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HIGH POWER R-F WINDOW STUDY PROGRAM

QUARTERLY TECHNICAL NOTE NO. 2

1 October Through 31 December 1962

VARIAN ASSOCIATES
PALO ALTO, CALIFORNIA

CONTRACT NO. AF 30(602)-2844

Prepared For

ROME AIR DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
RESEARCH AND TECHNOLOGY DIVISION
UNITED STATES AIR FORCE
GRIFFISS AIR FORCE BASE
NEW YORK

VARIAN REPORT NO. 304-2Q

JANUARY 1963

VARIAN associates
611 HANSEN WAY · PALO ALTO, CALIF.

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Project No. 5573
Task No. 557303

Prepared by: Floyd Johnson
Approved by: L. T. Zitelli

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ABSTRACT

Three fused quartz thin disc window assemblies were fabricated and tested in the ring resonator. Extreme localized dielectric heating was responsible for failure of two of the windows by melting. Failures occurred at power levels of 70 kilowatts cw or less in a nitrogen atmosphere.

Fabrication of a single disc zero degree cut sapphire window was completed and high power tests performed. This window was operated up to 235 kilowatts of power without failure or damage to the dielectric. Steady state power dissipation of this window has been less than any window tested on this program to date. A windowtron has been constructed using this device for tests with other window designs in vacuum. The crystal structure of other sapphire discs was also closely examined for spurious effects on window impedance matching.

Two vacuum-tight double disc aluminum oxide window assemblies were completed, with one of them failing in high power test at 180 kilowatts cw at 7750 Mc. This window had a mode free bandwidth of 33 per cent and was continuously cooled by recirculated FC75, an inert fluorocarbon liquid. The remaining window failed because of excessive cooling fluid pressures.

Three successfully brazed vacuum-tight beryllium oxide half-wavelength block windows were completed and high power tests showed that power transmission was as good as previously reported for this type of window. A maximum power of 252 kilowatts was transmitted with losses amounting to 0.37 per cent of the total power.

Mode-free broadbanding of half-wavelength block and thin disc windows is progressing satisfactorily. A mode pattern chart for a typical AL300 block is included in this report.

PUBLICATION REVIEW

This report has been reviewed and is approved.

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SECTION I

OBJECTIVES OF PROGRAM

1-1. INTRODUCTION

This report is the second of four quarterly technical notes and one final technical report to be prepared for Rome Air Development Center, Griffiss Air Force Base, New York. Varian Associates of Palo Alto, California, is conducting this study for the United States Air Force under Contract Number AF 30(602)-2844. This contract, awarded 6 July 1962 in accordance with RADC Exhibit "A", dated 29 December 1961, is entitled "High Power R-F Window Study."

1-2. OBJECTIVES

A. Primary

The program's final objective is the design of an X-band window with 25 per cent bandwidth and a 250 kilowatt c-w power handling capacity. In the pursuit of this objective various phenomena believed to be responsible for window failure in the field and under operating conditions will be thoroughly investigated. These include dielectric materials and their relative worth as windows, configurations best suited for high average power transmission, the study of dielectric material-configuration combinations, the multipactor phenomena, effects of stray magnetic fields, variations of gas pressure on window operation, and the merits of gaseous or liquid window coolants.

B. Second Quarter Objectives

A major effort to continue high power testing of waveguide windows was scheduled. Each sample was to be tested first in the resonant ring with a nitrogen pressurization of about 2 atmospheres. If the test were successful and the dielectric did not fail, each sample was to be retested in a windowtron assembly. The volume between the two windows was to be continuously pumped with a VacIon® pump to keep the pressure below 10^{-5} torr.

Scheduled for high power tests were relatively narrow band, half-wavelength block windows incorporating dielectrics such as AL300, AL995 and several forms of beryllium oxide. Thin disc single crystal sapphire, fused quartz and double disc windows utilizing AL400 and AL300 ceramics were also scheduled for high power testing in the order that the fabrication of each assembly was completed.

Before high power tests of the double disc window assemblies could be made it would be necessary to evaluate the performance of the newly designed heat exchanger using FC75 as the cooling medium. This fluorocarbon chemical, although inert, is highly volatile and expensive so handling procedures must be determined for this particular application.

A continued effort was scheduled to determine methods of mechanically strengthening thin disc windows and cold testing these devices for broadband, ghost mode free operation. The more favorable results of such tests would then be used in the design and high power test of such windows in the ring resonator.

SECTION II

TECHNICAL PROGRESS OF PROGRAM

2-1. GENERAL DISCUSSION

A. Ring Calibration

All high power tests reported to date have been performed at 7750 Mc. Calibration of the resonant ring 70 db sampler coupler was checked with the use of the Weinschel audio substitution method and cross checked by the calorimetric method at the 6 kilowatt c-w level. Measurements agreed within ± 8 per cent or better, which is quite good considering the difficulty in calibrations of 60 db or more. These measurements indicated that previously reported results may have been as much as 17 per cent high. Future reporting, including this report, will use the more conservative figures.

B. FC75 Heat Exchanger

High average power windows using most currently available dielectrics have been shown to dissipate considerable energy as heat even though it may only be a small percentage of the power transmitted through it. Removal of this heat can be accomplished with use of fluorocarbon chemicals such as FC75. In order to accomplish this action, a heat exchanger is needed to carry constantly cooled fluid to the window.

Varian Associates ordered such a device for use on this program. The C. H. Bull Company of San Francisco was to design and build it to specification. The device was to filter the coolant continuously and provide a means of controlling the pressures and rate of flow to the window being cooled. It was specified that the temperature of the coolant must be controllable over a 50° F to 150° F temperature range. A heater built into the cooling package along with proper automatic switching of the heat exchanger itself would provide a means of holding the temperature of the test window constant at any predetermined level. This would be accomplished regardless of the r-f power level being transmitted through the window. Provision was to be made to monitor input and output temperatures and flow rates continuously. A schematic of the FC75 heat exchanger system as delivered is shown in Figure 1.

Delivery of the unit was delayed, largely because it was required to be Freon-12 tight before it could be filled with FC75. When delivered early in November 1962, initial tests revealed that the system still leaked Freon-12 in several places. After much effort it was determined that repairs were not possible and that a complete rebuilding job was necessary. Much of the trouble occurred in the threaded pipe joints that were necessary to connect to the various components such as the flow meter. All unnecessary pipe thread joints were removed and replaced with soldered copper tubing.

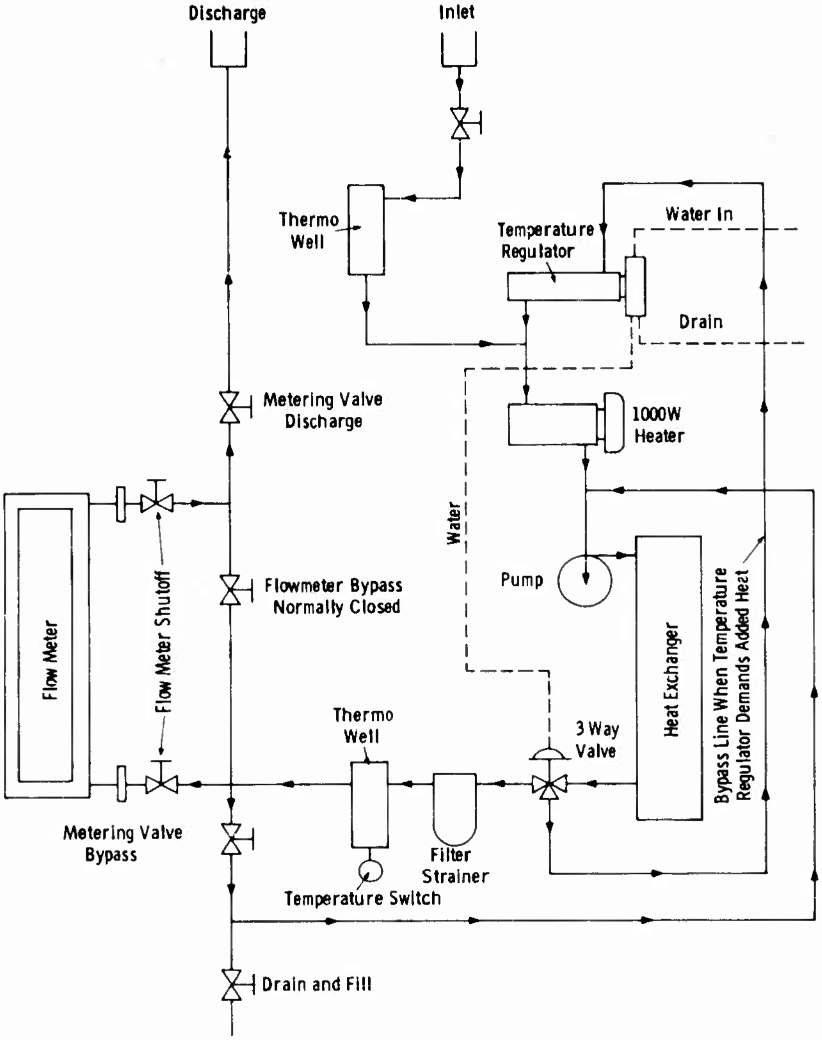

FIGURE 1
SCHEMATIC FLOW DIAGRAM FC75 HEAT EXCHANGER SYSTEM

Where threaded joints were necessary, a litharge and glycerin mixture was applied which, when hardened, formed leak-proof connections. All cast bronze valves were also removed and replaced with vacuum valves.

Once the system was rebuilt, it was tested tight up to 65 psi of Freon-12. Refrigeration people commonly determine if a freon system leaks by using a presto (acetylene) tank and torch with an attached short hose which sucks a little air (or air containing freon) up into the acetylene flame. If the flame changes color and grows larger, there is a leak in the joint at which the short hose is directed. Since FC75 and Freon-12 are chemically very similar, it was felt that such a test might be valid for FC75. An experiment subsequently showed that the acetylene torch method will work just as well with inert fluorocarbon systems.

C. Dangers of Beryllium Oxide

Although the work leading to the following report was not performed on this contract, it is felt of great enough significance to warrant mention here. Certain high power tests on beryllium oxide windows were made in Varian's "S" band resonant ring. During the course of the experiments one of the windows failed under very high power conditions. When the waveguide test setup was disassembled, a strong pungent odor was detected. One short piece of the waveguide was submitted to the chemical laboratory for analysis. The following report was returned. "A wipe test of the interior of the waveguide submitted was positive for beryllium. The quantity was 4 micrograms of beryllium; however, a wipe test is not a quantitative sampling and is not to be considered an order of magnitude estimation of the amount present."

In the interest of personnel safety, a number of filtered face masks have been ordered for use when testing beryllium oxide windows.

2-2. WINDOW CONSTRUCTION AND HIGH POWER TESTING

A. Single Thin Disc Fused Quartz Windows

Early in the first quarter of this program, ground and polished fused quartz discs were requisitioned. The particular material ordered was the General Electric type 101 standard commercial grade. Cold tests were performed[1] with the objective of fabricating an assembly for testing and evaluation of fused quartz in high power density fields.

Since most metallizing techniques for quartz-to-metal seals have not been successful, a mechanical seal was made. This assembly is not vacuum-tight at bakeout temperatures but serves the purpose for resonant ring testing. The intention was to determine if fused quartz does constitute a desirable high power window dielectric material.

During this reporting period three assemblies, shown in Figure 2, were fabricated and tested in the ring resonator. The first was tested to failure at approximately 70 kilowatts. At this power level, the dielectric melted near the center of the highest electric field density area as shown in the photographs of Figures 3 and 4. This is significant since fused quartz softens at approximately 1670° C and fuses at about 1800° C. The area where melting occurred had a diameter of approximately 0.100 inch. Apparently the low thermal conductivity of the quartz body supports a high temperature gradient at the window center. Since the loss tangent of the body increases with temperature,* a mechanism is clearly provided for the observed thermal runaway phenomenon.

Further increase in power was not possible, since the high temperatures involved are believed responsible for causing a visually observed plasma discharge at the window face. Such a discharge has always been shown to mismatch the resonant ring to such a point that useful results are no longer obtainable.

Figure 5 illustrates the stress pattern remaining in the vicinity of the melted area after cooling. Prior to the test, the stress pattern had been observed, under polarized light, to be negligible. Encasing the disc in a resin and grinding a cross-sectional view of the melted area revealed the pattern shown in Figure 6. Note the pinpoint opening on the power output side.

As power in this test had been increased in 10-kilowatt steps until the window failed, and because failure occurred at an unexpectedly low level, insufficient data had been taken. A second window was fabricated, with the location of the larger bubbles within the quartz carefully noted. This window failed in the same manner as the first, but at 50 kilowatts cw. The observed sequence of visible effects leading to the window's failure was spectacular. As the power was slowly increased to the 50-kilowatt level, in approximately 5-kilowatt steps, no visual effects were seen. Once at 50 kilowatts for a few seconds, a small area near the center of the disc began to glow faintly with an orange color. Then it became brighter very rapidly to culminate in a very bright white flash of light. At this point the nitrogen in the ring ionized, detuning the ring and preventing further increase in power. The ionized atmosphere in the ring was violet in color.

Post test examination of the quartz showed a melted area similar to the first one, and that melting had not occurred at any of the previously observed larger bubbles. A photograph of that failure is shown in Figure 7. The cross section of the melted area was also very similar to that of Figure 6 with the pinpoint opening appearing on the power output side and not on the power input side. The significance of this, if any, is not clear at this time. Perhaps a very small bubble of air when heated to very high temperatures forces its way out of the quartz. With this in mind, another

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* See Quarterly Technical Note No. 1, Figure 2, p. 6.

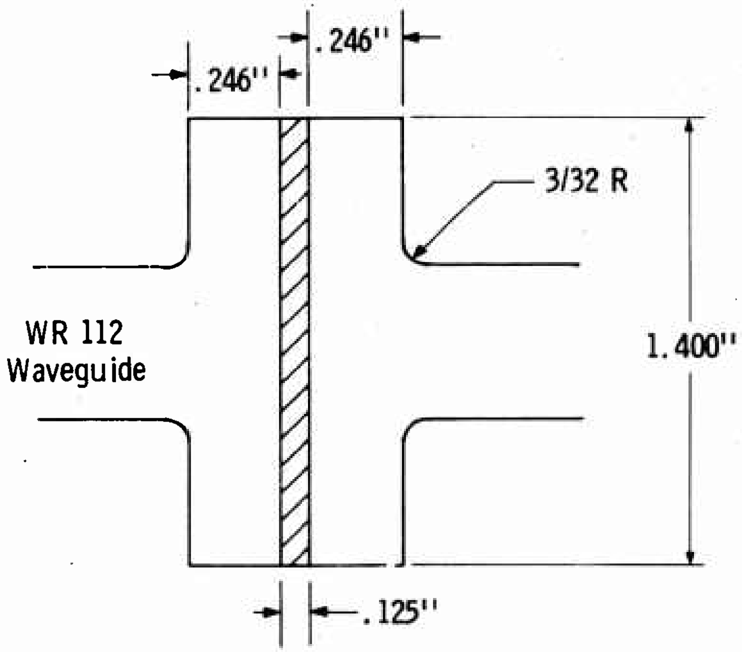


FIGURE 2
DIMENSIONS OF FUSED QUARTZ WINDOW USED FOR HIGH POWER TESTS

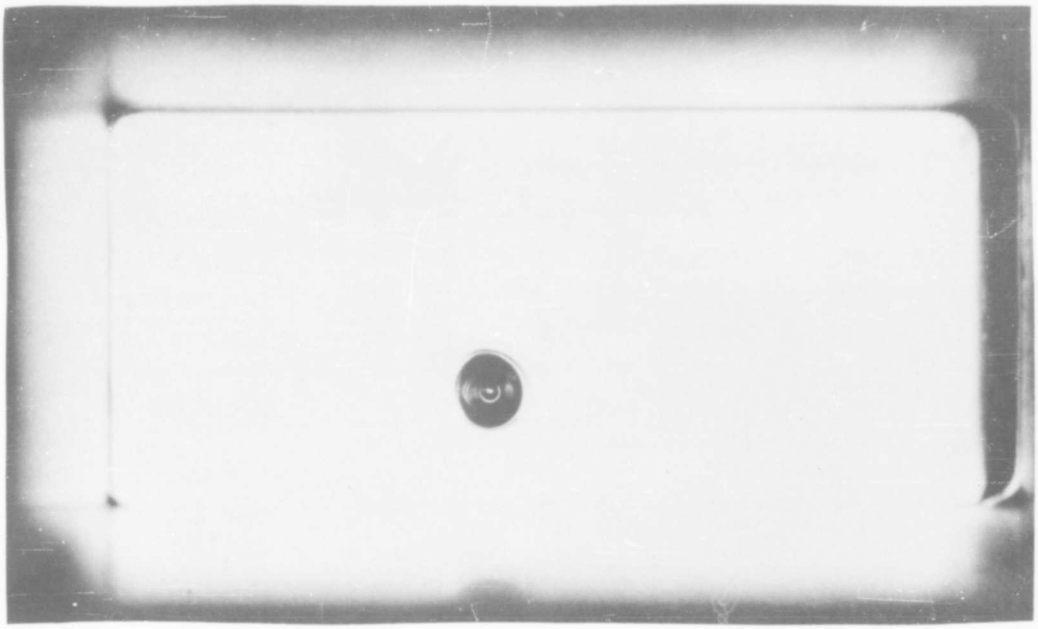


FIGURE 3
POWER INPUT SIDE OF FUSED QUARTZ WINDOW
SHOWING MELTED AREA

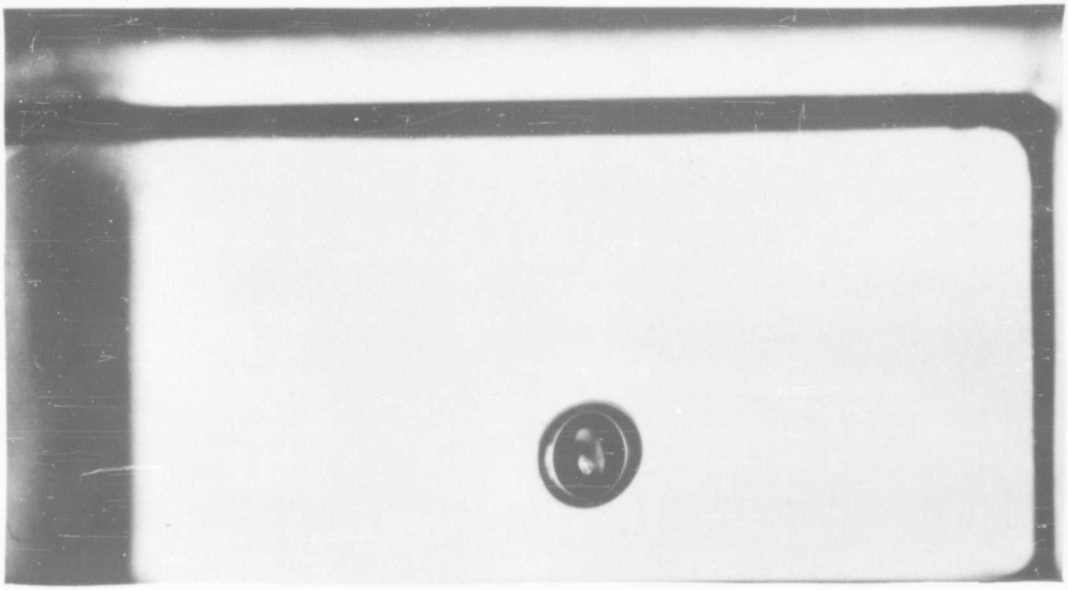


FIGURE 4
POWER OUTPUT SIDE OF FUSED QUARTZ WINDOW
SHOWING MELTED AREA

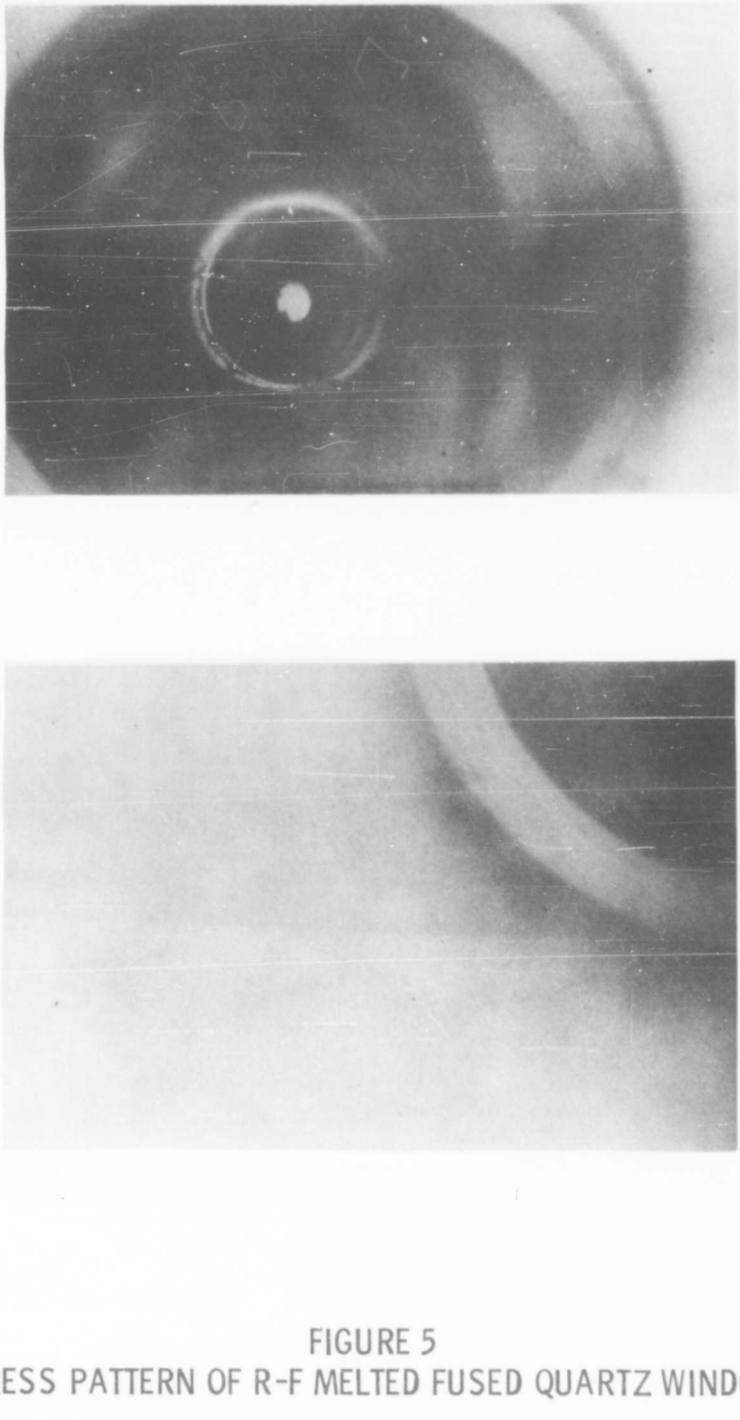
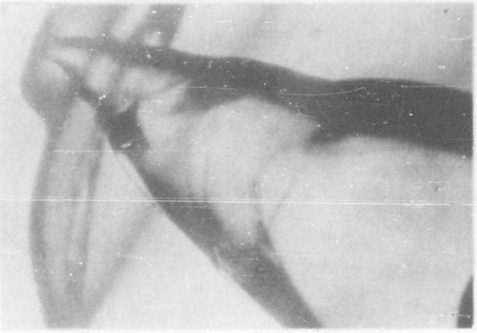


FIGURE 5
STRESS PATTERN OF R-F MELTED FUSED QUARTZ WINDOW



(a)

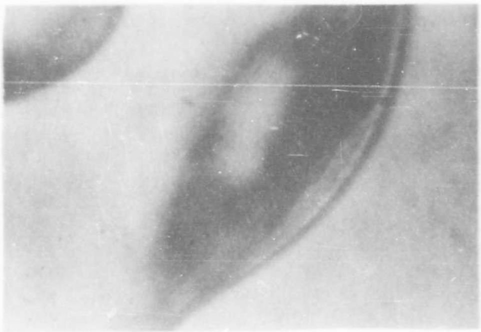
Cross Section from Window Center to Power Output Side

Magnification 30 Times

(b)

Cross Section Showing Power Output Side of Window

Magnification 100 Times



(c)

Cross Section Showing Power Input Side of Window

Magnification 100 Times

FIGURE 6
CROSS SECTIONS OF R-F MELTED FUSED QUARTZ BUBBLE

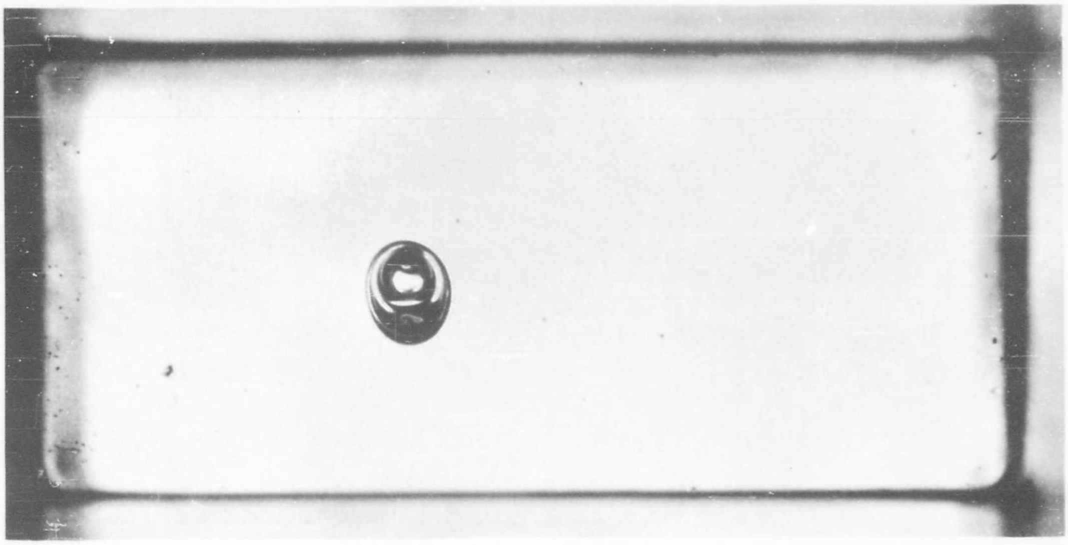


FIGURE 7
FAILURE OF FUSED QUARTZ WINDOW NO. 2

near bubble-free disc was selected for test. The power through this window was gradually increased to 120 kilowatts without melting, but the ring's nitrogen atmosphere again ionized and repeated attempts to get by this limit failed. Apparently the very high temperatures generated on the face of the window due to its extremely low thermal conductivity cause the ionization. In all of these tests the window perimeter was held at about 20° C by water cooling.

Calorimetric heat dissipation of quartz window No. 1 was recorded and is shown in Figure 8. It is quite evident that very little heat is getting out of the quartz.

In an attempt to establish definitely whether bubbles in quartz help to trigger the excessive heating and failure, a premium grade 100 per cent bubble-free fused quartz (Homosil) made by the Amersil Co. has been ordered.

B. Single Thin Disc Sapphire Windows

Several single crystal synthetic sapphire discs were obtained during this quarter, and cold tests were initiated immediately. Figure 9 shows dimensions and characteristics of the first vacuum-tight sapphire window which was tested without failure to 235 kilowatts. The test in this case was limited by severe arcing in the input hybrid phase shifters. The drive power was about 7.5 kilowatts. The dissipation at 235 kilowatts, shown in Figure 10 was 0.14 per cent of the total power. This test was performed with the resonant ring pressurized to 30 psi of nitrogen.

Because this sapphire worked so well and because it is perfectly transparent, it was decided to modify the assembly for use as a windowtron. (See Figure 11.) The evacuated space between the sapphire window and any other test window can be visually monitored on the vacuum side. Pumping of the space is done continuously with a one-liter VacIon pump. No high power tests have yet been made using the windowtron.

Other samples of single-disc zero degree cut sapphire have been cold tested. One of the samples was at first believed to be other than zero degree cut because of the unpredictable characteristics in cold testing. Further investigation has shown that this particular sample was indeed zero degree cut but that the seed of the boule from which it had been cut was located near the circumference of the disc as shown in Figure 12. An otherwise identical disc, which exhibited predictable cold test results, has been shown (Figure 13) to have been cut with the boule seed at its center. These photos, taken with polarized light, illustrate very nicely the crystal structure of zero degree cut single crystal sapphire discs.

Not shown, but observable under a microscope, are minute bubbles within the disc in the vicinity of the seed. These bubbles could be significant if they contained air at reduced pressure which might initiate early breakdown in high r-f fields.

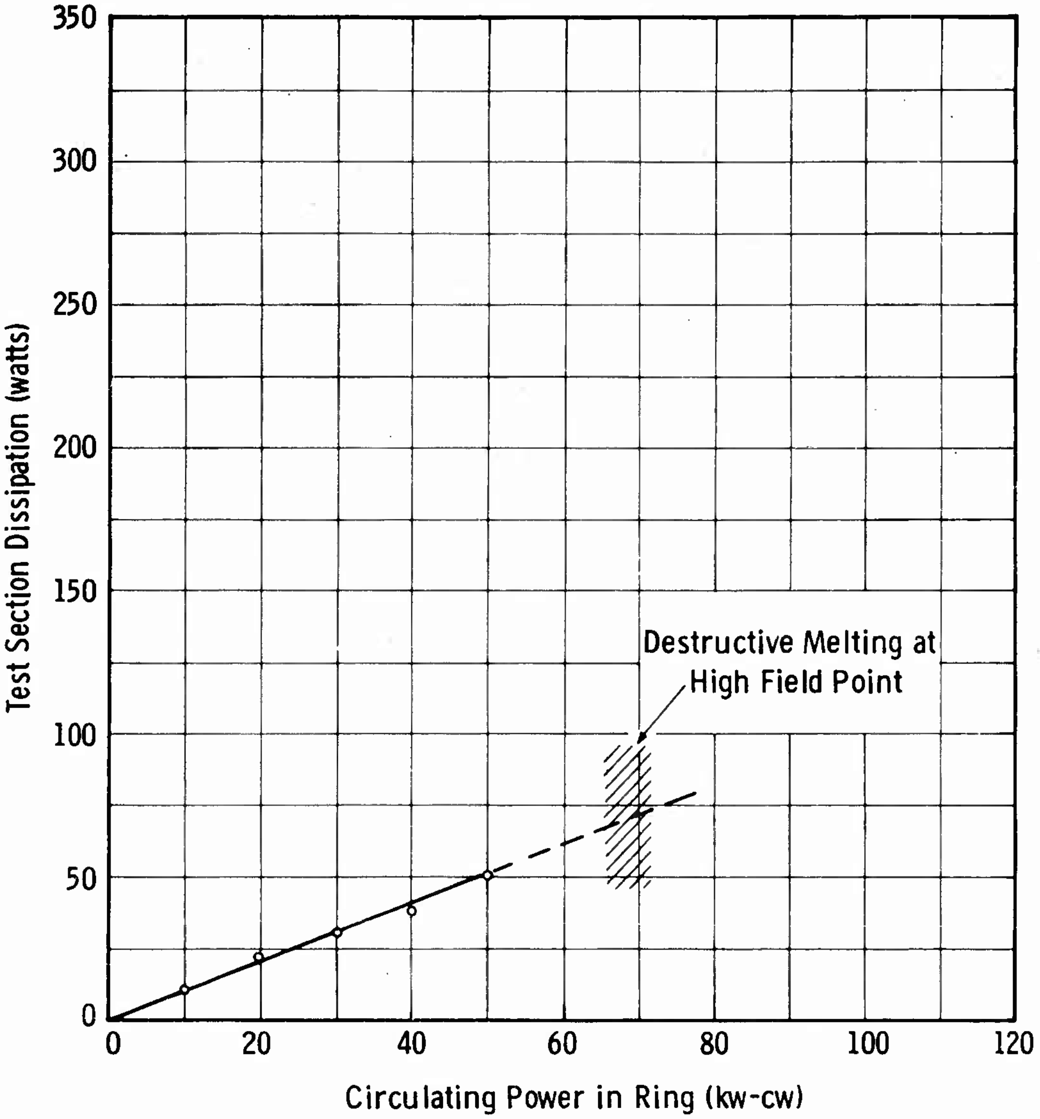


FIGURE 8
POWER DISSIPATION IN FUSED QUARTZ WINDOW NO. 1

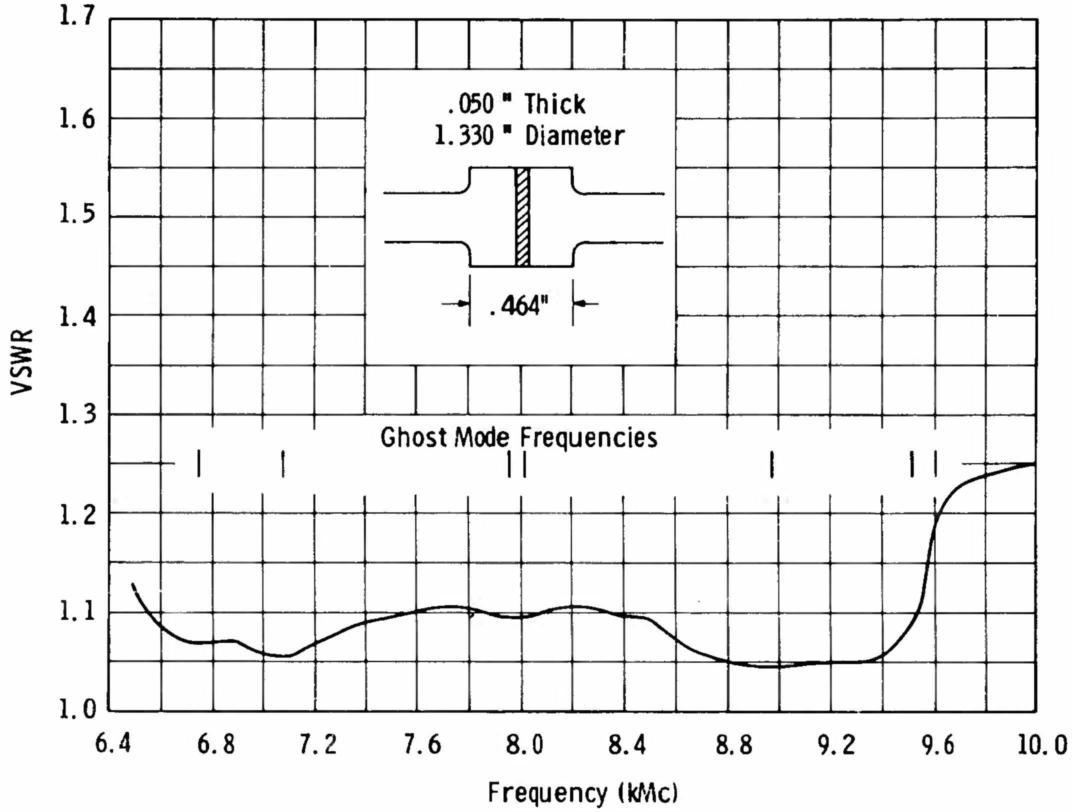


FIGURE 9
SINGLE DISC SAPPHIRE WINDOW CHARACTERISTICS
(VSWR VERSUS FREQUENCY)

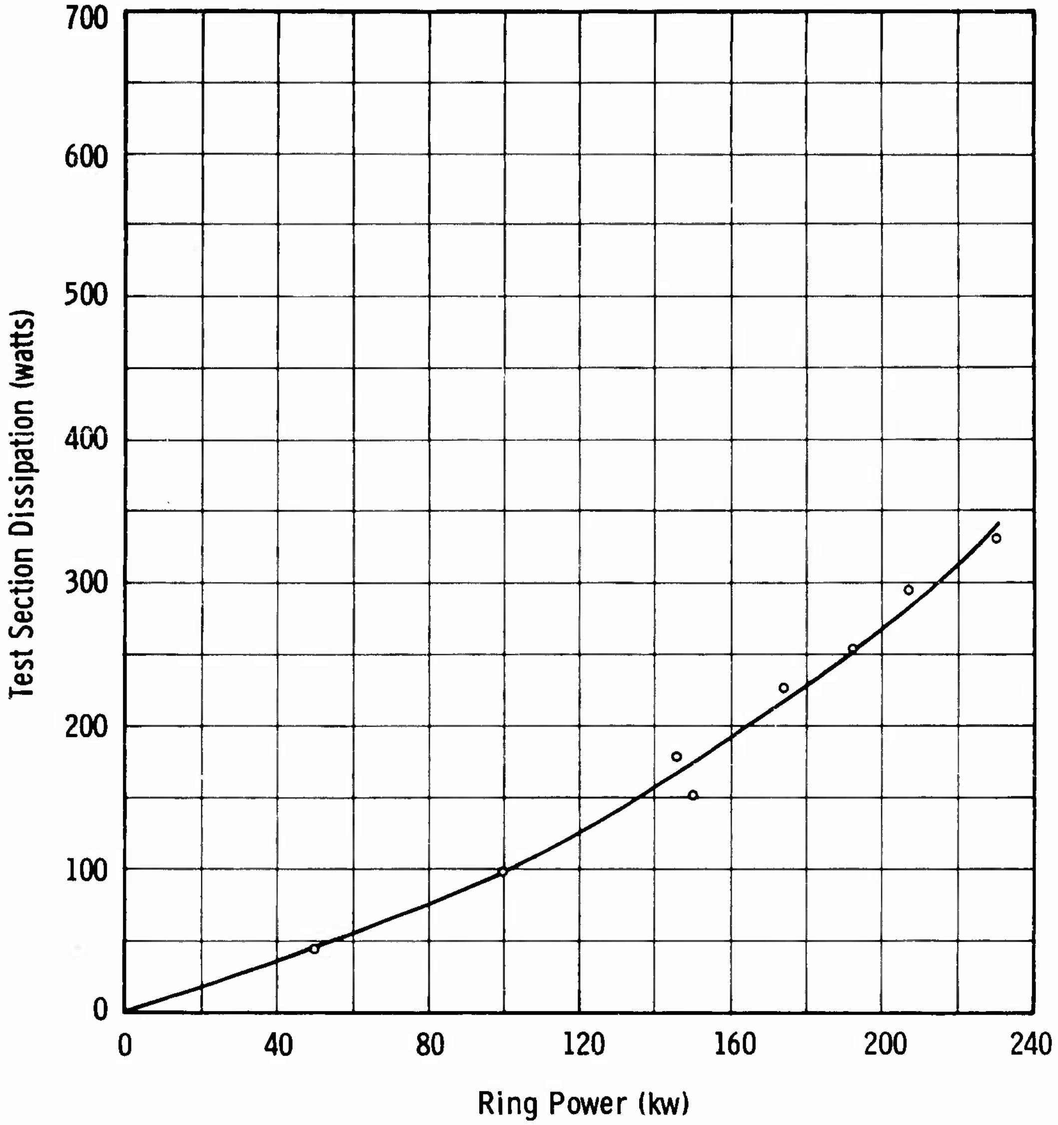


FIGURE 10
POWER DISSIPATION IN SINGLE DISC SAPPHIRE WINDOW ASSEMBLY

FIGURE 11
WINDOWTRON AND VACION PUMPING STATION

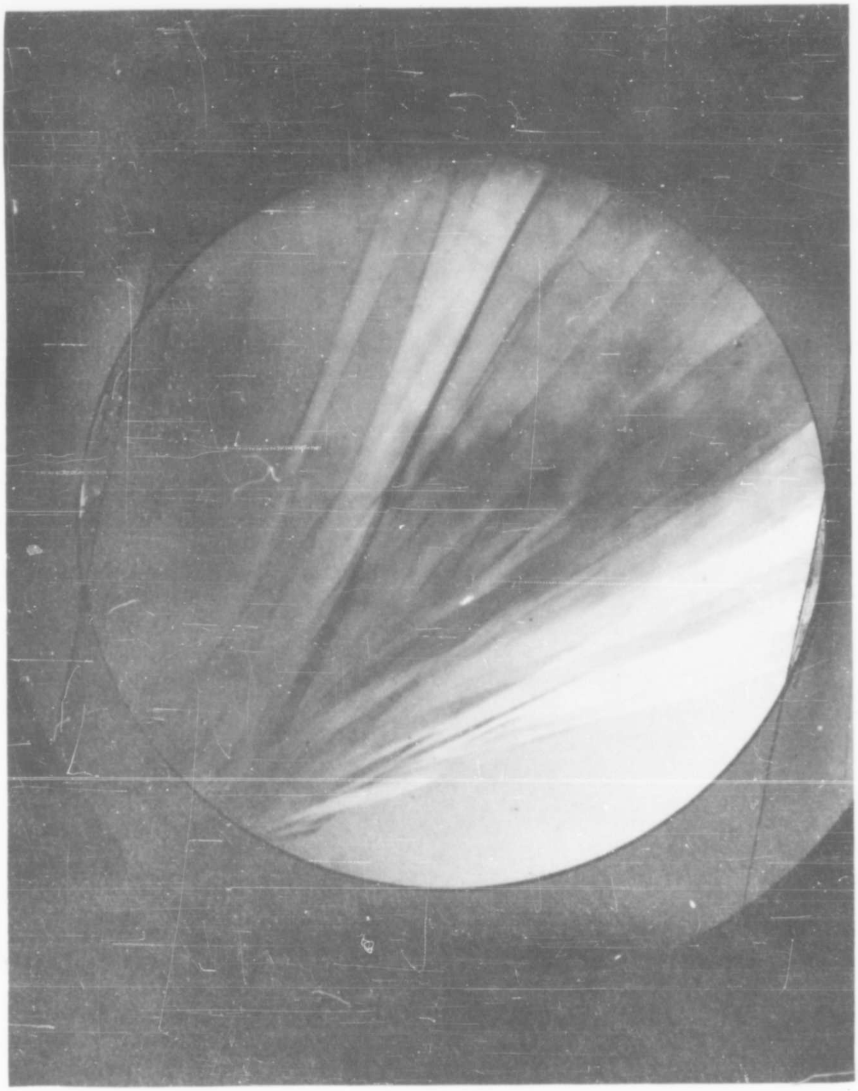


FIGURE 12
ZERO DEGREE CUT SAPPHIRE DISC CRYSTAL STRUCTURE
SHOWING BOULE SEED NEAR CIRCUMFERENCE

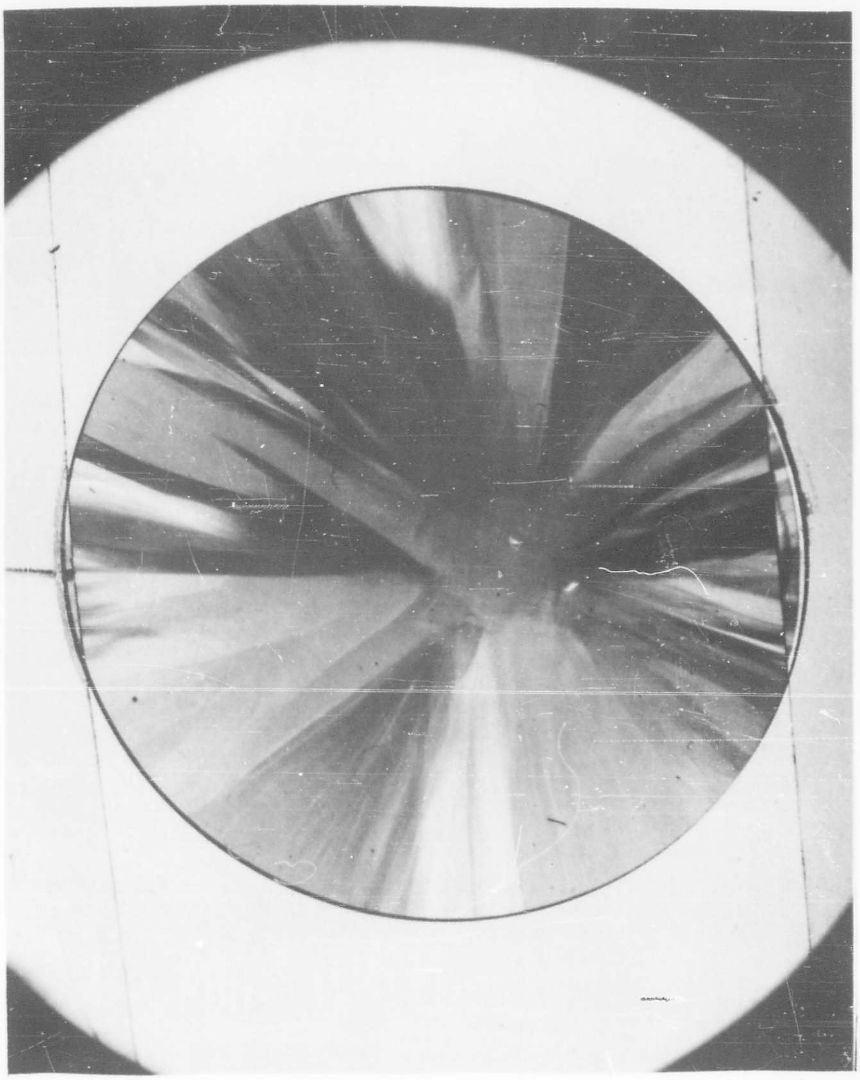


FIGURE 13
ZERO DEGREE CUT SAPPHIRE DISC CRYSTAL STRUCTURE
SHOWING BOULE SEED NEAR CENTER

Very careful investigation has shown that early indications of electrical dissimilarities between zero degree cut sapphire discs cut from different portions of the boule were erroneous. The discs are identical and can be used interchangeably in any design.

C. Single Thin Disc Beryllium Oxide Windows

The fabrication of a circular thin disc beryllium oxide window has not yet been accomplished satisfactorily. The first attempt was not successful because the OFHC cylinder to which the disc is brazed developed a leak through the copper. New beryllium oxide discs have been received and cold tested. Metallizing of these discs is now in progress.

D. Double Thin Disc Windows

Two vacuum-tight double disc window assemblies were fabricated during this quarter. The cold test results from the first one completed are shown in Figure 14. The broken line shows the standing wave ratio versus frequency when the space between the windows is air filled. A relatively minor improvement is obtained when the assembly has FC75 between the discs. In either case the bandwidth is over 40 per cent with a VSWR under 1.2. However, this does not take into consideration the resonant ghost modes which are present.

Cavity perturbation techniques were employed in exciting and identifying the modes shown in Figure 14. The maximum mode-free bandwidth is then reduced to 19.6 per cent. Design tests on this window had indicated that a 0.040 space between the dual discs would load the modes down to an undetectable level. Apparently the loss tangent of the Eccostock R20* is somewhat higher than quoted by the manufacturer. If this is so, the modes would be more greatly damped.

With greater mode damping (lowering of mode Q) in mind, another double disc window (this time using AL400 ceramic) was designed and fabricated with the window spacing doubled. Thicker discs of AL400 were used to increase the window's strength. Not only does the greater thickness improve the strength but AL400 has a greater flexural strength than AL300. This, of course, was accomplished at the expense of some bandwidth. Cold test results from the vacuum-tight AL400 window with FC75 between the discs are shown in Figure 15. No resonant ghost modes are detectable in this window and the bandwidth is 33.3 per cent.

The first experiment with the FC75 heat exchanger was to connect the AL300 dual disc window to it and circulate the fluid. Using the built-in heater, the temperature was raised slowly over a period of several hours to 65° C. During this cycle

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* See Quarterly Technical Note No. 1, pp. 26, 27.

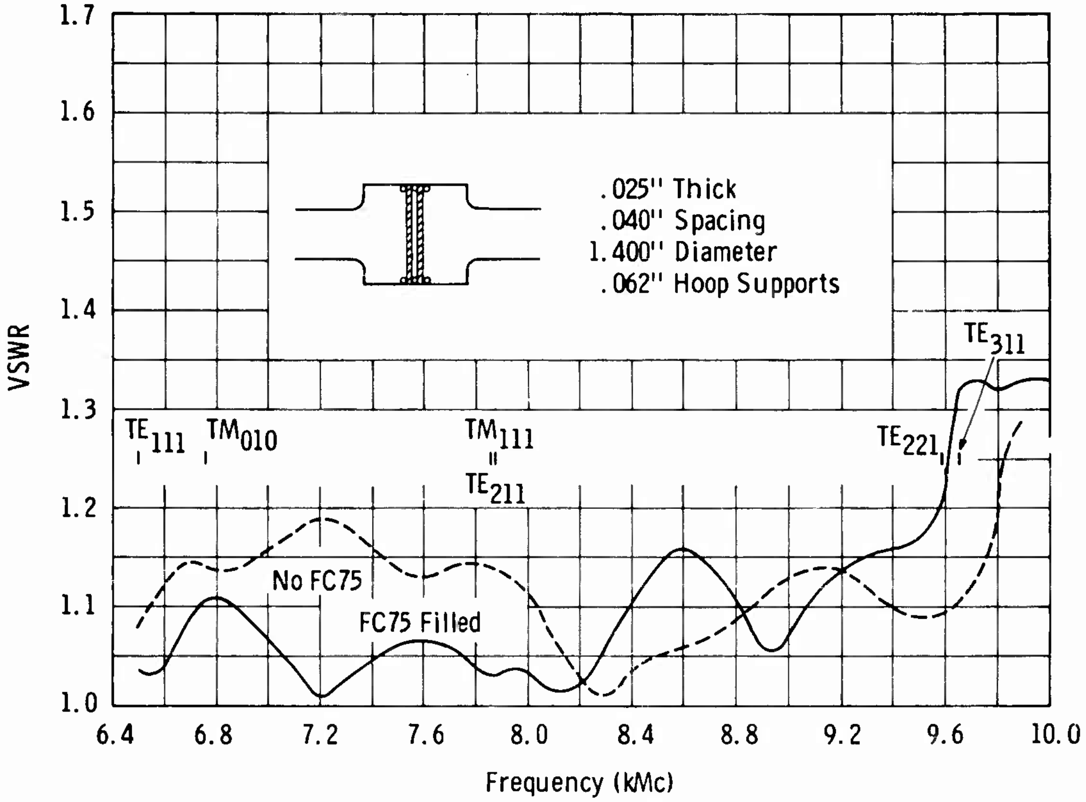

FIGURE 14
VACUUM-TIGHT DOUBLE DISC AL300 FC75 COOLED WINDOW CHARACTERISTICS (VSWR VERSUS FREQUENCY)

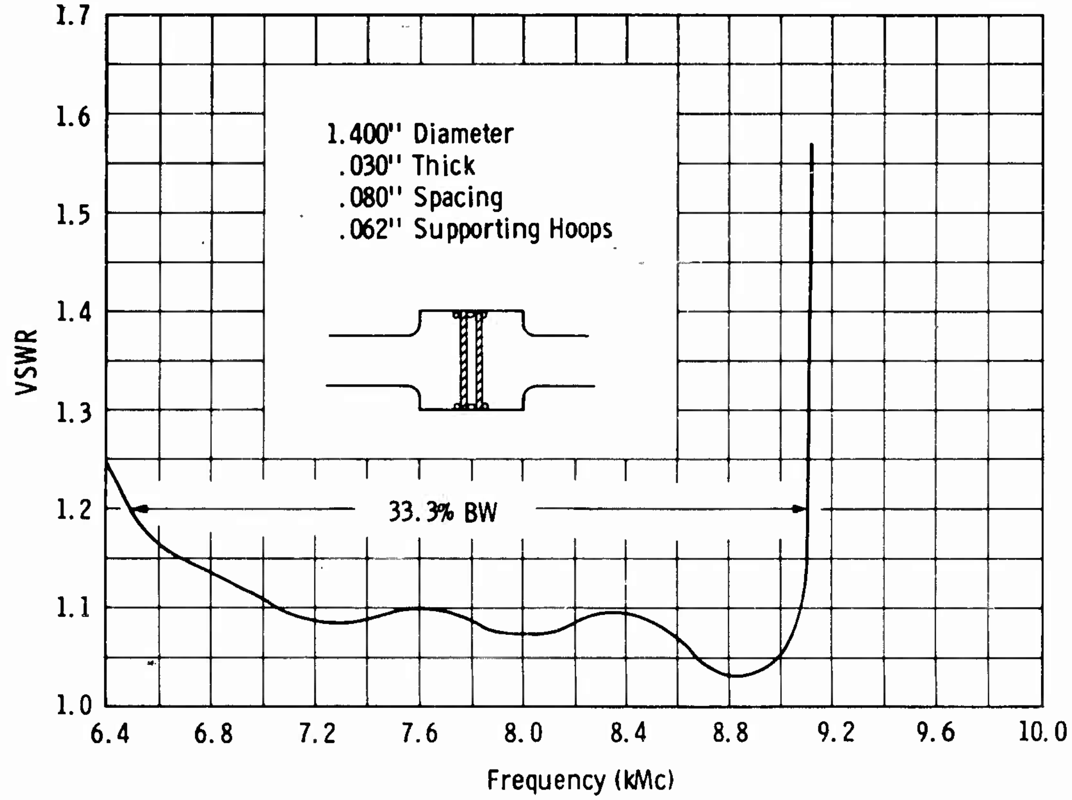

FIGURE 15
VACUUM-TIGHT DOUBLE DISC AL400 FC75
COOLED WINDOW CHARACTERISTICS

the standing wave ratio across the frequency band was monitored continuously. No change in this response was noted. The fluid input line pressure was slowly increased to 65 psi with no adverse affects upon the window. Unfortunately this window was accidently destroyed by excessive input line pressure when, inadvertently, the pressure-reducing valve was opened while the system was off. When the pump was switched on again for the next test, a surge of pressure fractured one of the discs. An estimate of this fracture pressure from calculation, and considering that the windows were reinforced with hoops, indicate that it would have taken more than 100 psi input pressure to break the window.

Preliminary temperature and VSWR tests on the AL400 dual window were performed with the same results as with the AL300 version. High power tests were then begun in the ring resonator. During the first day of tests, the power was increased in 10-kilowatt steps to a total of 120 kilowatts. No difficulty was experienced. During the second day, power was increased fairly rapidly to the 120-kilowatt level where the previous procedure was resumed. At 180 kilowatts a waveguide arc was struck at a point which appeared to be near the input flange to the window. The arc cracked one of the windows and a small amount of FC75 leaked into the resonator. The arc decomposed the FC75, depositing carbon on the waveguide walls and the window face as shown in the photograph of Figure 16. Chemical analysis of the decomposition products showed only a trace of copper and no trace of fluorine.

Power dissipation in the window, as measured during the above experiment, is plotted in Figure 17. Approximately 1300 watts out of 180 kilowatts, or 0.72 per cent of the input power, is being carried away as heat. The temperature difference between window input and output at 180 kilowatts was 20° C with a flow rate of 0.5 gallon per minute. This window was pressurized on both sides to 30 psi of nitrogen.

E. Half Wavelength Beryllium Oxide Block Windows

The fourth, fifth and sixth samples of Brush Beryllia's dry isostatically pressed beryllium oxide body (now denoted as F-1 or B-10) were metallized and brazed successfully into vacuum-tight window test assemblies. Three previous attempts at brazing vacuum-tight windows with this material had failed. The success of these three brazes is believed to be due to the manufacturer's slight adjustment of firing schedules which eliminated the small amount of shrinking observed during metallizing and braze firing.

Window No. 4 was tested to 252 kilowatts cw with the ring pressurized with 25 psi of nitrogen at a test frequency of 7762 Mc. As expected, in light of similar tests previously performed on identical but not vacuum-tight windows, little difficulty was experienced in transmitting this much power through the window. Testing of this window was concluded after less than one hour's operation at 252 kilowatts because of severe arcing in the input hybrid tuner. The test window maintained its vacuum integrity and the dielectric suffered no observable damage. Figure 18 illustrates the standing wave

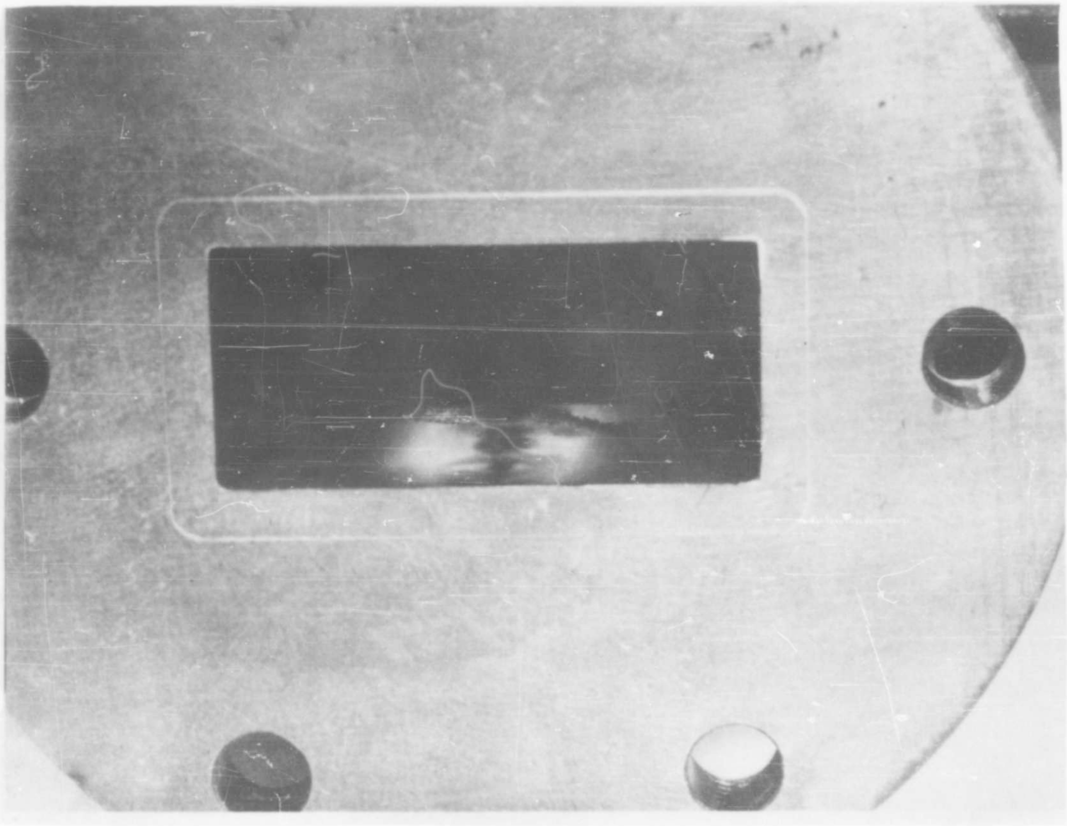

FIGURE 16
AL400 DUAL DISC WINDOW SHOWING ARC
MARKS AND CARBON DEPOSITS

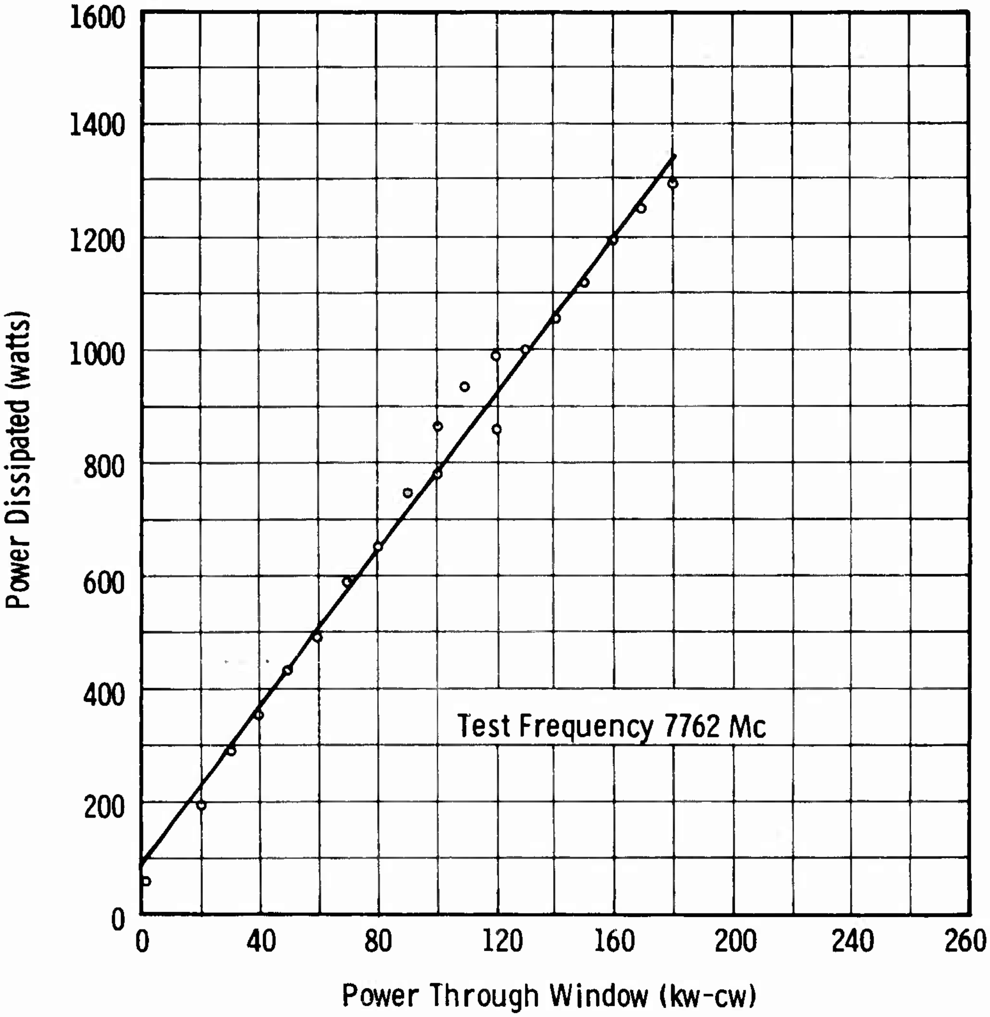

FIGURE 17
POWER DISSIPATION IN AL400 DOUBLE DISC FC75 COOLED WINDOW

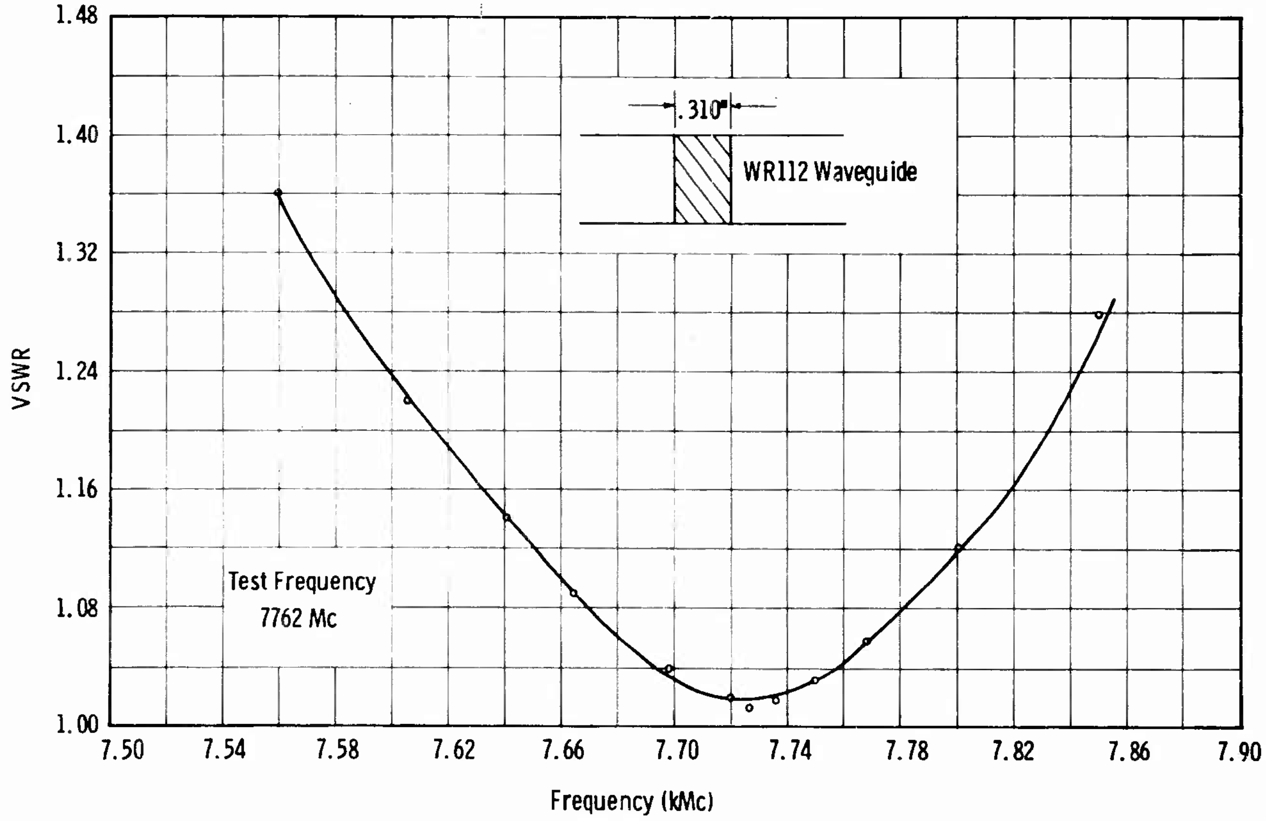

FIGURE 18
VACUUM-TIGHT BERYLLIUM OXIDE BLOCK WINDOW CHARACTERISTICS

characteristics of the test window with no attempt made to broadband match it. The power dissipation in the assembly is illustrated in Figure 19. It should be noted that 0.37 per cent of the transmitted power through the window is dissipated as heat.

A sample of National Beryllia's high density ceramic has also been successfully brazed and is now awaiting high power testing.

F. Half Wavelength Aluminum Oxide Block Windows

The construction of vacuum-tight AL300, AL995 and AL399 half wavelength block windows has been completed and high power tests are currently in progress. This group of aluminum windows is being tested to establish, in comparison with beryllium oxide, the relative worth of all these materials. No broadband impedance matching has been done on any of them. The ceramics were cut $\lambda_g/2$ long at the test frequency of 7750 Mc and a single inductive iris was used if necessary to trim the VSWR down to 1.03 or better at the ring resonator test frequency.

Mode free, broadband designs are being pursued, however. An analysis of the mode pattern from solutions of the ghost mode resonance equations* shows, as in Figure 20, that extremely wide bandwidths are unobtainable using half wavelength block windows.

For example, the AL300 block of Figure 20, cut $\lambda_g/2$ at 7750 Mc and with a normal aspect ratio (indicated by dashed line), has a maximum mode free bandwidth of 17.2 per cent. This area, with center frequency of 7200 Mc, falls between the intersections of the $TE_{30}^{\square}$ - $TE_{21}^{\square}$ and $TE_{31}^{\square}$ - $TM_{11}^{\square}$ modes. It is readily seen that the higher the frequency, the higher the density of the modes. For this particular window thickness and ceramic, an increase in aspect ratio would give a greater mode free range. For example, consider an aspect ratio of 4.0. A 21.9 per cent mode free bandwidth would be obtainable but now the window must be built in approximately half height guide. The power banding capacity of such a window would obviously suffer.

Design of a well matched maximum mode-free bandwidth is now being pursued and will be described in future reports.

G. Resonant Ring Limitations

From the results of the high power tests on the double disc and half wavelength block windows it has become increasingly apparent that the present ring resonator will not perform satisfactorily above 250 kilowatts. With the double disc window the gain of the circuit was about 26 as compared to a gain of up to 40 for low loss thin discs and up to 33 for thick block windows.

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* See Quarterly Technical Note No. 1, pp. 33-40.

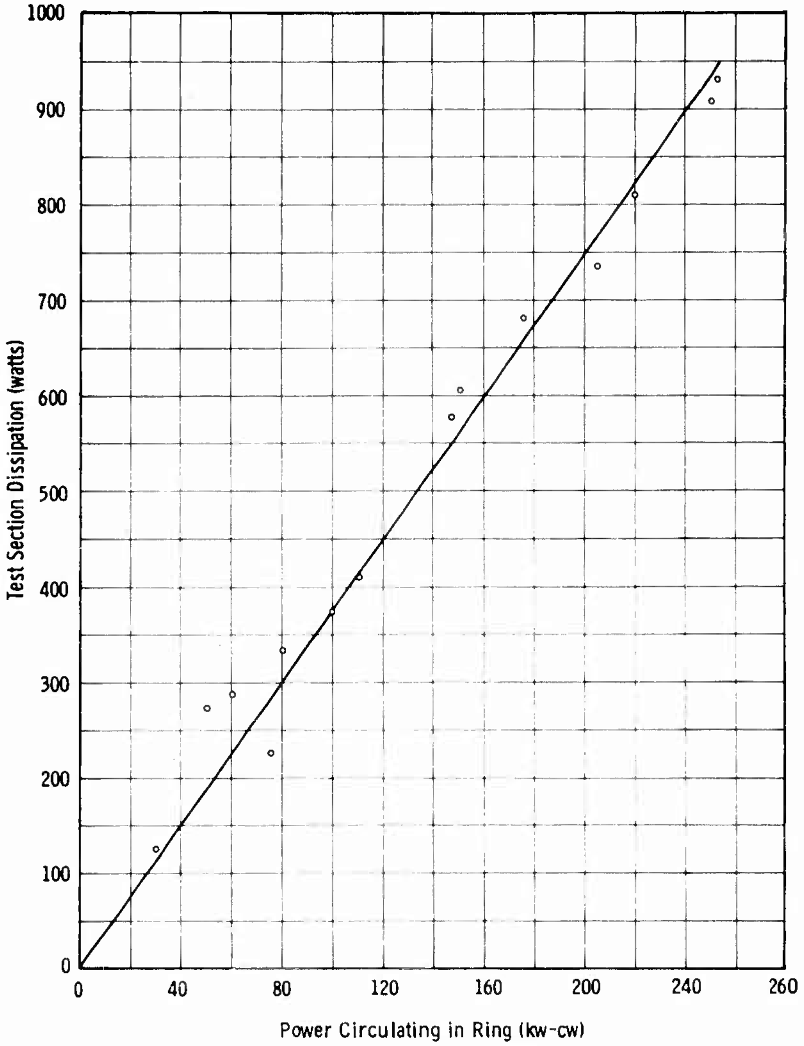

FIGURE 19
POWER DISSIPATION IN BERYLLIUM OXIDE WINDOW NO. 4

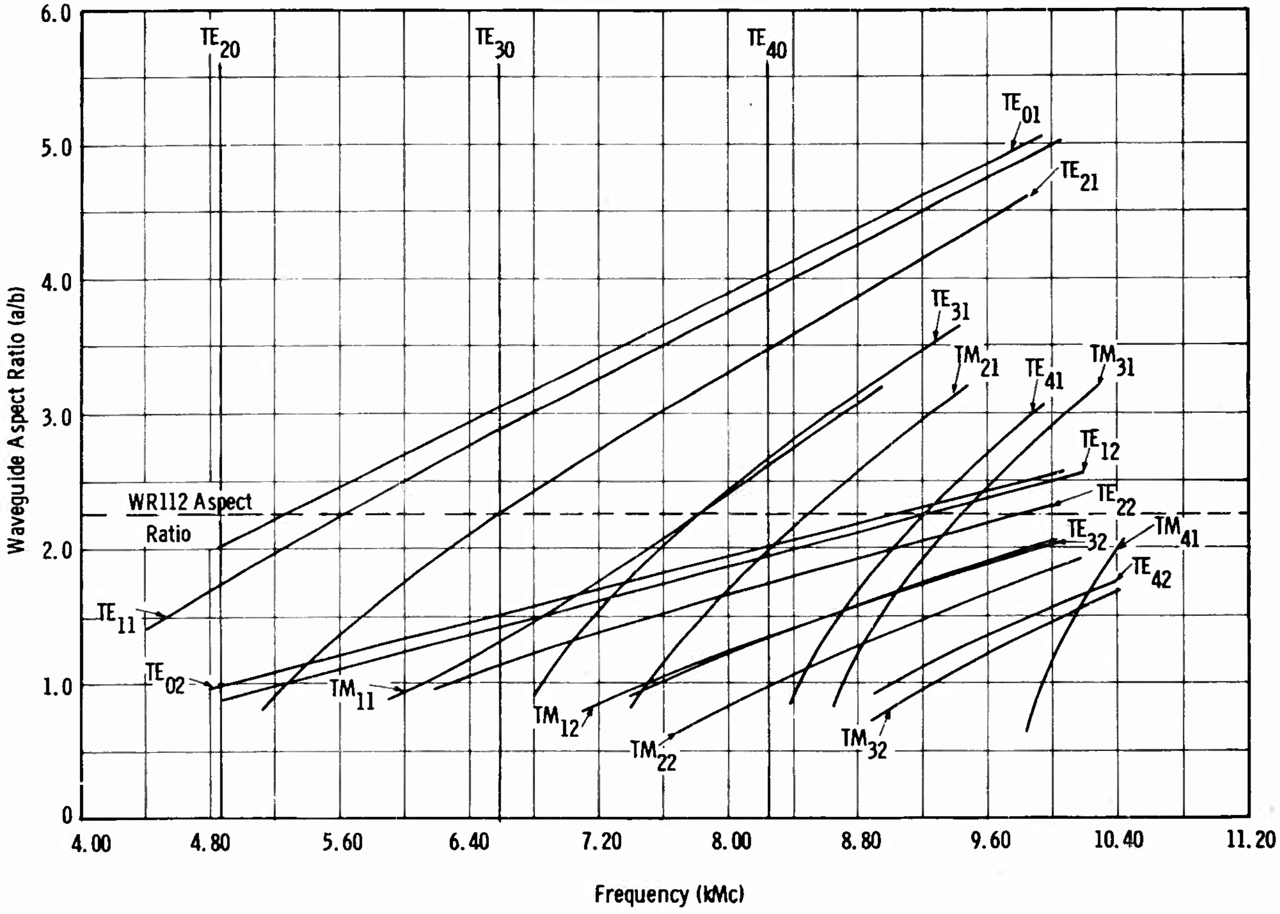

FIGURE 20
MODE PATTERNS FOR AL300 BLOCK WINDOW
(ASPECT RATIO VERSUS FREQUENCY)

Ordinarily a 0.7 per cent loss in power as in the dual window would not be considered too great if the window were being used on a tube. However, when ring gain is down, a greater drive power must be supplied to obtain a given circulating power. A life test attempted with the half wavelength beryllium oxide window at the 250-kilowatt level was terminated in less than one hour because of arcing in the input tuners. This arcing actuates the tube arc protecting system which shuts off the driver. Examination of the hybrids showed very strong evidences of arcing around the sliding shorts. Several previous breakdowns had also been experienced with these hybrids in the 200 to 275 kilowatt range of power levels. Some improvement in the threshold of breakdown has been obtained by encasing or potting the sliding shorts with a thin layer of dielectric material. About 8 kilowatts of drive power seems to be the limit for these particular hybrid tuners. In fact, one of them is inoperable at the present time and is responsible for a temporary lag in the high power testing portion of the program.

If this tuner difficulty cannot be resolved shortly, it may be necessary to divert some of the window effort into building devices to do the job at the power levels being discussed. It would also be advantageous to be able to go to even higher power levels because the upper limit of some of the windows tested is still not known.

An E-H tuner can also be used in place of the hybrid unit. The sliding shorts on the E-H tuner also fail, but it is felt that a dielectric line stretcher like the one described by Ragan[2] could be used in each arm of the tuner to accomplish the same results at even higher powers.

2-3. REFERENCES

1. Quarterly Technical Note No. 1, High Power R-F Window Study Program, RADC-TDR-62-510, furnished by Varian Associates under Contract No. AF 30(602)-2844.

2. Ragan, G. L. Microwave Transmission Circuits, Radiation Laboratory, MIT, Cambridge, Mass., 1948, p. 514.

SECTION III

FISCAL STATUS OF PROGRAM

The rate of expenditure on the High Power R-F Window Study Program during the quarter has been approximately $5,900 per month. This includes about $168 per month spent on materials and supplies for window construction. There were 1645 man-hours expended during the second quarter.

Estimated expenditures for the remainder of the program are $4,600 and 390 man-hours per month.

SECTION IV

PROGRAM FOR NEXT QUARTER

During the coming quarter all windows previously tested successfully in the resonant ring will be retested in a windowtron assembly. The windowtron will be evacuated between the transparent sapphire disc and the window being tested. Included in these tests will be high density beryllium oxide from two different manufacturers, AL995 and AL300. The alumina blocks will be pretested in a nitrogen atmosphere for direct comparison with their beryllium oxide counterparts. The performance of the various block windows will then be analyzed to find which material, if any, is preferable for construction of even higher power windows.

Additional double disc windows will be fabricated and tested to verify the experimental results from the AL400 version. Certain other double disc designs now in various stages of cold testing will be pursued further to improve power handling capacity at the possible expense of bandwidth.

It is anticipated that the windowtron will also be used as a device to measure the effects on power handling of small variations in gas pressure in the 10^{-4} to 10^{-8} torr range. Methods of inducing multipactor and the phenomenon of multipactor in general will be studied using the windowtron.

Since there has been difficulty with breakdown at the sliding shorts of the hybrid phase shifters, some effort will be made this coming quarter to improve the present upper limit of power circulating in the ring resonator.

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