the surface. The potential of a good insulator is not uniform, but is in the form of a random distribution. The local fields favoring electron emission do more than the fields counteracting emission. This favored emission can be reduced by a small amount of surface conductivity. There exist no low secondary emission materials without an electric conductivity. On window surfaces we cannot tolerate any appreciable conductivity because of ohmic losses. The window coating should have high specific resistance. The thermal coefficient of resistivity should not have a highly negative value, as found in semiconductors, to prevent runaway condition for the window temperature. The coating must be thin and, therefore, thermally and chemically stable. Titanium suboxides seem to fulfill these conditions[4]. This material was proposed and strongly recommended at Eimac by the author as a window coating for secondary emission prevention in late 1960 as a result of the data in reference (4). It is very likely that the 100 angstrom thick titanium coatings used by Ruth Talcott and Don Preist might easily have changed into titanium suboxides due to the chemical activity of this metal. This subject will be investigated further during the course of this study. Titanium monoxide is similar in property to a metal, having a positive temperature coefficient of resistivity. The resistivity is 2.8×10^{-4} (Ωcm). (TiC and TiN have very similar properties.) With higher degrees of oxidation the temperature coefficient becomes gradually negative and the resistivity goes up. The temperature coefficient for Ti_2O_3 at room temperature is about -8×10^{-3} per degree C with a resistivity

---

[4] L. E. Hollander and P. L. Castro, "Anisotropic Conduction in Non-Stoichimoetric Rutile (TiO_2)" in Sept. 1960, Phys. Rev., Vol. 119, Pg. 1882.

of about 3 (Ωcm). The small negative temperature coefficient still promises stability and the resistance value is not too low and would permit coating layers of 10^{-5} cm thick. After sputtering with TiO and sending the coating through a vacuum bakeout the approximate composition of the materials is Ti_2O_3.

2. Space defocusing of electrons in order to prevent multipactor may be achieved by electric dc fields pushing electrons away from the window surface. We have, however, no free choice for the potential of the insulating surface. It has the tendency to become positively charged with a secondary emission ratio greater than one, and attracts electrons. We have to use other forces for moving electrons away from windows such as an inhomogeneous constant magnetic field or the "disquiest forces" making the electrons spin or oscillate more violently near the window than at greater distances. In the latter case, any inhomogeneity of the high frequency electric field pushes electrons into the regions of smaller field strength. The dc energy gained between two points on the electron trajectory equals the difference of the two peak oscillatory energies of the electron at these two points. We can discriminate three different inhomogeneities of the electric field. The resulting three types of inhomogeneity pumping of electrons are illustrated in Figure 4 with corresponding applications to windows.

    a. Inhomogeneity in the direction of diverging lines of force.

    The cyclical acceleration away from the strong field is always greater than the acceleration backwards, resulting in a net outward electron acceleration. For example, a concentric line window drives electrons from the inner .o the outer conductor. A slight conical window shape lifts electrons from the window surface on the vacuum side.

    b. Inhomogeneity perpendicular to the curved lines of force.

    Centrifugal force makes electrons overshoot the lines of force radially, resulting in

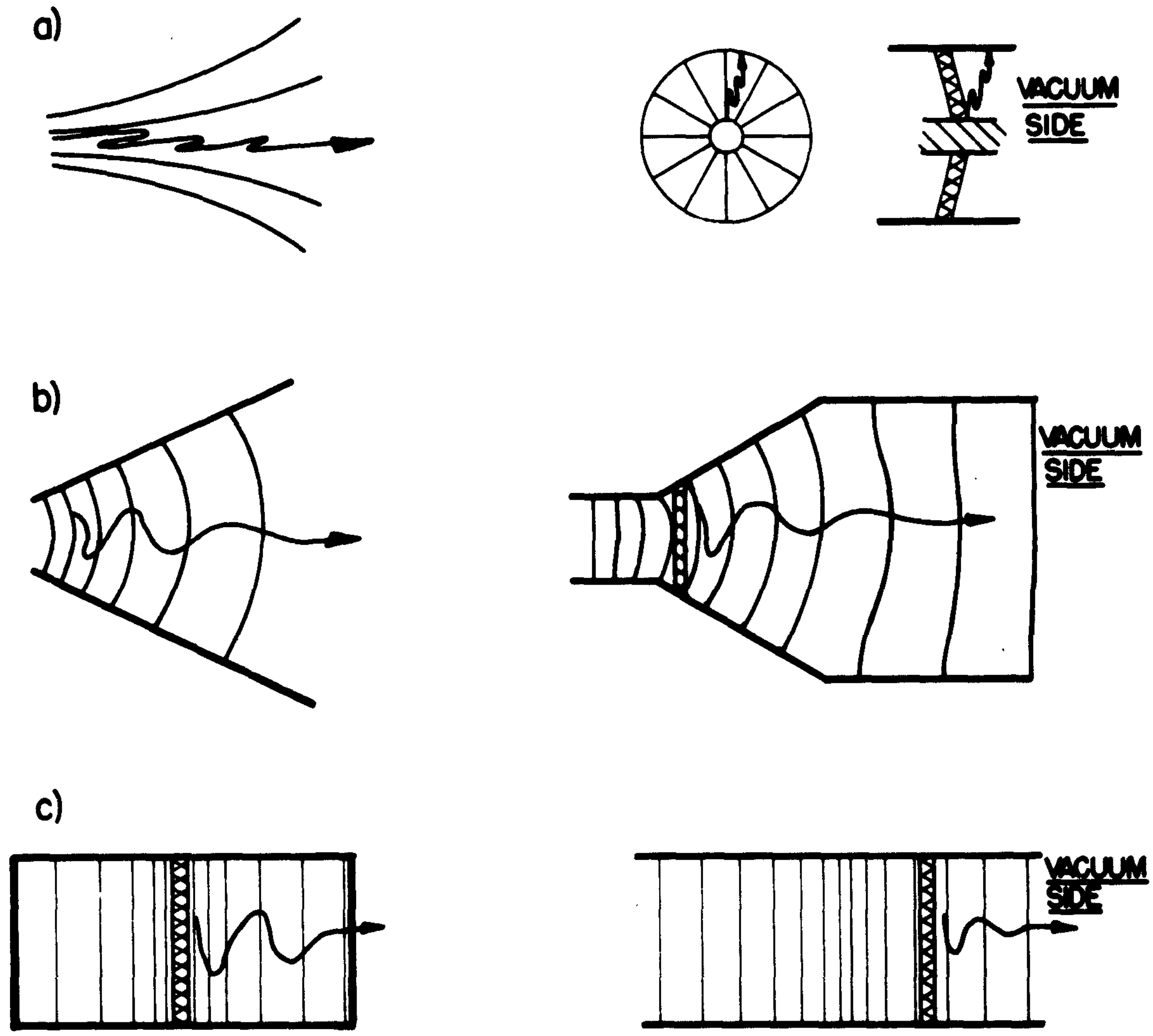


Fig. 4 Inhomogeneity Acceleration of Electrons

electron acceleration. A waveguide tapered in height with a window near the narrow end gives the electric field lines the required curvature to accelerate electrons away from the window.

c. Inhomogeneity perpendicular to the straight lines of force (standing wave).

An inhomogeneous electric field with straight lines of force is obtained dynamically in a standing wave, for instance in a half-wave section of a waveguide or in a cylindrical resonance cavity. Also, in this inhomogeneous field electrons move toward the quiet area. The motion comes from magnetic deflections in the magnetic, high-frequency field. Electrons have their peak velocity when the electric field is zero. At this moment the magnetic field is at its peak value, which results in an outward deflecting force. When reaching the resonator wall the radial velocity of the electron equals the peak oscillating velocity, which it had when starting its motion.

This electron acceleration exists whenever there is a standing wave energy. For instance, the propagation of a wave in a waveguide can be interpreted as a superposition of two symmetrical planar waves moving at an angle to the waveguide axis, which is identical to a propagating wave in the direction of the axis. This standing wave will accelerate electrons according to its electric field inhomogeneity, which in the TE 10 mode is a motion away from the center to the side walls of the waveguide.

The electron accelerations obtained from the three kinds of inhomogeneities can, of course, appear simultaneously and superimpose their effects. For instance, a tapered waveguide (case b) can contain some longitudinal standing wave energy (case c) of the proper phase location and the two effects combine. The acceleration due to a standing wave can also be used to reduce multipactor on flat disc windows on concentric lines. A slight standing wave, properly positioned, in conjunction with the radial acceleration of the concentric line fields, will drain the electrons away from the flat window. Alternatively, a wrong phase location of some standing wave energy near the window can drive electrons to the window surface and favor multipactoring.

The electron accelerating field inhomogeneities need not be of the same frequency as the working frequency. Also, a different mode or plane of polarization can be used to clear the window of electrons. All these methods have one thing in common, they increase the specific dielectric load on the window. The price paid for the liberation of possible multipactors is higher dielectric losses caused by the purposefully added field inhomogeneities. The inhomogeneity forces reverse their direction when going from free to bound electrons. The electron is considered bound when its natural oscillation or rotation frequency is higher than the frequency applied. This would take place for electrons under the influence of a constant magnetic field of greater value than the gyromagnetic resonance field. Such fields are rather high for practical application.

5.1.4 Phase Dependent dc Velocity for Fast Multipactor Detection and Window Protection

Until now we were concerned with dc velocities which were obtained by acceleration in either dc fields or in ac field inhomogeneities. In addition, electrons have certain dc velocities in a direction parallel to the window, superimposed on their oscillating motion, which depend on the phase angle at which they are first exposed to the influence of the high frequency field. Electrons released at the peak value of the field have no dc velocity, except in the direction of the axis of the guide, Figure 5a. Those released at zero field have the highest dc velocities in a direction parallel to the window. The velocities of these electrons, Figure 5b, equal the peak ac velocities of the undisturbed electron, Figure 5a. The dc velocity is proportional to -cosine of the phase angle of the release time. Figure 5 illustrates how this dc velocity of electrons can be utilized for detection of a multipactor or any other kind of discharge on the window surface within a time of only a few high frequency cycles. A slot (c) in the waveguide wall does not interfere with its high frequency property since it is not crossed by any high frequency current, but allows the fast electrons to strike the electrode (d). This signal on (d) can be amplified and used to either turn the power klystron off or a window protecting auxiliary frequency on, as discussed

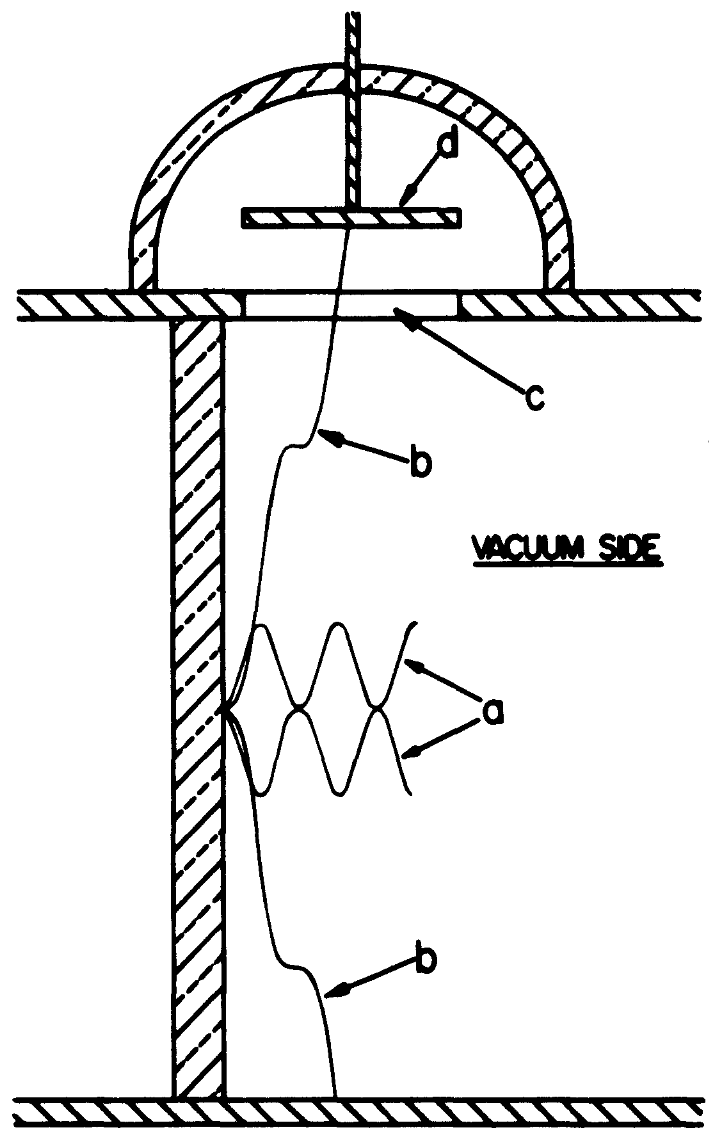


Fig. 5 D.C. Velocity of Electron and Multipactor Detection

below. It is known and was described in a paper by H. Seiwatz and C. M. Groom at the 1962 American Physical Society Conference in Seattle, Washington, that nondestructive dc breakthrough tests on dielectrics can be made by early interruption of the beginning discharge. It should therefore be possible with the above described method to protect high frequency windows from destruction.

5.1.5 Multipactor or Arc Detection by Rotation of the Plane of Polarization

In addition to the fast multipactor detection described above, which utilizes the fast escaping electrons, another detection method is possible. It is based on the rotation of the plane of oscillation of electrons in a weak magnetic field. If a magnetic field in an axial direction of a circular waveguide is arranged near the window, the multipactor electrons or any other free electrons will rotate the direction of their oscillation and thereby couple energy into a wave with a perpendicular plane of polarization. This can be detected with a suitable probe or coupling loop. The energy on the detector is directly proportional to the number of free electrons near the window.

5.1.6 Hard X-rays Near Power Windows

The highest velocity of electron (b) in Figure 5 is twice that of electron (a) and it has, therefore, four times the energy. If it would experience, at the moment of its highest energy, a reflection without energy loss at the waveguide wall, the phase of the high frequency field is such that an additional acceleration would bring its highest velocity to four times and its energy to sixteen times the value of electron (a).

This process is not very probable, but possible, and can explain the observed hard X-rays near windows. Phase dependent dc velocities tend to spread electrons away from the window surface and, as we have shown above, additional dc velocities can be produced by electron acceleration in field inhomogeneities, which can help prevent multipactor by space defocusing. We come now to the third method for multipactor prevention by phase defocusing.

5.1.7 Phase Defocusing

If electrons arrive at the wrong phase at the secondary emitting surface the multipactor cannot build up with exception of the gliding type, as explained above. Phase defocusing can be obtained by shortening or lengthening the transitions of electrons between impacts. Shortening is to be preferred because lengthening can lead to a higher order multipactor and is therefore not so safe. The arrangement of an open metal venetian blind, touching the inner surface of the window, with blades running perpendicular to the electric lines of force will kill any multipactor if the distance between blades is smaller than the distance required for the lowest order two-surface multipactor. The electrons do not reach their full velocity and the secondaries are released at a moment when the field brings them right back to the emitting surface. The venetian blinds can be considered as nontransparent for electrons because under the presence of the high frequency field practically no electron can pass through, whereas the electromagnetic wave passes almost undisturbed. For a reasonable ratio of blade thickness to blade distance (about 5), the resulting dielectric constant of the venetian blind is only 1/5. The blades could be slightly embedded in the dielectric window material for window cooling. Hollow blades could have internal liquid cooling. A major disadvantage, besides its complexity, is the following: The blades would have to follow rather precisely the equipotential surfaces, or excessive length currents, and possible arcing on the blade edges might result.

A compromise solution for the venetian blind idea has been prepared for experimental testing. Instead of metal blinds, the surface of the dielectric material has v-shaped parallel grooves running approximately perpendicular to the electric field. The field configurations between the grooves and inside the dielectric have been plotted using a resistance network for a dielectric constant of 8 and 4, and for groove angles of 60°, 90° and 120°. A dielectric constant of 8 is close to that of alumina, and 4 close to that of silica, the two materials we intend to test. The resulting fields are illustrated by equipotential surfaces in Figure 6 for alumina, and in Figure 7 for silica. The

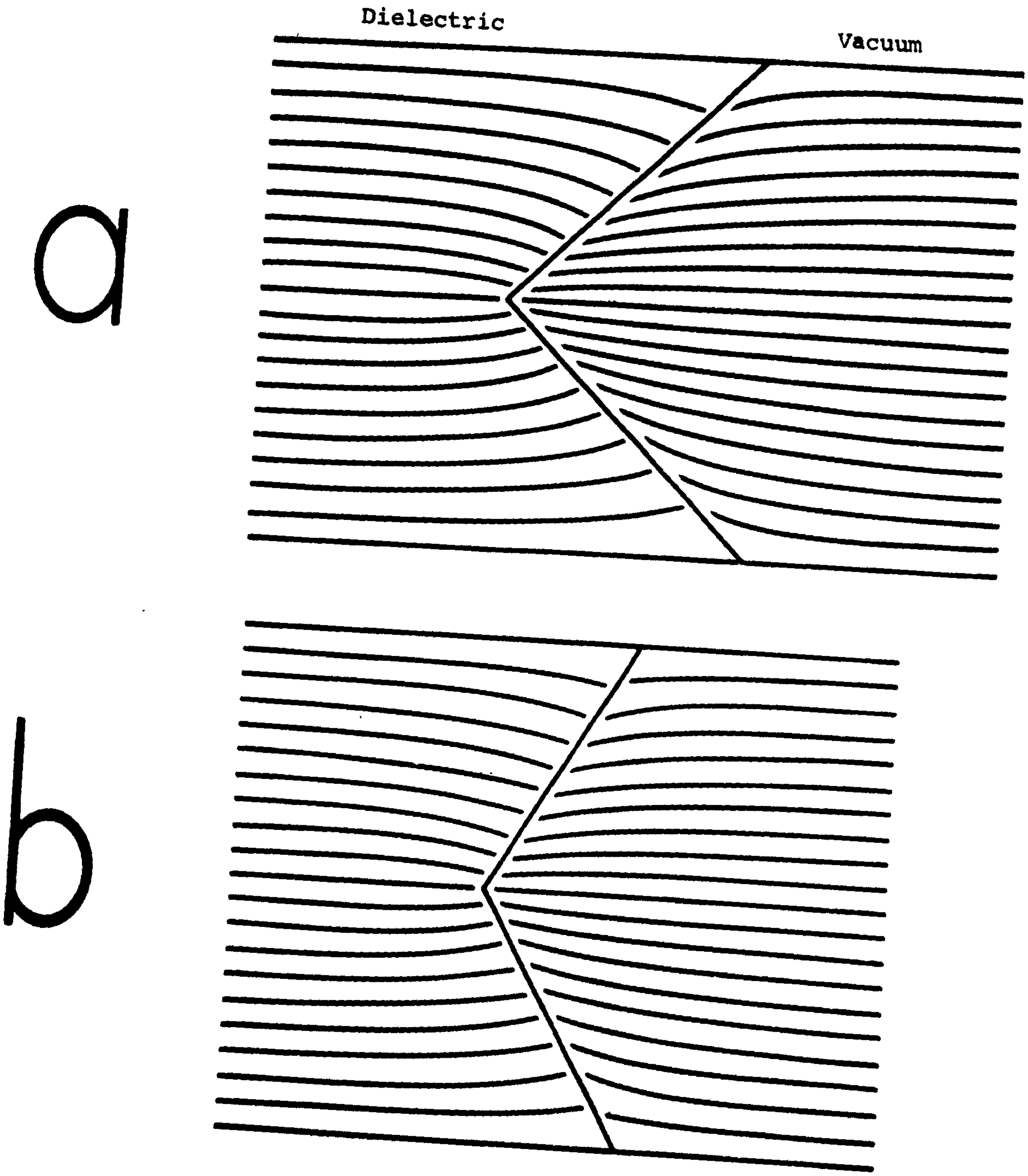


Fig. 7 Field Inhomogeneity Around Grooves (Silica)
a (90°); b (120°).

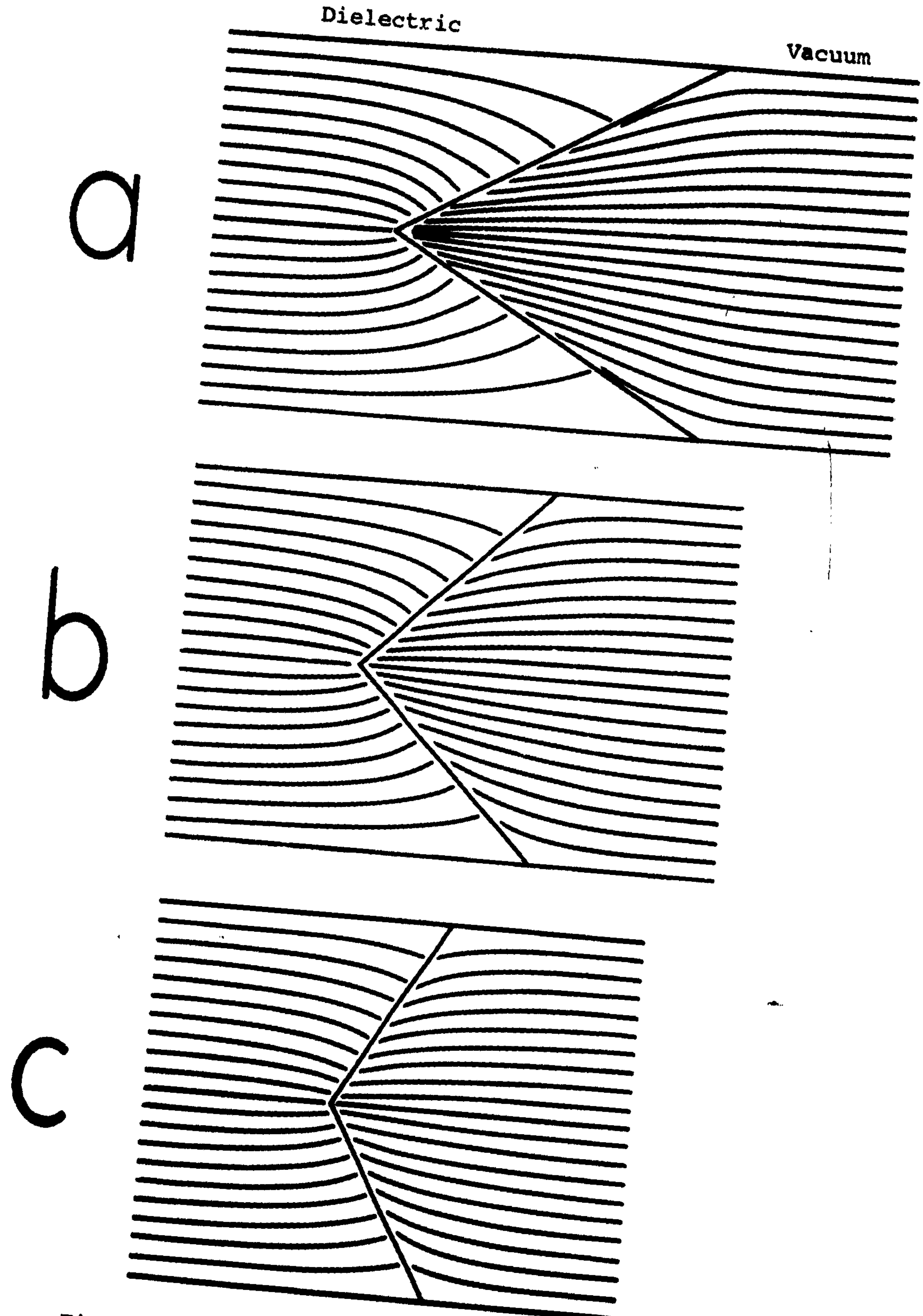


Fig. 6 Field Inhomogeneity Around Grooves (Alumina)
a (60°); b (90°); c (120°).

strongest fields exist near the bottom of the grooves where the dielectric loading of the window material will be heaviest. For small electron amplitudes the field inhomogeneity will drive the electrons out of the grooves, thereby destroying the multipactor through space and phase defocusing. In the case of electron amplitudes, which are large when compared to the groove width, a kind of periodic field focusing, produced by the periodic distortion of the field by the teeth, will repel electrons away from the surface. The field strength variations along the surface was plotted in Figure 8. In addition, the field variation at the bottoms of the grooves is shown and gives a measure for the nonuniformity of dielectric loaing. The curves are for 90° grooves and a dielectric constant of 8. For an electron oscillating across the crests of the ridges, the high frequency field strength variation is about ± 30%. Because of the rather high frequency of this disturbance the energy in this jitter oscillation remains low and therefore the repelling action on the electrons stays small. The presence of the grooves prevents the gliding type of multipactor because there exists no tangential incidence of electrons. Electrons can strike only near the crests of the ridges. The valleys should be free of any multipactors because of lack of space. Therefore, if a low secondary emission coating is applied to the window surface it need only cover the crests of the ridges in the form of narrow strips. This is done either by evaporating from two sides at a shallow angle, which leaves the valleys with wires. The narrow stripes of coating lack coherence in the electric field direction, which results in less ohmic losses for a given coating thickness or in thicker coatings for a given amount of ohmic loss. Another advantage of the grooving is the following: A possible small arc across the window is prevented from growing larger because the anchoring points of the arc cannot freely travel across the surface. They will be anchored to the bottom of the grooves due to the field strength variation. From this it seems that there are quite a few favorable conditions connected with the grooving of the window surface.

5.1.8 Manufacturing of Grooved Windows

Grooved alumina windows were made by Western Gold,

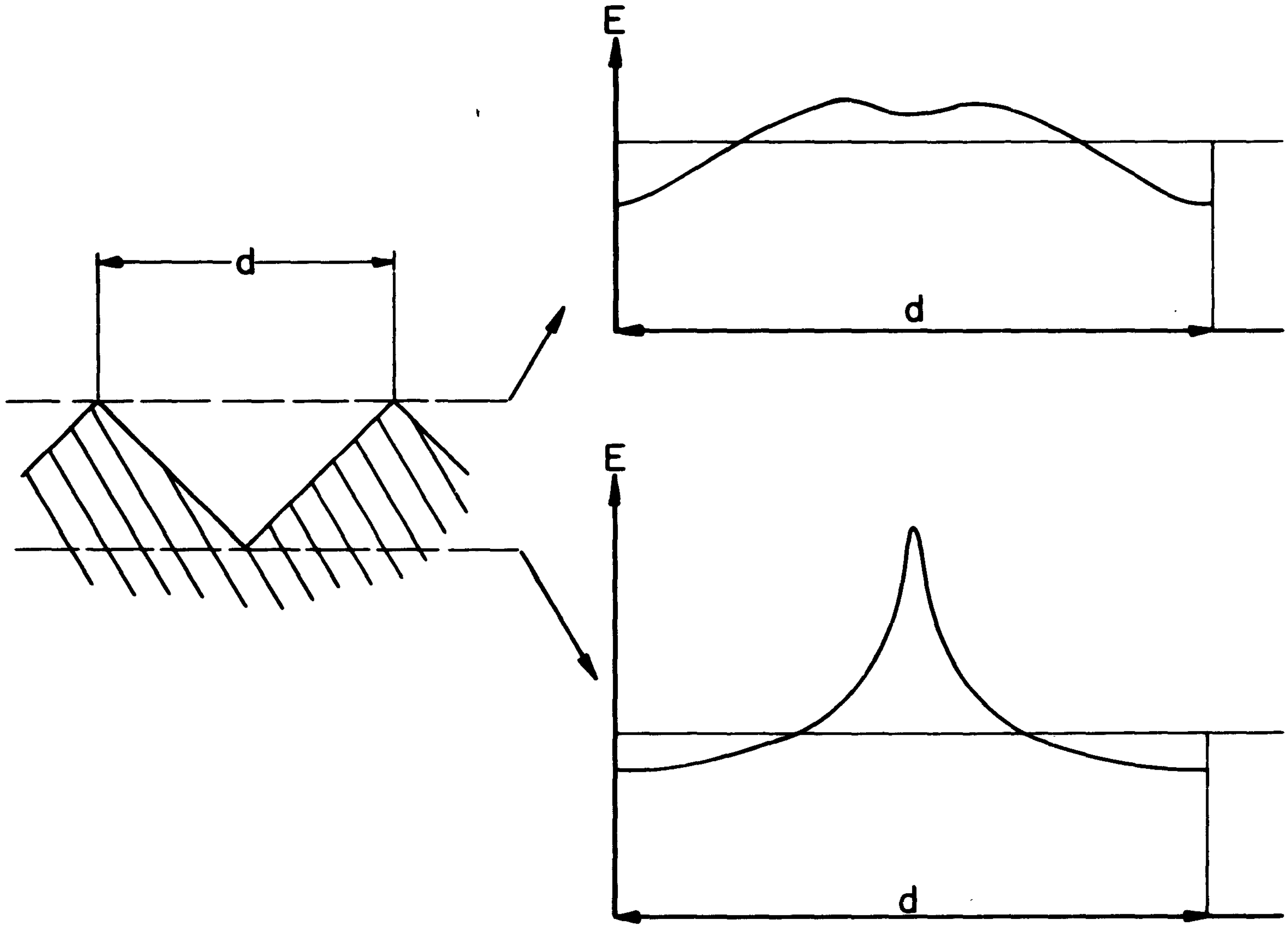


Fig. 8 Field Strength Variation Across Top and Bottom of Grooves

Belmont, California in close collaboration with Eimac. A specific amount of alumina powder was pressed between grooved hardened and polished steel plates. The outer cylindrical edge was ground to size after firing but the grooved surfaces did not require any finishing. The windows varied less than 0.33% in weight. Figure 9 shows a steel tool and a finished window disc. Discs with 60°, 90° and 120° groove angles have been made. The finished groove width is 1.25 mm, the disc diameter 76 mm (3") and the thickness 3.5 mm. Tests with and without coatings will be made using linear accelerator test equipment at Stanford University. Since these windows will have a vacuum on both sides, the grooving will be performed on both sides.

Silica grooved windows will also be made and tested. This grooving will be performed by grinding the surface with diamond wheels followed by fire polishing.

5.1.9 Window Coating

Window coating was performed on test pieces by sputtering titanium-monoxide with mercury ions. A glass bell jar was pumped with a mecury diffusion pump and the mercury pressure was kept at a constant value by holding a trap between pump and bell jar at an exact temperature of 18°C. A plasma was generated by a high frequency coil wound around the bell jar, which was energized by a 27 Mc oscillator of several hundred watts. The ion bombarding velocity was 1500 volts. During the first experiments the connecting wires to the titanium monoxide and to the target were hidden inside graphite tubing to prevent the sputtering of impurities from the wires themselves. Graphite was used because it is supposed to sputter very little. However, some chemi-sputtering apparently took place and the carbon compound seems to have reacted with the freshly depositied TiO to form a carbon containing titanium compound, as a resistive layer. In the next experiments graphite was replaced with quartz glass as a shielding material and the results became more consistent. Relatively thick coatings were put on alumina ceramics and on silica. The temperature coefficient of the resistivity was taken as an indication of the chemical composition of the coating. This varies in a known manner

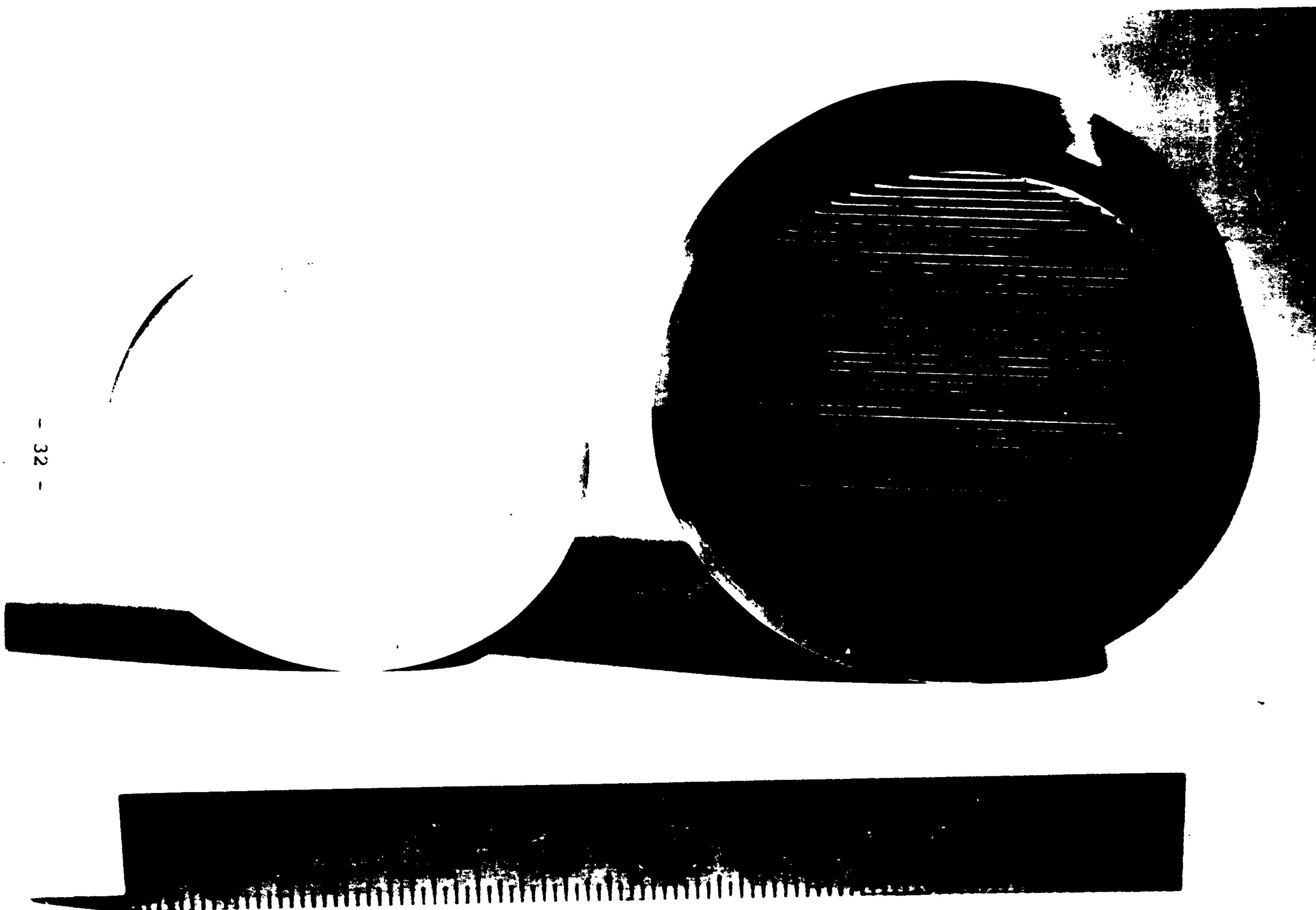


Fig. 9 Photo of Grooved Alumina Window and Pressing Tool

continuously with the degree of oxidization[5,6]. In a series of experiments the distance between the titanium monoxide and the ceramic discs was varied and the sputtering rate was kept constant. The targets at greater distance showed systematically a higher degree of oxidization. Because the coverage rate becomes smaller with distance, more oxygen or other impurities are built into the coating and the observations indicate that the quality of vacuum is not sufficient for reproducible coatings. However, the bell jar did not go through a bakeout, which can explain the results.

An additional titanium evaporator unit was built to go between the mercury pump and the bell jar. With the heavy ionization produced by the high frequency, impurities should be pumped away with high speed.

Coatings in an actual tube have to go through a bakeout process. Several samples of coatings, varying greatly in resistance value and also in temperature coefficient, were sealed in a glass vacuum envelope and submitted to a one-hour bakeout. The resistance values changed but the temperature coefficient of resistivity was practically the same for all samples and correspond to that of Ti_2O_3. If this can be confirmed, the exact initial composition of the coating is of no great importance.

Coating by sputtering does not require that the window be heated to obtain good adherence of the coating. In contract to vapor deposition the atoms and molecules arrive with a high velocity, which assures a good bond.

5.2 CONCLUSIONS

There are a great variety of window and electromagnetic field geometries which show advantages for use in multipactor reduction or prevention. Our experimental work will restrict itself to grooved windows with partial coating on the crests, with total surface coating, and with no coating.

---

[5] A. D. Pearson, "Studies on the Lower Oxides of Titanium," J. Phys. Chem. Solids, 1958, Vol. 5 p. 316

[6] W. D. Fuller, "Titanium Integrated Electronic Componets."

5.3 PROGRAM FOR NEXT INTERVAL

Tests on alumina and silica grooved windows with different groove angles with and without titanium suboxide coatings are planned. Further studies of the coating process will be performed.

6. IDENTIFICATION OF KEY TECHNICAL PERSONNEL

The hours worked by all those participating in the program are:

TASK A:

	Manhours
D. Preist	135
R. Talcott	84
J. Soderstrum	192
J. Zegers	---
B. Hill	35.5
K. Scholz	52
J. Leidigh	54.5

TASK B:

O. Heil	385
G. Brauns	250.5
B. Morozovsky	424
S. Zott	422

DR. OSKAR HEIL
ASSOCIATE DIRECTOR OF RESEARCH (ADVANCED RESEARCH)

Dr. Heil received his Ph.D. in Physics at the University of Gottingen in 1932. He did research work at the University of Gottingen, in the Cavendish Laboratory, Cambridge, England, at Standard Telephones and Cables, England, and with C. H. Lorenz, A.G., Julius Pintech, K.G., and Telefunken of Germany. Prior to joining Eimac, he was employed by the Wright Air Development Center and was engaged in research and development in the tube laboratory at Ohio State University.

Dr. Heil is credited with the discovery of the basic velocity modulation principle and with building of the first tube of this type. An article published in Zeitschrift fur Physik, Vol. 95, page 762, 1935, and later translated, Electronics, Vol. 16, page 164, July, 1943, gives the first published theory of velocity modulation of an electron beam and describes a tube utilizing this principle. Patents based on this concept were issued to Dr. Heil in the United States and Germany. All present day klystrons utilize the principles described by Dr. Heil in this early work. Another significant patent of Dr. Heil's was issued in 1950 for development of the Heil Electron Gun which, because of its high area convergence, is now being used in many tube designs. Other work of Dr. Heil includes harmonic oscillators, plasma studies, electron beam optics and diagnostics, a semi-conductor, amplifier, the floating-drift-tube klystron, and more recently, a technique for quartz-to-metal sealing and a new high efficiency bunching technique for high power tubes.

DONALD H. PREIST
ASSOCIATE DIRECTOR OF RESEARCH (SPECIAL STUDIES)

Mr. Preist received his Bachelor of Science degree and Diploma in Engineering from King's College, London University, in 1936, and subsequently entered the British Government Service as a member of the first radar team in England under Sir Robert Watson-Watt. From then until 1946, he was associated with various aspects of radar development; in particular, the early experiments on detection of ships, development of high power ground radar transmitters, and development of the MKV IFF and beacon systems, including a period with the Combined Research Group at the Naval Research Laboratory, Washington, D. C., from 1943 to 1945. During 1946, he served in the British Ministry of Supply, London, on the application of radio and radar to civil aviation, and represented the Ministry at PICAO (Provisional International Conference aeronautical Organization) International Conferences as a scientific advisor.

During the early part of the war he served as a flight lieutenant in the Royal Air Force in connection with the establishment of radar in France, and later with Combined Operations Headquarters.

Mr. Preist joined the Research staff of Eitel-McCullough, Inc., in 1946 and has been responsible for the design and development of many high power triodes, tetrodes and circuits for CW and pulse applications. Later, Mr. Preist was instrumental in the development of the Eimac line of external cavity high power amplifier klystrons and other microwave tubes, and was responsible for the design of the first super power klystrons for BMEWS radar.

More recently he has concentrated on research on tubes leading to higher power levels, and under his direction substantial advances have been made in the understanding of window phenomena and improvements to windows, in extended interaction klystrons, and in the evolution of new concepts for the design of super power negative grid tubes.

He has served as Klystron Project Coordinator, as Chief Research Engineer and presently is Associate Director of Research.

Mr. Preist has published numerous papers concerning electron tubes and their applications and holds many patents in the field.

He is a full member of the Institute of Electrical Engineers of Great Britain.

RUTH CARLSON TALCOTT
CONSULTANT

Mrs. Talcott received her Bachelor of Arts (Chemistry) degree from the University of Colorado in 1948.

Mrs. Talcott joined Eitel-McCullough, Inc., in 1950 and has been continuously working on experimental physical and chemical processes and materials, and tube technology. Specific projects have included grid and heater coatings, fabrication and evaluation of oxide-coated cathodes, metallizing, plating and brazing of high alumina and beryllia emission, and thermal stresses in ceramic cylinders.

More recently, Mrs. Talcott has been working on the problems associated with dielectric windows in high power klystrons. This work has already resulted in the use of sintered beryllium oxide windows in several Eimac klystrons which are now in production, and in the isolation and analysis of certain electron bombardment phenomena of great significance at windows of high power microwave tubes. She has also originated and developed successful coatings for both metals and dielectrics which have very low secondary emission yield resulting in greatly improved tube performance.

Mrs. Talcott has published several papers and is a member of the Vacuum Society of American and the International Organization for Vacuum Science and Technology.

In February, 1962, Mrs. Talcott relinquished her position as Senior Research Scientist in order to take a research appointment at the University of California. She is serving the company as a Consultant.

DISTRIBUTION LIST

Constract DA 36-039 SC-90818	No. of Copies
OASD (R&E) Attn: Technical Library Rm. 3E1065, The Pentagon Washington 25, D. C.	1
Commander Armed Services Technical Information Agency Attn: TIPCR Arlington Hall Station Arlington 12, Virginia	10
Advisory Group on Electron Devices 346 Broadway New York 13, New York	2
Director U. S. Naval Research Laboratory Attn: Code 2027 Washington 25, D. C.	1
Commanding Officer & Director U. S. Navy Electronics Laboratory San Diego 52, California	1
Chief, Bureau of Ships Department of the Navy Attn: 681A-1 Washington 25, D. C.	2
Commander Aeronautical Systems Division Attn: ASAPRL Wright-Patterson AFB, Ohio	1
Commander, AF Command & Control Development Division Air Research & Development Command Attn: CCRR (1 cy) CCSD (1 cy) CRZC (1 cy) USAF, L. G. Hanscom Field Bedford, Massachusetts	3
Commander Air Force Cambridge Research Laboratory Attn: CRXL-R, Research Library L. G. Hanscom Field Bedord, Massachusetts	1

	No. of Copies
Commander Rome Air Development Center Attn: RAALD Griffiss Air Force Base, New York	1
AFSC Liaison Office Naval Air R & D Activities Command Johnsville, Pennsylvania	1
Chief of Research and Development Department of the Army Washington 25, D. C.	1
Chief, U. S. Army Security Agency Arlington Hall Station Arlington 12, Virginia	2
Deputy President U. S. Army Security Agency Board Arlington Hall Station Arlington 12, Virginia	1
Commanding Officer U. S. Army Electronics Research Unit P. O. Box 205 Mountain View, California	1
Commanding Officer Diamond Ordnance Fuze Laboratory Attn: Library, Rm. 211, Bldg. 92 Washington 25, D. C.	1
Commander Army Missile Command Attn: Technical Library Redstone Arsenal, Alabama	1
Commanding Officer U. S. Army Electronics Command Attn: AMSEL-RD Fort Monmouth, New Jersey	1
Commanding Officer U. S. Army Electronics Materiel Support Agency Attn: SELMS-ADJ Fort Monmouth, New Jersey	1
Corps of Engineers Liaison Office U. S. Army Electronics R & D Laboratory Fort Monmouth, New Jersey	1

	No. of Copies
Marine Corps Liaison Officer U. S. Army Electronics R & D Laboratory Attn: SELRA/LNR Fort Monmouth, New Jersey	1
Commanding Officer U. S. Army Electronics R & D Laboratory Attn: Director of Research Fort Monmouth, New Jersey	1
Commanding Officer U. S. Army Electronics R & D Laboratory Attn: Technical Document Center Fort Monmouth, New Jersey	1
Commanding Officer U. S. Army Electronics R & D Laboratory Attn: Technical Information Division (FOR RETRANSMITTAL TO ACCREDITED BRITISH AND CANADIAN GOVERNMENT REPRESENTATIVES) Fort Monmouth, New Jersey	3
Commanding Officer U. S. Army Electronics R & D Laboratory Attn: SELRA/PR (Mr. Garoff) (1 cy) SELRA/PR (Mr. Hanley) (1 cy) SELRA/PRG (Mr. Zinn) (1 cy) SELRA/PRM (Mr. Hersh) (1 cy) Fort Monmouth, New Jersey	4
Commanding Officer U. S. Army Electronics R & D Laboratory Attn: Logistics Division (For: SELRA/PRT Project Engineer) Fort Monmouth, New Jersey	2
Commanding Officer U. S. Army Electronics R & D Laboratory Attn: SELRA/PRT, Record File Copy Fort Monmouth, New Jersey	1
Stanford University Microwave Laboratory, W. W. Hansen Labs Stanford, California Attn: Prof. S. Sonkin	1
Commanding Officer U. S. Army Electronics Materiel Agency 225 So. 18th Street Philadelphia, Pennsylvania Attn: SELMA/R2A	1

	No. of Copies
Director of Defense Research and Engineering Office of Secretary of Defense Washington 25, D. C. Attn: Mr. James M. Bridges	1
Advanced Research Projects Agency Office of Secretary of Defense Washington 25, D. C. Attn: Program Manager, AO 318	3
Chief, Bureau of Ships Department of the Navy Washington 25, D. C.	
Attn: Code 680	1
Attn: Code 335	1
Attn: Code 670B	1
Attn: Code 361B	1
Chief of Naval Operations Department of the Navy Washington 25, D. C. Attn: OP-07	1
Chief, Bureau of Naval Weapons Department of the Navy Washington 25, D. C.	
Attn: RRRE	1
Attn: RAAV-4423	1
Attn: RREN-3	1
Attn: RNWC	1
Applied Physics Laboratory Attn: Mr. William Dobbins Howard County, Maryland Via. Bureau of Naval Weapons Representative Silver Spring, Maryland	1
Chief of Naval Research Department of the Navy Washington 25, D. C.	
Attn: 461	1
Attn: 427	1
Director U. S. Naval Research Laboratory Washington 25, D. C.	
Attn: Dr. S. T. Snith, Code 5240	1
Attn: Mr. R. C. Guthrie, Code 5300	1

	No. of Copies
Commander New York Naval Shipyard Naval Material Laboratory Brooklyn 1, New York Attn: Code 920	1
Commander, Air Force Systems Command R & T Division Attn: Mr. S. Tepper, RTH Bolling AFB, Washington 25, D. C.	1
Commander, Air Systems Division Attn: ASWRNET Wright-Patterson AFB, Ohio	1
Commander, Aerospace Systems Division Attn: ASRNET Wright-Patterson AFB, Ohio	1
Commander, Electronic Systems Division Air Force Systems Command Attn: ESRDE Bedford, Massachusetts	1
Commander, Rome Air Development Center Griffiss Air Force Base, New York	
Attn: RCLTT	1
Attn: RCLS	1
Attn: RCLC	1
Attn: RCLTM	1
Attn: RALTP	1
Commander Aeronautical Systems Division Attn: ASDL-9 Wright-Patterson AFB, Ohio	1
Commander, Air Force Ballistic Missile Division Air Force Unit Post Office Attn: WDZRS Los Angeles 45, California	1
AMC Liaison Officer Bell Telephone Laboratories Attn: Lt. Col. Lee G. Jones Whippany, New Jersey	

	No. of Copies
Commanding Officer U. S. Army Electronics Research and Development Laboratory Fort Monmouth, New Jersey	
Attn: SELRA/SR (Dir., Radar Div.)	1
Attn: SELRA/S (Dir., Cm Div.)	1
Attn: SELRA/PE (Dir., EP&M Div.)	1
Attn: SELRA/N (Dir., Comm Dept.)	1
Attn: SELRA/SC	1
Attn: SELRA/PEM	1
Commander U. S. Army Materiel Command Washington 25, D. C. Attn: AMCRD-RS-PE-E	1
Commanding Officer Frankford Arsenal Attn: ORDBA-FEL Philadelphia 37, Pennsylvania	1
Commander Army Missile Command Attn: ORDXM-RMP Redstone Arsenal, Alabama	1
General Electric Company Power Tube Department 1 River Road Schenectady, New York Attn: Mr. E. D. McArthur, Knolls Research Lab	1
Eitel-McCullough, Inc. 301 Industrial Way San Carlos, California	
Attn: Dr. George Caryotakis	1
Attn: Mr. Earl Shelton	1
Radio Corporation of America Lancaster, Pennsylvania Attn: Mr. E. E. Spitzer	1
David Sarnoff Research Center RCA Laboratories Princeton, New Jersey Attn: Dr. L. S. Nergaard	1

	No. of Copies
General Electric Company Traveling Wave Tube Products Section 601 California Avenue Palo Alto, California Attn: Mr. S. E. Webber	1
Kane Engineering Laboratories 845 Commercial Street Palo Alto, California Attn: Mr. John Kane	1
Sylvania Electric Products, Inc. Chief Engineer of Microwave Device Division 500 Evelyn Avenue Mountain View, California Attn: Dr. Rudy Hutter	1
Sylvania Electric Products, Inc. East 3rd Street Williamsport, Pennsylvania Attn: Dr. John Whitmore	1
Sperry Electronic Tube Division Sperry Rand Corporation Gainesville, Florida Attn: Dr. A. D. Sutherland	1
Manager Applied Research Department Electron Tube Division Westinghouse Electric Corporation P. O. Box 746 Baltimore 3, Maryland Attn: Mr. G. R. Kilgore	1
Raytheon Company Attn: Mr. William C. Brown Waltham, Massachusetts	1
Sperry Gyroscope Company Attn: Dr. V. R. Learned Great Neck, Long Island, New York	1
Varian Associates	
Attn: Dr. T. Moreno	1
Attn: Dr. A. Staprans	1
Attn: Dr. E. W. Herald	1
611 Hansen Way Palo Alto, California	

	No. of Copies
SFD Laboratories Attn: Dr. J. Feinstein 800 Rahway Avenue Union, New Jersey	1
Litton Industries Attn: Dr. J. F. Hull 960 Industrial Road San Carlos, California	1
Hughes Aircraft Company Attn: Dr. L. M. Field, Microwave Tube Division Culver City, California	1
Watkins-Johnson Company 3333 Hillview Avenue Palo Alto, California Attn: Dr. Rolf Peter	1
Field Emission Corporation McMinnville, Oregon Attn: Dr. F. M. Charbonnier	1
Sperry Gyroscope Company Division of Sperry Rand Corporation Attn: D. Churchill, J. McLinden (1 cy ea) Great Neck, Long Island, New York	2
General Electric Company Superpower Microwave Tube Laboratory 1 River Road Schenectady, New York Attn: R. Bondley, Knolls Research Laboratory	1
Eitel-McCullough, Inc. Attn: L. Reed San Carlos, California	1
Stanford Research Institute Attn: L. Feinstein Menlo Park, California	1
General Telephone and Electronics Corp. Bayside Laboratory Attn: B. W. Leavitt Bayside, New York	1

	No. of Copies
Mitronics, Inc. 132 Floral Avenue Attn: S. S. Cole Murray Hill, New Jersey	1
General Electric Company 3001 East Lake Road Attn: J. J. Cacciotti Erie, Pennsylvania	1
Ford Instrument Company 31-10 Thomas Avenue Attn: W. Franklin, Long Island City, New York	1
Director, Lincoln Laboratory Attn: Dr. R. Butman P. O. Box 73 Lexington 73, Massachusetts	1
Stanford University Attn: Prof. M. Chodorow, Director Microwave Laboratory Stanford, California	1
Aerospace Corporation Attn: Dr. I. Getting Los Angeles 45, California	1
RAND Corporation 1700 Main Street Santa Monica, California	1
Project M Stanford University Stanford, California Attn: Mr. J. Jasberg	1
Polytechnic Institute of Brooklyn 55 Johnston Street Attn: J. W. Griemsmann Brooklyn 1, New York	1
Physics Laboratory University of Utah Salt Lake City, Utah Attn: P. Gibbs Attn: G. Baker	 1 1

	No. of Copies
Laboratory of Insulation Research Massachusetts Institute of Technology Cambridge, Massachusetts Attn: D. A. Powers	1
Battelle Memorial Institute 505 King Avenue Columbus 1, Ohio Attn: Defender Library	1
Cornell Aeronautical Laboratory, Inc. 4455 Genesee Street Buffalo 21, New York Attn: Mr. R. C. Beitz	1
MITRE Corporation Bedford, Massachusetts Attn: Dr. R. F. Naka, Associate Technical Director, Bldg. 2A-251	1
Chief, Army Research Office Washington 25, D. C.	1

This contract is supervised by the Techniques Branch, Electron Tubes Division, ECD, USAELCTRDLAB, Fort Monmouth, New Jersey. For further technical information contact Mr. Louis Heynick, Project Engineer, Telephone 201-59-61414.

Eitel-McCullough, Inc., San Carlos, California

Microwave Window Multipactor and Its Inhibition, by O. Heil and D. Preist

Quarterly Progress Report No. 1, September 1962, 47 pages including illustrations

Contract DA-36-039-SC-90818, DA Task No. OST-76-10-318-28-03, Unclassified Report

Various methods of improving the control and application of evaporation coatings to waveguide windows for multipactor reduction is discussed. Special

(over)

1. Multipactor
2. Microwave Windows
3. Microwave Power Generation

I. Heil, Oskar
II. Preist, Donald
III. Project Defender
IV. USAERDL Contract No. DA-36-039-SC-90818
V. DA Task No. OST-76-10-318-28-03
VI. In ASTIA Collectio

Eitel-McCullough, Inc., San Carlos, California.

Microwave Window Multipactor and Its Inhibition, by O. Heil and D. Preist

Quarterly Progress Report No. 1, September 1962, 47 pages including illustrations

Contract DA-36-039-SC-90818, DA Task No. OST-76-10-318-28-03, Unclassified Report

Various methods of improving the control and application of evaporation coatings to waveguide windows for multipactor reduction is discussed. Special

(over)

1. Multipactor
2. Microwave Windows
3. Microwave Power Generation

I. Heil, Oskar
II. Preist, Donald
III. Project Defender
IV. USAERDL Contract No. DA-36-039-SC-90818
V. DA Task No. OST-76-10-318-03
VI. In ASTIA Collectio

emphasis is given to multipactor reduction using the electron accelerating forces resulting from field inhomogeneities. Two methods for instantaneous multipactor detection are given. Expected effects from a grooved window surface are discussed.

emphasis is given to multipactor reduction using the electron accelerating forces resulting from field inhomogeneities. Two methods for instantaneous multipactor detection are given. Expected effects from a grooved window surface are discussed.