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STUDY PROGRAM
FOR DESIGN IMPROVEMENTS
OF THE X-3060 AND X-3075

Phase I: Study Definition

FINAL REPORT

by

Art Goldfinger

January 1978

JPL Contract No. 954782

Prepared for:

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Jet Propulsion Laboratory
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Study Program for Design Improvement of the X-3060 and X-3075 S-Band Klystrons

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ABSTRACT

This study program is directed toward the eventual redesign of the X-3060 and X-3075 S-band klystrons. The prime objective of this redesign is to improve reliability, with a secondary objective or improved efficiency.

The study program is divided into the four phases shown below:

I. Study Definition
II. Design Improvement
III. Electron Gun Fabrication and Beam Analyzer Evaluation
IV. Klystron Prototype Fabrication and Delivery

This report deals with the completion of Phase I: Study Definition.

During this phase of the study, the existing designs of the X-3060 and X-3075 klystrons were critically examined to determine whether or not realistic redesign goals could be established.

Additionally, Varian failure analyses and JPL field failure reports were examined to identify any design weaknesses. Results of this critical analysis indicate that substantial improvements can be made to the overall design of both the X-3060 and X-3075 klystrons.

Pertinent and detailed data concerning these improvements have been presented at a final design review meeting and are reported herein.

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I. INTRODUCTION

A. BACKGROUND

The X-3060 klystron was first introduced in 1965. It is a 100 kW CW amplifier klystron, tunable over the 2100 - 2400 MHz range.

Questions have arisen about the field performance record of the X-3060, but its operational performance is difficult to assess. Field reports taken over an eleven-year period indicate only 2526 total combined operational hours for six X-3060 klystrons. All tubes, however, are still in operable condition.

An early design defect in the heater/cathode configuration was corrected in 1974 by rebuilding all tubes with an improved potted heater design. Since that time only one failure has been recorded in field operation. However, because of early "start-up" failures, the age of the present design, and an increased desire to provide the most reliable performance possible, it is prudent to review and critically analyze the design of the X-3060 to determine whether improved reliability and performance can be achieved. This analysis was an assignment of Phase I of the present study program.

The X-3075 klystron was first delivered to JPL in July of 1969. It is a 500 kW CW amplifier klystron, fix-tuned at a center frequency of 2110 MHz. Field performance of this klystron can best be described as dismal. One could expect that any device operating at such high average powers might be troublesome, but it is not at all clear from historical data that all of the X-3075's problems are associated strictly with high power phenomena. What is clear is that all three of the X-3075s constructed are now scrap. There are no operable X-3075 klystrons.

A prime objective of Phase I of the study program is to analyze both historical records of failures and the basic design of the X-3075 to determine whether or not realistic improvements could be made to improve its performance and reliability.

B. STUDY DEFINITION: PHASE I DEFINED

The purpose of Phase I of the study program is to examine the existing design of both the X-3060 and X-3075 klystrons and suggest to JPL realistic redesign goals, if possible, for each important design parameter. In addition, Phase I includes an examination of failure reports of both klystron types to identify any possible design weaknesses.

Prior to the initiation of Phase I, a study plan was submitted to and approved by JPL. This study plan encompasses all desired aspects of the investigation and is shown here in Table I-1.

TABLE I-1
PHASE I STUDY PLAN

X-3060 I. History of Tubes and Available Failure Reports
II. Study and Recommendations
- A. Electron Gun
    1. Cathode/filament
    2. Cathode loading
    3. Voltage gradients
    4. Modulating anode
- B. Klystron Body
    1. Tailpipe
    2. Tube/magnet alignment
    3. Advantages and disadvantages of tuners
    4. Higher efficiency
- C. Magnet
    1. Tube/magnet alignment
    2. Individual control of focus coil currents

X-3075 I. History of Tubes and Available Failure Reports
II. Study and Recommendations
- A. Electron Gun
    1. Cathode/filament
    2. Cathode loading
    3. Voltage gradients
    4. Modulating anode
- B. Klystron Body
    1. Tailpipe
    2. Mechanical tube support
    3. Tube/magnet alignment
- C. Collector
    1. Collector assembly
    2. Power density
- D. Magnet
    1. Tube/magnet alignment
    2. Individual control of focus coil currents

II. DESIGN ANALYSIS

A. ELECTRON GUN

1. Cathode/Filament Structure

Although no failures occurred with the original X-3060 heater design, examination of klystrons returned from field service for other reasons showed deterioration of the heater insulation. The deterioration was serious enough that eventual failure would have occurred.

All X-3060 klystrons were recalled in 1974 to have this design weakness corrected. The original design was replaced with the potted heater/cathode design shown here in Figure II-1. In the author's opinion, this is the most efficient and reliable design available at the present time, and no further change in this design is recommended.

This design operates satisfactorily with ac supply voltages of 60 to 400 cycles. Operation with dc is not recommended.

The cathode/filament structure of the X-3075 is similar to the design used originally in the X-3060 but on a larger scale. It is recommended that a scaled-up version of the potted heater/cathode structure used in the later X-3060s be incorporated in any improved version of the X-3075.

2. Cathode Loading

The emission density demands on the present X-3060 cathode are a conservative 1.375 A/cm^2 and will provide long and reliable life for the X-3060 klystron. No change in the cathode's design is recommended.

Likewise, the current demand from the surface of the X-3075 cathode is a conservative 1.45 A/cm^2 and no design change is recommended.

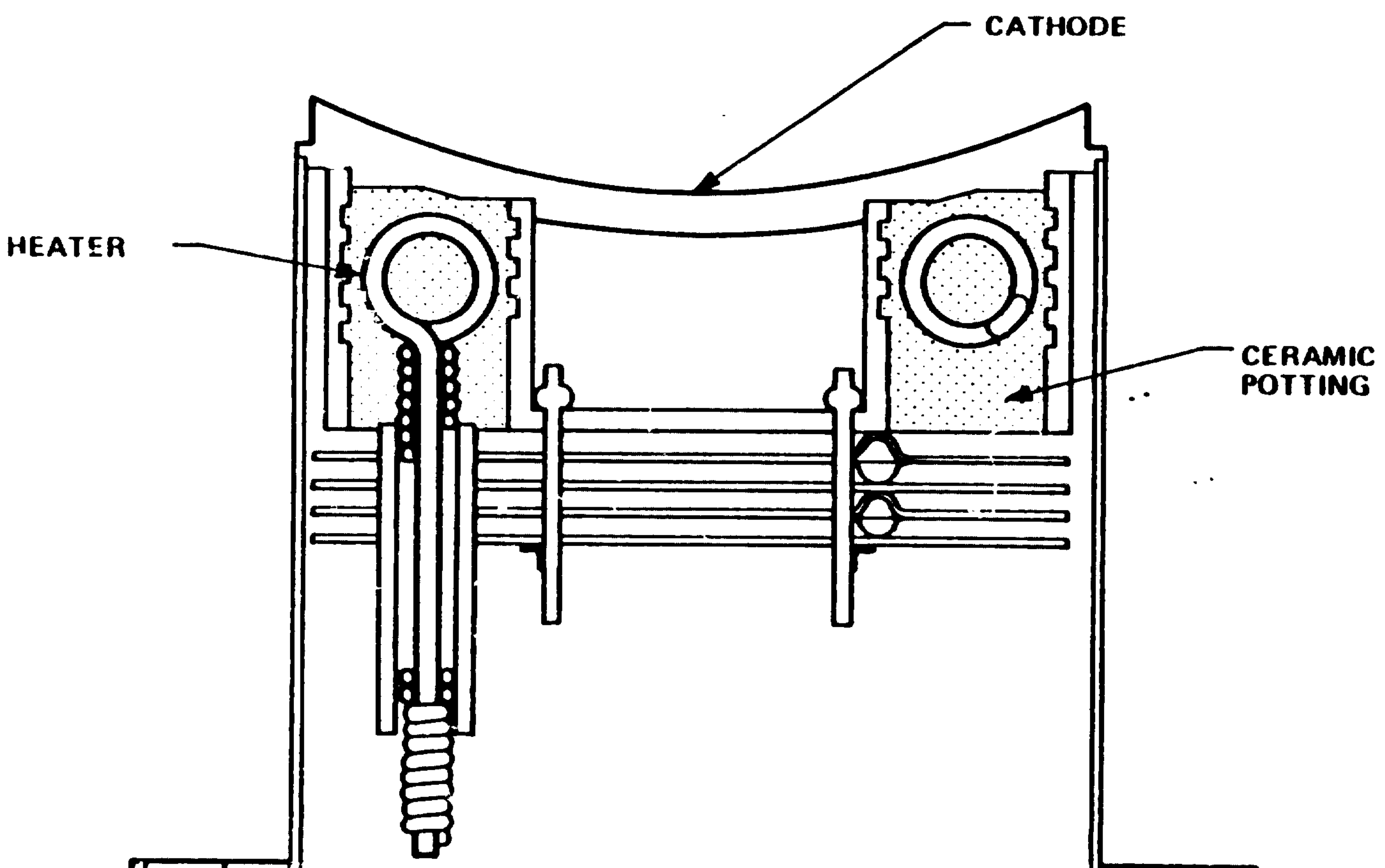


FIGURE II-1. X-3060 POTTED HEATER/CATHODE ASSEMBLY

3. High Voltage Gradients

Electron gun arcing due to the presence of high voltage field gradients is an ever troublesome phenomen associated with high power klystrons.

Factory and field performance records do not indicate any serious problems caused by gun arcing in the X-3060. Nevertheless, an examination of the gradients was undertaken to determine whether or not any improvements could be made to insure greater reliability.

A generally accepted value for conservative gradient design in a dc application is 250 kV/in, and that value is used here as an approximate reference.

Another frame of reference can be established by comparing the design under study to a design with known performance. This technique is used here by comparing both the X-3060 and X-3075 gradient profiles with that of the VA-949J electron gun. The VA-949J gun has shown persistent gun arcing problems. Shown in Figure II-2 is a comparison of the three high voltage guns compared. Shown in Figures II-3 and II-4 are the computer plots used to determine field gradients in the X-3060 and X-3075.

In the diagrammatic view of an electron gun in Figure II-2, the numbered arrows at the tip of the focus electrode identify the zones of highest field gradients found in the three electron guns. These numbered zones form the abscissa for all graphs used to present gradient data in this report.

The VA-949J electron gun does not in fact have a modulating anode. It does have, however, a magnetic shield at ground potential, in exactly the same physical position as the modulating anode found in the X-3060 and X-3075 guns. This makes the gradient comparison a valid one.

Predictions that can be drawn from examination of Figure II-2 are as follows:

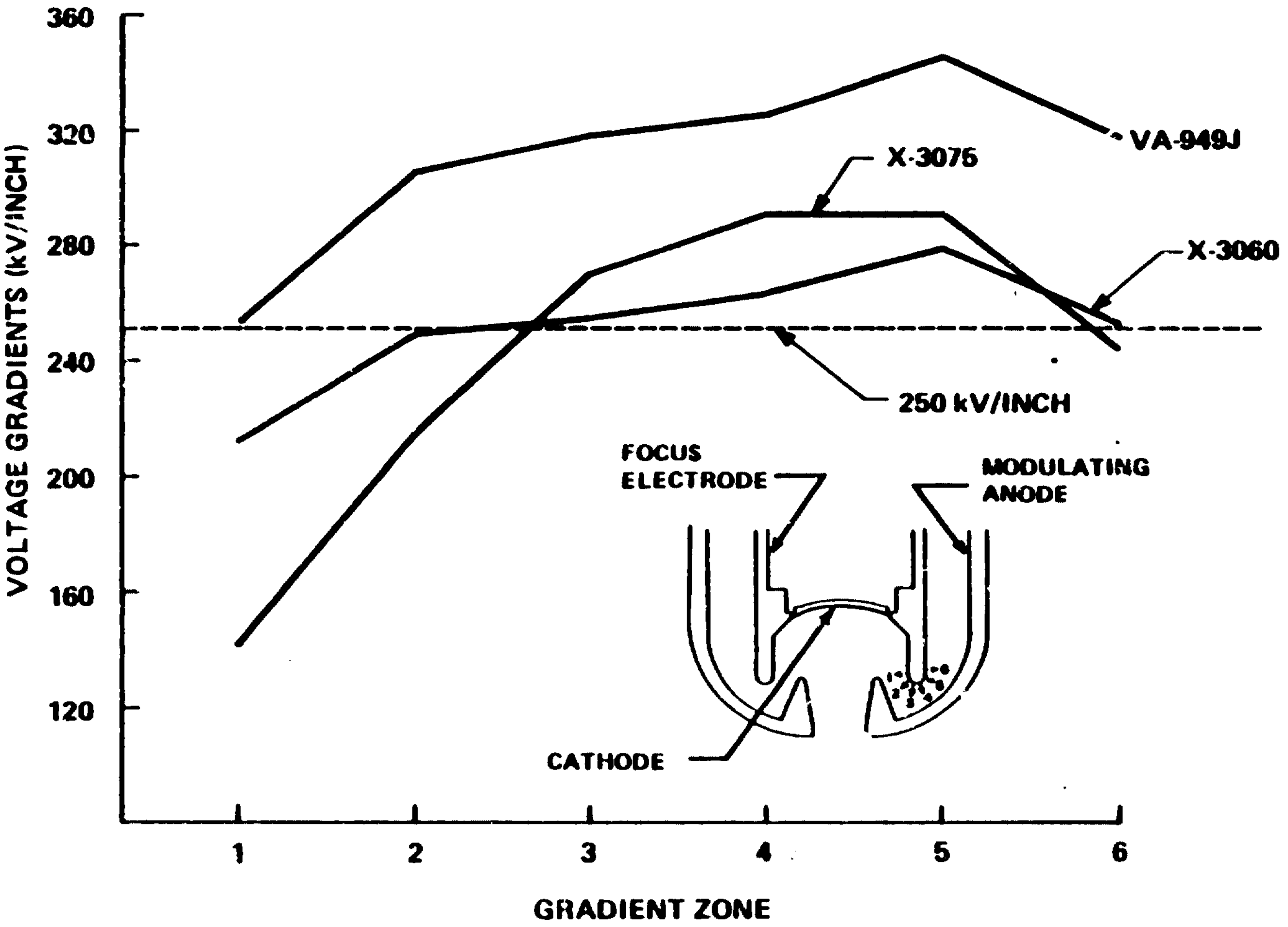
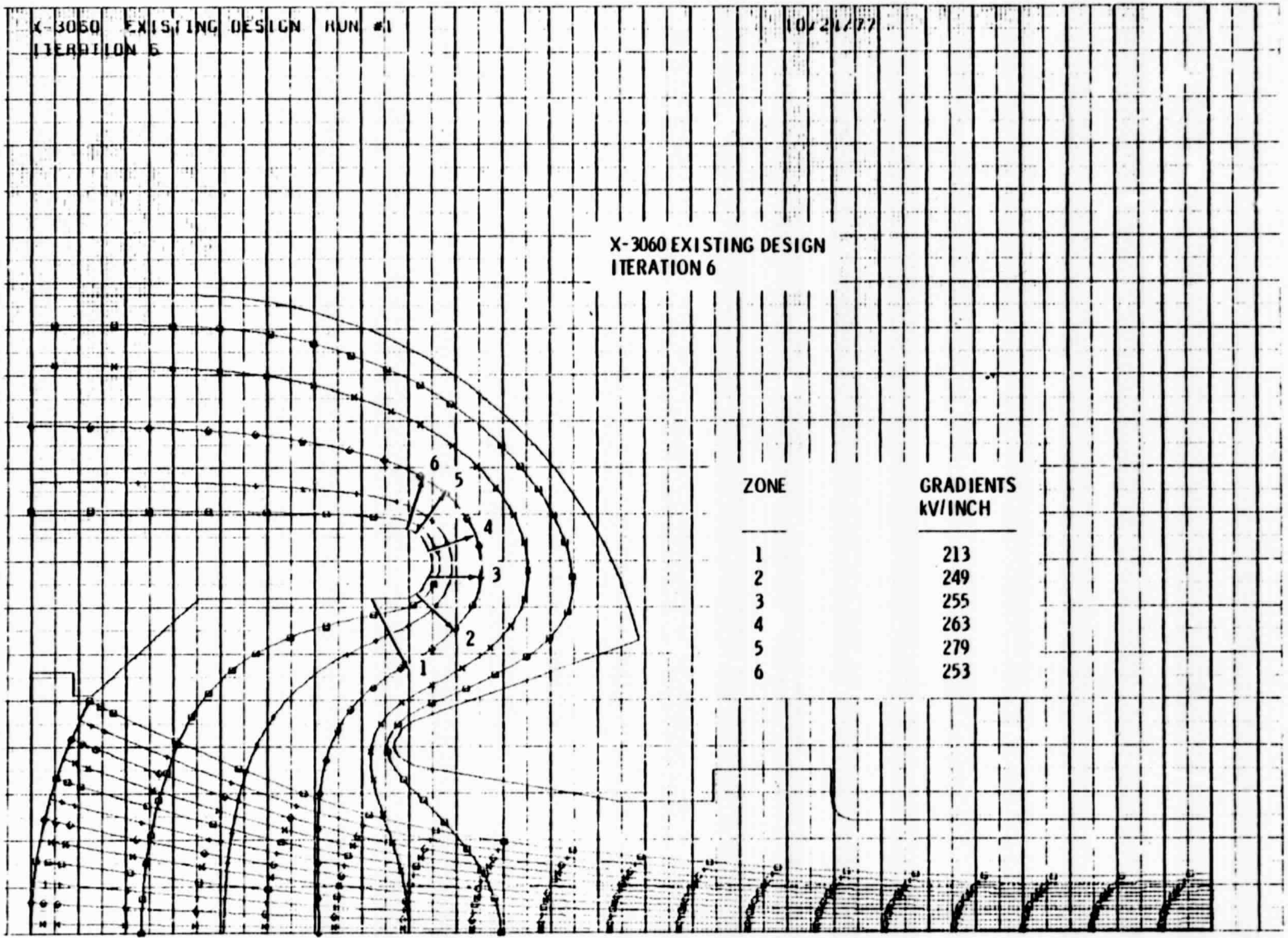


FIGURE II-2. THREE HIGH VOLTAGE GUNS COMPARED



ZONE	GRADIENTS kV/INCH
1	213
2	249
3	255
4	263
5	279
6	253

FIGURE II-3. X-3060 FIELD GRADIENTS

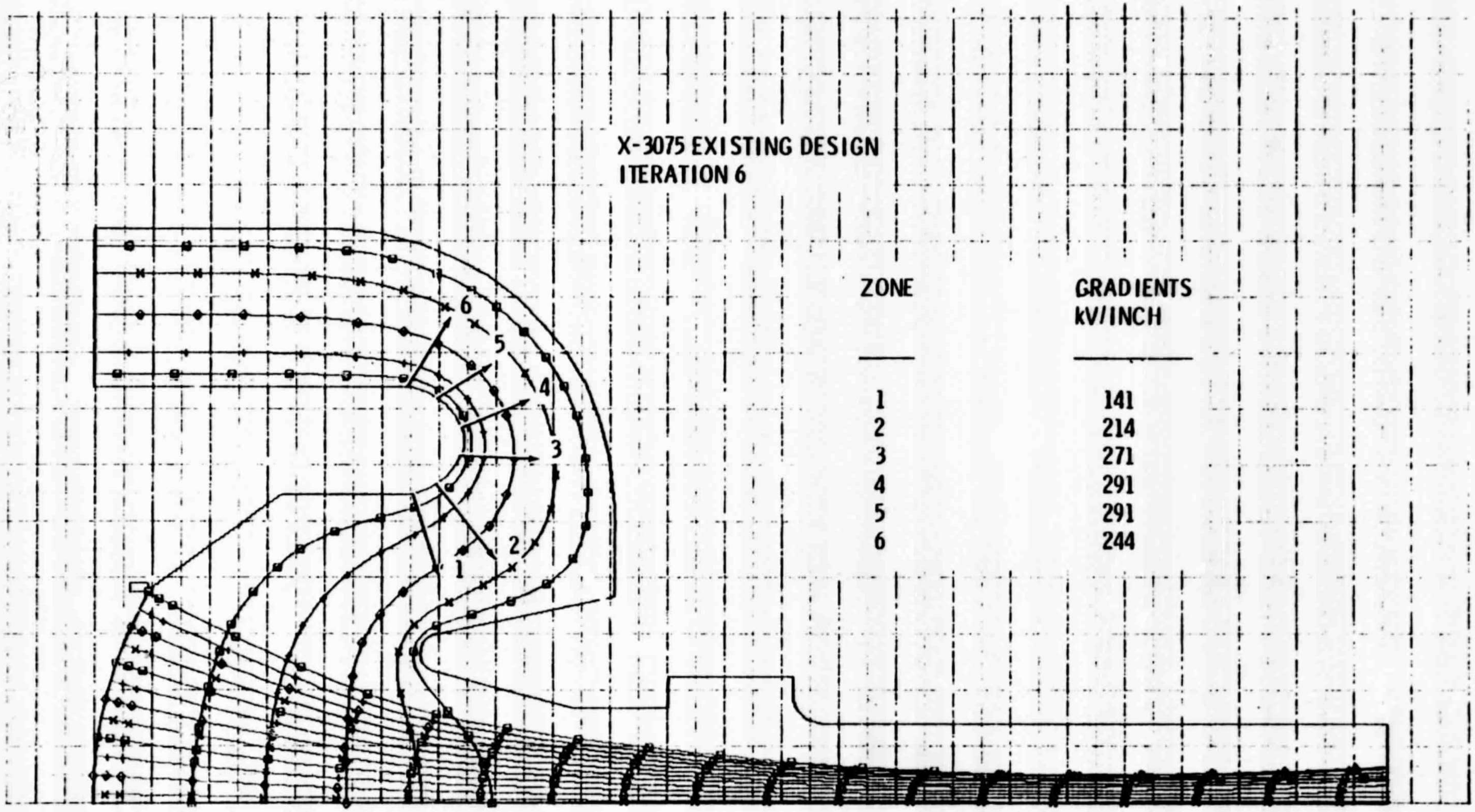


FIGURE II-4. X-3075 FIELD GRADIENTS

a. Neither the X-3060 or X-3075 guns should be as troublesome as the VA-949J with regard to arcing.

b. The X-3060 electron gun should be the least troublesome of the three designs.

c. Improvements should be made to both the X-3060 and X-3075 guns for improved reliability and reduced incidence to arcing.

The first two conditions can and have been substantiated by historical data gathered on the three tube types. As to the desired improvement, it can be accomplished only if the modulating anode can be eliminated. Elimination of the modulating anode is recommended in both the X-3060 and X-3075 to reduce the high voltage field gradients. The modulating anode function is more fully explained in the following section.

4. Modulating Anode

The modulating anode was originally introduced as a low μ nonintercepting grid for pulse applications. Coincidentally, it was found that the high impedance circuits associated with either modulating or biasing this anode provided an excellent protective mechanism for the physically delicate oxide cathodes used at that time.

In some applications, employing oxide cathodes, the modulating anode has been used only as a protective element. In other applications, this protective feature could be used unnecessarily to protect cathodes which require no such protection. For example, the X-3060 and X-3075 employ tungsten-impregnated cathodes. These cathodes are physically very rugged and simply do not need the protection required by oxide-coated cathodes. Additionally, very high-power klystrons, such as the X-3060 and X-3075, should be and are normally protected from the stored energy of the dc power supply by a "crow-bar" circuit. This crow-bar is used to protect the klystron from a number of fault conditions, one of which can be cathode arcs.

On the other hand, indiscriminate use of the modulating anode can incur an unnecessary penalty. It has been shown in a recent study of the high voltage gradients in the VA-949J electron gun, that a metallic element in the physical position normally occupied by the modulating anode seriously increases the voltage gradients in the electron gun.

Based on the VA-949J gradient study, a very close estimate can be made of the gradient improvement available by removing the modulating anode from the X-3060 and X-3075 klystrons. This estimate is shown in Figures II-5 and II-6 which compare gradients with and without the modulating anode.

It can be seen from these figures that a substantial improvement can be made by removal of the modulating anode. By the same reasoning, one may conclude that incorporation of the modulating anode may enhance gun arcing and create the situation it is used to protect against.

One final word on the modulating anode. The physical position of the modulating anode requires additional distance between the cathode and the main magnetic focusing field and generally makes shaping of the convergent magnetic field in the cathode region very difficult. Usually some compromise of the electron optics is accepted. In such high-power tubes as the X-3060 and X-3075 this compromise should be accepted only if absolutely necessary.

The information presented here on the modulating anode should enable JPL personnel to make proper decisions with regard to its use.

Elimination of the modulating anode from a design standpoint is definitely recommended.

B. RF STRUCTURE

1. Basic RF Design Parameters

An analysis of the rf design parameters of the X-3060 was made. The computer calculations for this analysis are shown here in Tables II-1a and II-1b.

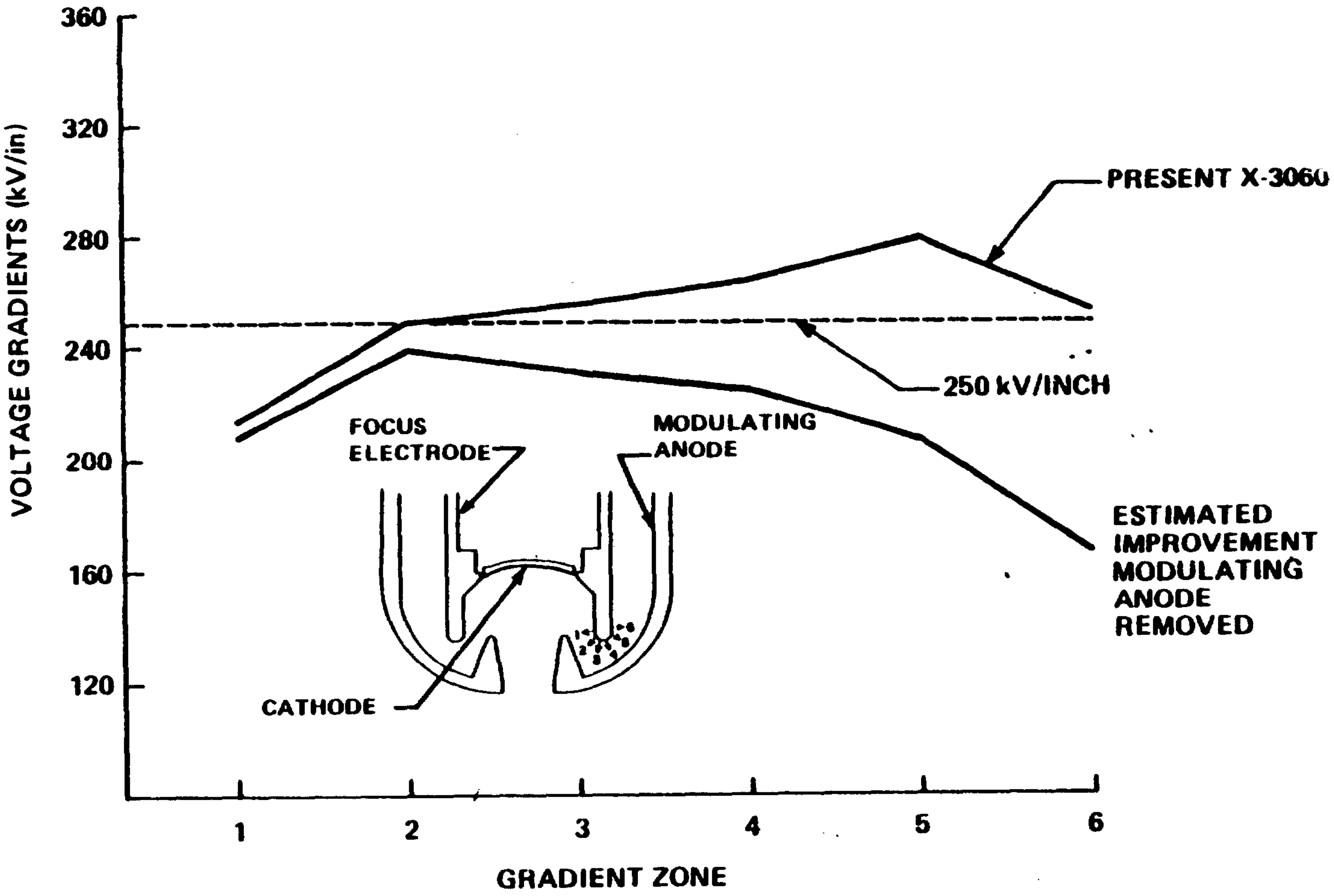


FIGURE II-5. X-3060 GRADIENT COMPARISON: MODULATING ANODE REMOVED

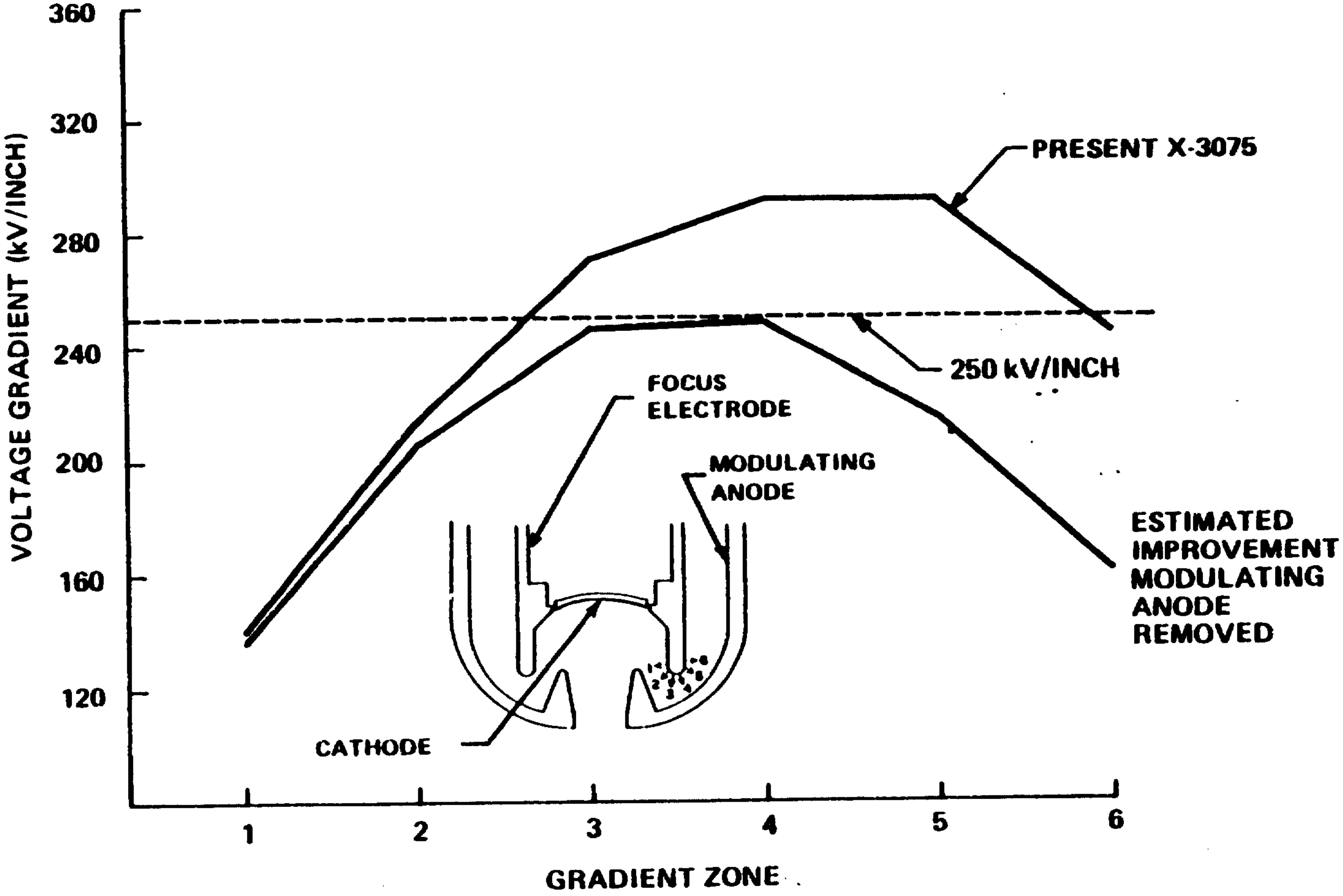


FIGURE II-6. X-3075 GRADIENT COMPARISON; MODULATING ANODE REMOVED

TABLE II-1a

X-3060

DESIGN CALCULATIONS

```
KLYSTRON DESIGN CALCULATIONS

VOLTAGE(KV)      =  36.0
K(MICROPERVS)    =  1.02
FREQUENCY(GHZ)   =  2.114
TUNNEL DIA(IN)   =  0.480
BEAM DIA(IN)     =  0.312
FOCUSSING TYPE   =  CONFINED

VO =  36.000 KV          VO/IO =  5167.1 OHMS      U/C = 0.3568
IO =   6.967 AMPS        IO/VO = 1.935E-04 MHOS    RCF = 1.0705
KO = 1.020 MICROPERVS    VO*IO = 250.817 KW

B/A = 0.6500        FO = 2.1140 GHZ          GAMMA   =  2.9466 RAD/IN
2A  = 0.4800 IN     GAMMA A = 0.7072 RAD     BETA E  =  3.1542 RAD/IN
2B  = 0.3120 IN     GAMMA B = 0.4597 RAD     BETA Q  =  0.2900 RAD/IN

WQ/WP =  0.2641     WP = 4.6245E+09 RAD/SEC   LAMBDA P = 5.7214 IN
W/WQ  = 10.8762     WQ = 1.2213E+09 RAD/SEC   LAMBDA Q =21.6652 IN

J BEAM =  14.12 AMPS/SQ CM   BRILLOUIN FIELD (REL.) =  397.9 GAUSS

CODE = 0
D(IN) = 0.300
L(IN) = 2.970
R/Q = 90.0

D =  .3000 IN    BED =  .9463 RAD,    54.22 DEG
L = 2.9700 IN    BQL =  .8613 RAD,    49.35 DEG

      M =   .8593          M+ =  .8330          M- =  .8842
 M(REL) =   .7754     M+(REL) =  .7517     M-(REL) =  .7979
*M(REL) =   .8163    *M+(REL) =  .7913    *M-(REL) =  .8399
*FOR GAIN-BANDWIDTH PROGRAM ONLY

R/Q =  90 OHMS   GB/GO =  0.10792   Q BEAM =  532
SINGLE STAGE GAIN: V2/V1 = 25.41,   DB GAIN =  28.10

CODE = 0
D(IN) = 0.300
L(IN) = 2.820
R/Q = 90.0

D =  .3000 IN    BED =  .9463 RAD,    54.22 DEG
L = 2.8200 IN    BQL =  .8178 RAD,    46.86 DEG
```

TABLE II-1b

X-3060 DESIGN CALCULATIONS (Con't)

```
      M =  .8593          M+ =  .8330          M- =  .8842
 M(REL) =  .7754     M+(REL) =  .7517     M-(REL) =  .7979
*M(REL) =  .8163    *M+(REL) =  .7913    *M-(REL) =  .8399
*FOR GAIN-BANDWIDTH PROGRAM ONLY

R/Q =  90 OHMS   GB/GO =  0.10792   Q BEAM =  532
SINGLE STAGE GAIN: V2/V1 = 24.44,   DB GAIN =  27.76

CODE = 0
D(IN) = 0.300
L(IN) = 2.820
R/Q = 90.0

D =  .3000 IN   BED =  .9463 RAD,   54.22 DEG
L = 2.8200 IN   BQL =  .8178 RAD,   46.86 DEG

      M =  .8593          M+ =  .8330          M- =  .8842
 M(REL) =  .7754     M+(REL) =  .7517     M-(REL) =  .7979
*M(REL) =  .8163    *M+(REL) =  .7913    *M-(REL) =  .8399
*FOR GAIN-BANDWIDTH PROGRAM ONLY

R/Q =  90 OHMS   GB/GO =  0.10792   Q BEAM =  532
SINGLE STAGE GAIN: V2/V1 = 24.44,   DB GAIN =  27.76

CODE = 0
D(IN) = 0.300
L(IN) = 1.655
R/Q = 90.0

D =  .3000 IN   BED =  .9463 RAD,   54.22 DEG
L = 1.6550 IN   BQL =  .4800 RAD,   27.50 DEG

      M =  .8593          M+ =  .8330          M- =  .8842
 M(REL) =  .7754     M+(REL) =  .7517     M-(REL) =  .7979
*M(REL) =  .8163    *M+(REL) =  .7913    *M-(REL) =  .8399
*FOR GAIN-BANDWIDTH PROGRAM ONLY

R/Q =  90 OHMS   GB/GO =  0.10792   Q BEAM =  532
SINGLE STAGE GAIN: V2/V1 = 15.46,   DB GAIN =  23.79

CODE = 0
D(IN) = 0.300
L(IN) = 1.655
R/Q = 90.0

D =  .3000 IN   BED =  .9463 RAD,   54.22 DEG
L = 1.6550 IN   BQL =  .4800 RAD,   27.50 DEG

      M =  .8593          M+ =  .8330          M- =  .8842
 M(REL) =  .7754     M+(REL) =  .7517     M-(REL) =  .7979
*M(REL) =  .8163    *M+(REL) =  .7913    *M-(REL) =  .8399
*FOR GAIN-BANDWIDTH PROGRAM ONLY

R/Q =  90 OHMS   GB/GO =  0.10792   Q BEAM =  532
SINGLE STAGE GAIN: V2/V1 = 15.46,   DB GAIN =  23.79
```

Compared to more modern designs, the X-3060 design can be considered only fair. Current knowledge, coupled with more sophisticated large-signal computer programs, can raise the operating efficiency of the X-3060 from a nominal 45% to the mid 50% range without radical overhaul of the basic design.

In order to more fully exploit design improvements, it is suggested that the tuning range requirement (2114 - 2388 MHz) be eliminated, if possible. If operation at both end frequencies is required, but operation in the range between the two frequencies is not, then a two-tube approach can be employed. Each tube could be optimized electrically, but be constructed in such a way as to be physically interchangeable.

The two-tube approach has two advantages. It permits optimization of electrical design at each frequency and eliminates the need for wide-range cavity tuners. Wide-range tuners invariably detract from the reliability of very high power klystrons.

The obvious disadvantage is that both tube types would have to be available at those sites operating at two frequencies.

This suggestion is presented here for JPL consideration only. A reliable tube can be built with a tuning range of 2114 - 2388 MHz.

The analysis of the X-3075 design parameters did not show the deficiencies seen in the X-3060 design. Drift tube diameters, gap spacings and drift tube lengths are very nearly optimum. A few minor changes can be made to obtain optimum efficiency, but the basic design is sound. The X-3075 operates at a single frequency and uses only "trim" tuners, historically reliable in this and other designs. Design calculations for the X-3075 are included here in Tables II-2a and II-2b.

No design improvement program would be complete without consideration of the 2nd harmonic bunching techniques introduced by Mr. Erling Lien, of Varian.[1]

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[1] E. L. Lien, <u>High Efficiency Klystron Amplifiers</u>, MOGA Conference Proceedings, pp 11-21 to 11-27, September 1970.

TABLE II-2a

X-3075

DESIGN CALCULATIONS

```
KLYSTRON DESIGN CALCULATIONS

VOLTAGE(KV)    =  65.0
K(MICROPERVS)  =  1.0
FREQUENCY(GHZ) =  2.110
TUNNEL DIA(IN) =  0.570
BEAM DIA(IN)   =  0.370
FOCUSSING TYPE =  CONFINED

VO =  65.000 KV          VO/IO =  3922.3 OHMS      U/C = 0.4615
IO = 16.572 AMPS         IO/VO = 2.550E-04 MHOS    RCF = 1.1272
KO = 1.000 MICROPERVS    VO*IO =1077.168 KW

B/A = 0.6491      FO = 2.1100 GHZ        GAMMA   =  2.1594 RAD/IN
2A  = 0.5700 IN   GAMMA A = 0.6154 RAD   BETA E  =  2.4341 RAD/IN
2B  = 0.3700 IN   GAMMA B = 0.3995 RAD   BETA Q  =  0.2084 RAD/IN

WQ/WP =  0.2319   WP = 4.8939E+09 RAD/SEC   LAMBDA P = 6.9929 IN
W/WQ  = 11.6808   WQ = 1.1350E+09 RAD/SEC   LAMBDA Q =30.1525 IN

J BEAM =  23.89 AMPS/SQ CM   BRILLOUIN FIELD (REL.) =  443.4 GAUSS

CODE = 0
D(IN) = 0.414
L(IN) = 5.460
R/Q = 140.0

D =  .4140 IN   BED = 1.0077 RAD,   57.74 DEG
L = 5.4600 IN   BQL = 1.1378 RAD,   65.19 DEG

      M =  .8719          M+ =  .8461          M-  =  .8944
 M(REL) =  .7272    M+(REL) =  .7074     M-(REL) =  .7460
*M(REL) =  .7963   *M+(REL) =  .7746    *M-(REL) =  .8169
*FOR GAIN-BANDWIDTH PROGRAM ONLY

R/Q = 140 OHMS   GB/GO =  0.09821   Q BEAM =  285
SINGLE STAGE GAIN: V2/V1 = 34.15,   DB GAIN =  30.67

CODE = 0
D(IN) = 0.414
L(IN) = 5.460
R/Q = 140.0

D =  .4140 IN   BED = 1.0077 RAD,   57.74 DEG
L = 5.4600 IN   BQL = 1.1378 RAD,   65.19 DEG
```

TABLE II-2b

X-3075 DESIGN CALCULATIONS (cont'd)

```
      M =   .8719          M+ =   .8481          M- =   .8944
 M(REL) =   .7272     M+(REL) =   .7074     M-(REL) =   .7460
*M(REL) =   .7963    *M+(REL) =   .7746    *M-(REL) =   .8169
*FOR GAIN-BANDWIDTH PROGRAM ONLY

R/Q = 140 OHMS   GB/GO =  0.09821   Q BEAM =  285
SINGLE STAGE GAIN: V2/V1 = 34.15,   DB GAIN =  30.67

CODE = 0
D(IN) = 0.414
L(IN) = 5.028
R/Q = 140.0

D =  .4140 IN   BED = 1.0077 RAD,   57.74 DEG
L = 5.0280 IN   BQL = 1.0477 RAD,   60.03 DEG

      M =   .8719          M+ =   .8481          M- =   .8944
 M(REL) =   .7272     M+(REL) =   .7074     M-(REL) =   .7460
*M(REL) =   .7963    *M+(REL) =   .7746    *M-(REL) =   .8169
*FOR GAIN-BANDWIDTH PROGRAM ONLY

R/Q = 140 OHMS   GB/GO =  0.09821   Q BEAM =  285
SINGLE STAGE GAIN: V2/V1 = 32.60,   DB GAIN =  30.26

CODE = 0
D(IN) = 0.331
L(IN) = 2.785
R/Q = 100.0

D =  .3310 IN   BED =  .8057 RAD,   46.16 DEG
L = 2.7850 IN   BQL =  .5803 RAD,   33.25 DEG

      M =   .8926          M+ =   .8721          M- =   .9121
 M(REL) =   .7446     M+(REL) =   .7274     M-(REL) =   .7608
*M(REL) =   .8152    *M+(REL) =   .7965    *M-(REL) =   .8330
*FOR GAIN-BANDWIDTH PROGRAM ONLY

R/Q = 100 OHMS   GB/GO =  0.08693   Q BEAM =  451
SINGLE STAGE GAIN: V2/V1 = 24.44,   DB GAIN =  27.76

CODE = 0
D(IN) = 0.331
L(IN) = 2.785
R/Q = 100.0

D =  .3310 IN   BED =  .8057 RAD,   46.16 DEG
L = 2.7850 IN   BQL =  .5803 RAD,   33.25 DEG

      M =   .8926          M+ =   .8721          M- =   .9121
 M(REL) =   .7446     M+(REL) =   .7274     M-(REL) =   .7608
*M(REL) =   .8152    *M+(REL) =   .7965    *M-(REL) =   .8330
*FOR GAIN-BANDWIDTH PROGRAM ONLY

R/Q = 100 OHMS   GB/GO =  0.08693   Q BEAM =  451
SINGLE STAGE GAIN: V2/V1 = 24.44,   DB GAIN =  27.76
```

This approach, however, is radical enough to be considered outside the scope of Phase I: Study Definition, and will be more properly addressed during Phase II of the study program: Design Improvement.

It is the author's suggestion that development of a high-efficiency, high-reliability klystron be established in two stages, establishing first this efficiency and reliability by conventional design and then advancing to the less certain performance of further increased efficiency.

2. Cavity Tuners

Experience with high-power, high-frequency wide-band cavity tuners has shown that numerous failures have occurred as a result of using these tuners in klystron designs. Some of the reasons for unreliable behavior are given below.

a. The tuner is normally subjected to high rf fields, the consequence of which is high rf loss and subsequent thermal stress.

b. Because of size limitations at high frequencies, coolant passages within the tuner are necessarily small and subject to blockage.

c. The tuner can easily be subjected to mishandling and mist[illegible]ients caused by inexperienced personnel.

d. Because of inherent fragility and complexity, it presents a problem with regard to its vacuum integrity both during its initial construction and/or subsequent rebuilding operations.

Since this study is directed to the design and development of a klystron with improved reliability, it is recommended that the wide-range tuning requirement of the X-3060 be eliminated, if possible.

To repeat, the X-3075 is a single-frequency device and no recommendation is necessary.

3. Tailpipe Design

Without question, the most obviously deficient component of the X-3060 and X-3075 designs is the "tailpipe." The term "tailpipe" refers to that region just beyond the output cavity drift tube gap. It can also be called the downstream output drift tube. This region can be seen diagrammatically in Figure II-7.

The configuration shown in Figure II-7 was first introduced in 1965. Its purpose was to minimize the asymmetry normally caused by the exit path of the output waveguide through the focusing magnet, and reduce to an absolute minimum body current interception caused by the magnetic asymmetry. Shown in Figure II-8 is the conventional method of coupling the output waveguide to the output cavity. It does, in fact, create a magnetic unbalance because a large notch is required either in the focusing coil or magnetic iron to provide the waveguide egress.

The configuration shown in Figure II-7 eliminates the asymmetry by providing a path for the output waveguide through a hole in the output polepiece symmetric with the electron-beam axis. Mechanical considerations, however, create an extended tailpipe section, which is exposed to the rapidly expanding electron beam just beyond the output gap. It is this extended section which has created both direct and directly related failures in both the X-3060 and X-3075 klystrons.

The basic problem is created because it is impossible to predict the action of the electron beam in the tailpipe region. For this reason, the tailpipe section in both the X-3060 and X-3075 klystrons intercepts as much as 10% of the electron beam when operating at rated rf power output. Since the tailpipe is electrically part of the klystron body, this tailpipe intercept current shows as body current. This body current can be as high as 1.5 A in the X-3075, contrasted to a nominal 0.3% interception expected in a conventional design (0.045 A in 15 A). A current interception of 1.5 A in the tailpipe region completely masks body current interception in any other part of the rf structure. In short, a properly conceived design approach created an unexpected and unacceptable result. The high body current situation is unacceptable because it

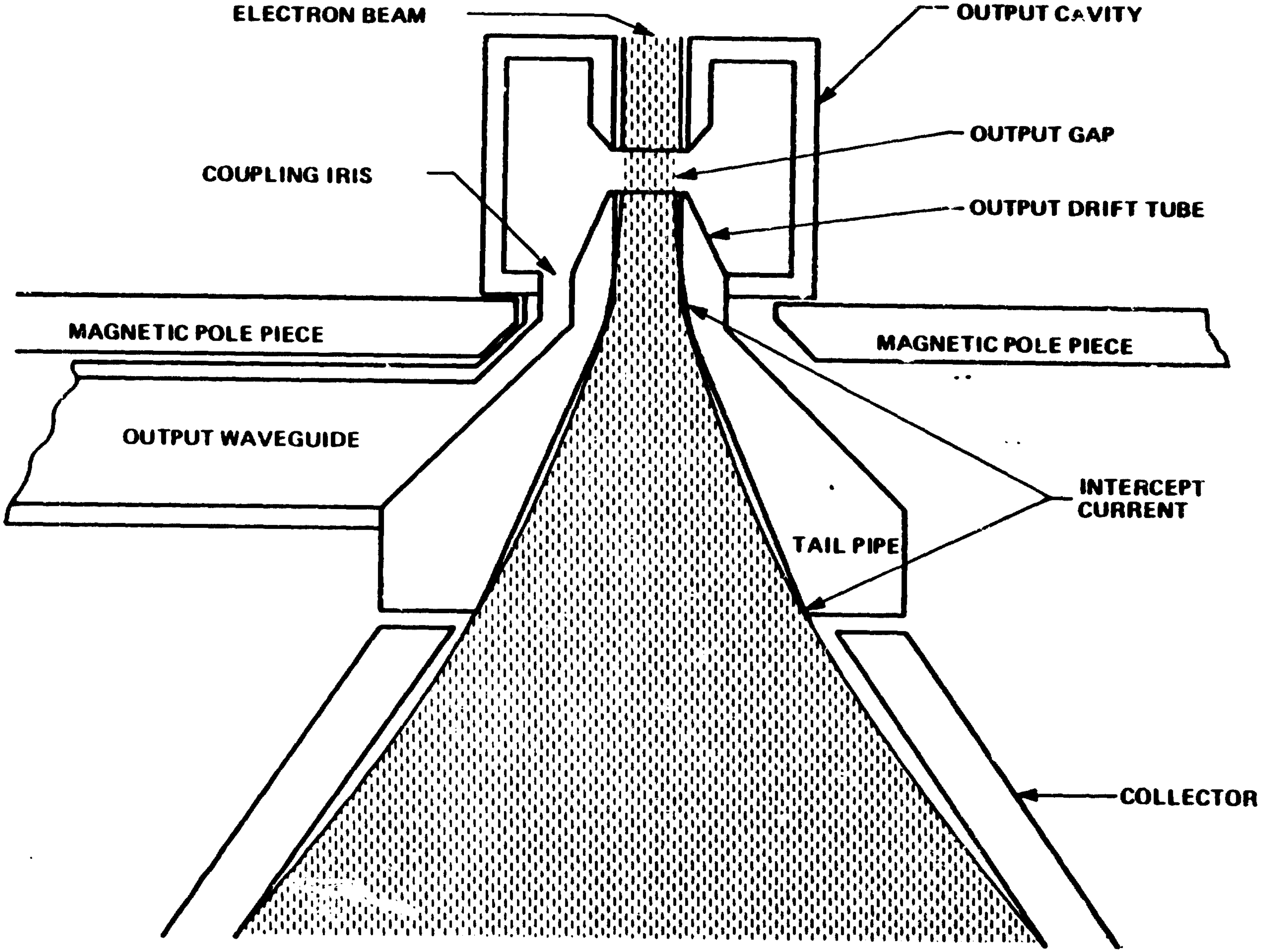

FIGURE II-7. X-3060 X-3075 OUTPUT CIRCUIT SHOWING EXTENDED TAILPIPE

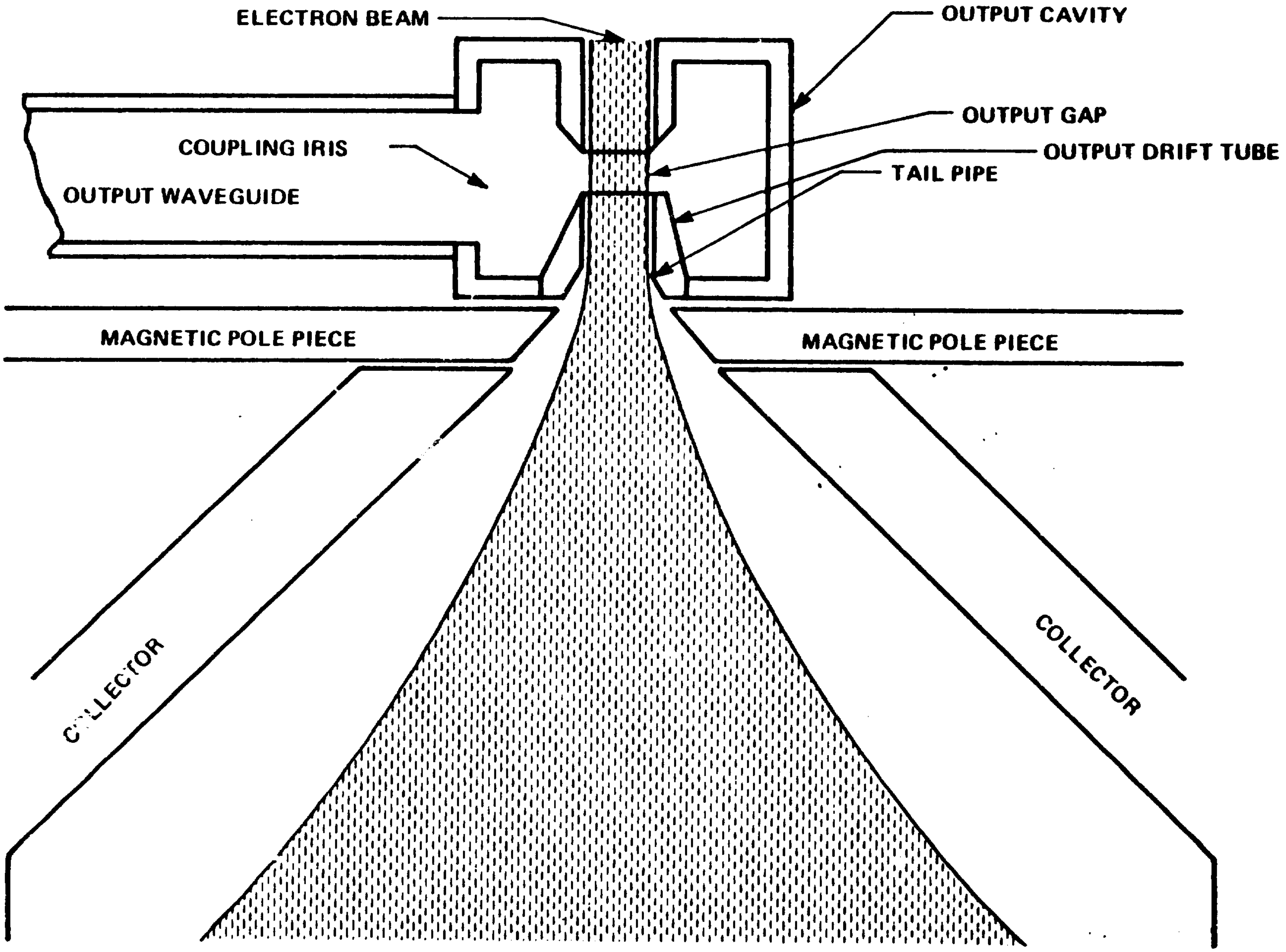

FIGURE II-8. CONVENTIONAL OUTPUT CIRCUIT requires that body current protective circuit trip levels be set too high (1.5 to 2.0 A). This removes the protection required in the remainder of the rf structure, which may suffer damage from relatively low-quantity (0.050 A) but high-velocity electrons.

Under the circumstances just described, protection cannot be provided for the following common field conditions:

a. low or incorrectly adjusted magnetic field;

b. incorrect tuning;

c. overdrive;

d. stray magnetic fields (gun region);

e. disturbance of the main magnetic field by accidental introduction of ferrous materials (screwdrivers, wrenches, etc.).

Elimination of the extended tailpipe design is not only recommended, it is a mandatory condition for reliability.

Referring to Figure II-7 and Figure II-8, it can be seen that in reverting to the conventional output circuit the tailpipe interception current is transferred to the collector, and body current readings return to normal. The magnetic asymmetry inherent in the conventional design can and has been reduced to a negligible degree in recent designs.

4. Tube Structure/Magnet Alignment

The rigidity of the rf structure in both the X-3060 and X-3075 is somewhat marginal and although no failures can be attributed to this deficiency, structural stiffeners will be employed in new designs.

The method of alignment of the X-3060 klystron in its focusing magnet has been somewhat deficient, but this matter has already been corrected on a magnet ready for delivery to JPL at the time of this writing. No further action will be required.

C. COLLECTOR

Shown in Figure II-9 are power density vs length plots for the X-3060 and X-3075 collectors.

Also shown is a reference level which the author considers a conservative goal line.

The X-3060 collector is not a candidate for redesign with regard to power density; whereas, the X-3075 can be considered marginal and redesign is recommended. The redesign for decreased power density is quite straightforward and presents no major problems although the collector may become physically larger.

Both the X-3060 and X-3075 collectors will have to be modified mechanically to afford compatibility with the recommended change in the tailpipe configuration (see Figures II-7 and II-8).

D. MAGNET

The basic design of the X-3060 and X-3075 magnets is satisfactory. Magnet failures were experienced during the development of the X-3075, and severe damage was inflicted on the klystrons, but the fault was one of manufacture rather than design. Vendors engaged to build magnetic circuits for Varian at the present time produce an extremely reliable product, and therefore no change in the basic coil design is recommended. As previously mentioned, a fix for the tube/magnet alignment problem has already been implemented in the X-3060 magnet assembly.

Modifications will have to be made, however, at the collector end of the magnet assembly to provide exit means for the output waveguide, assuming, of course, the recommended tailpipe redesign is implemented.

The use of at least three independently variable magnet power supplies at operational sites is strongly recommended for the following reasons: 1. Optimized power and lowest possible body intercept currents are obtainable with individual

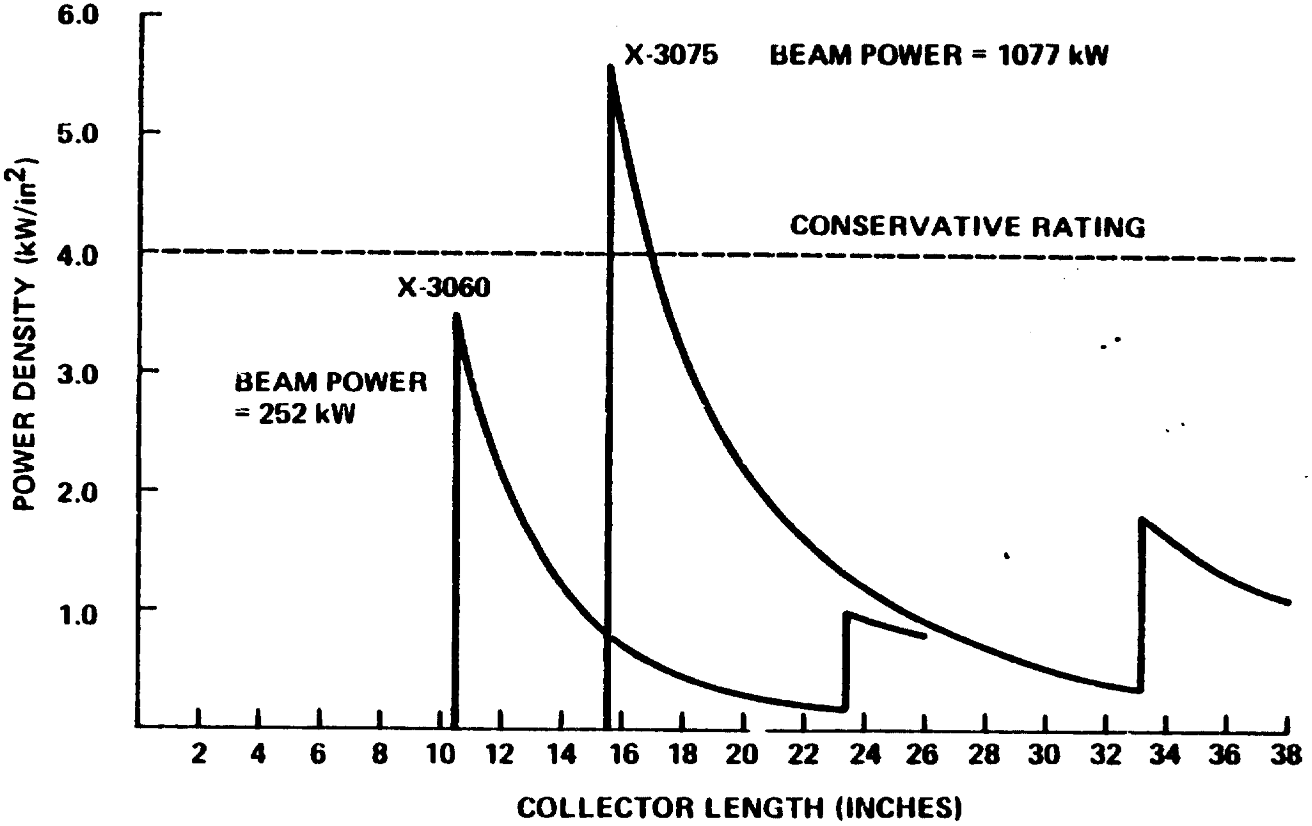

FIGURE II-9. POWER DENSITY vs. LENGTH X-3075 and X-3060 COLLECTORS.

control; and 2. redundant protection is afforded in the event of one magnet supply failure; i. e., under dc conditions and/or with less than saturation drive power, many klystrons will run well with 2/3 of their focusing field.

E. HISTORY AND FAILURE REPORTS

An objective of Phase I was the examination of failure reports of both the X-3060 and X-3075 klystrons to identify any possible design weaknesses. The chronological history of each tube developed from that examination is presented here in Tables II-3 and II-4.

Except for several random failures; i.e., two vacuum leaks, one water leak and one window failure at Varian, all other areas of concern have been addressed in the design analysis presented in the foregoing paragraphs. For added clarity, the damage suffered by both the X-3060 and X-3075 klystrons is summarized by the bar graph presentations of Figures II-10 and II-11.

Of the twenty-one incidents of failure shown in Figures II-10 and II-11, it is likely that eleven (52.4%) could have been prevented if the extended tailpipe was not involved and proper body current monitoring had been possible. A listing of the eleven failures is given below:

1.	Mistuning damage	(2)	X-3060
2.	Drift tube melting	(4)	X-3075
3.	Poor bandpass	(3)	X-3075 (probable melting)
4.	Tailpipe melting	(2)	X-3075

It is logical that the majority of these failures were incurred by the X-3075 because of the 5.0 to 1.0 power level difference between the X-3075 and the X-3060. However, the 100 kW operating-power level of the X-3060 cannot be considered low by any standards of present technology and continued production of this design in its present form is risky at best.

TABLE II-3

X-3060 HISTORY

Serial No. H5-30

October 1965	First Test and Shipment to JPL
July 1966	Returned to Varian. Penultimate tuner melted due to overdrive. No record of repair or re-shipment.
November 1973	Returned to Varian for poor vacuum. Found collector braze leak. Noted heater deterioration.
June 1974	Repaired and returned to JPL with new potted heater design.
January 1975	Water leak reported at JPL. Repaired at JPL.
October 1975	Thermal drift reported at site (Australia).
March 1976	Tube returned to Varian. Poor vacuum. Found ceramic to metal braze leak in collector insulator.
July 1976	Repaired and returned to JPL.

Serial No. J5-24

November 1965	First Test and Shipment to JPL.
June 1974	No failure. Returned to Varian for heater design modification.
September 1974	Tube returned to JPL.
December 1974	Tube returned to Varian with heater short.
May 1975	Tube repaired but window failure at Varian on re-test.
September 1975	Tube repaired and returned to JPL.

Serial No. K5-24

December 1965	First Test and Shipment to JPL
July 1974	No failure. Returned to Varian for heater design modification.
November 1974	Returned to JPL with new heater design.

TABLE II-3 (Cont'd)

Serial No. L5-3

December 1965	First Test and Shipment to JPL
June 1974	No failure. Returned to Varian for heater design modification.
September 1974	Returned to JPL with new heater design.

Serial No. L5-34

January 1966	First Test and Shipment to JPL
December 1973	No failure. Returned to Varian for heater design modification.
June 1974	Returned to JPL with new heater design.

Serial No. A6-17

January 1966	First Test and Shipment to JPL
October 1970	Penultimate cavity drift tubes melted due to mis-tuning.
September 1971	Test data taken. Probable return to JPL.
June 1974	No failure. Tube returned to Varian for heater design modification.
November 1974	Tube returned to JPL with new heater design.

TABLE II-4

X-3075 HISTORY

Serial No. G9-25

July 1969	First Test and Shipment to JPL.
January 1970	Returned to Varian for poor bandpass response.
April 1970	Retuned and returned to JPL.
April 1972	Returned to Varian. Examination showed magnet failure caused internal tube damage.
April 1973	Tube returned to JPL after repair and collector re-design tubes with new collector designated X-3075A.
July 1973	Tube returned to Varian for poor bandpass response.
October 1973	Found bent input connector. Attempt to straighten caused tube to lose vacuum.
December 1973	Tube repaired and returned to JPL
March 1974	Tube returned to Varian for gun arcing.
August 1974	Tube repaired and returned to JPL.
May 1975	Tube returned to Varian for low power. Examination showed tube down to water. Tail-pipe and collector melting.
August 1975	Tube scrapped.

Serial No. 002

December 1969	First Test and Shipment to JPL.
November 1971	Tube returned to Varian. Examination showed magnet failure caused internal damage to drift tubes. Tube repaired and collector lengthened.
October 1972	Tube returned to JPL.
June 1973	Tube returned to Varian . Down to oil due to mishandling accidental at JPL.
December 1973	Tube repaired and returned to JPL
September 1975	Tube returned to Varian. Examination revealed internal drift tube damage. JPL found body current cable cut.
June 1976	Attempt to repair failed.
July 1976	Tube scrapped and returned to JPL.

TABLE II-4 (Cont'd)

<u>Serial No. H1-101 (X-3075A)</u>

September 1971	First Test and Shipment to JPL.
April 1973	Returned to Varian for heater short. Collector and tailpipe melting noted.
November 1973	Tube repaired and returned to JPL.
June 1974	Tube returned to Varian with apparent internal damage. Re-tuned, but had sub specification performance.
February 1975	Tube returned to JPL.
March 1976	Tube returned to Varian with shorted heater.
July 1976	Tube returned to JPL "AS IS"

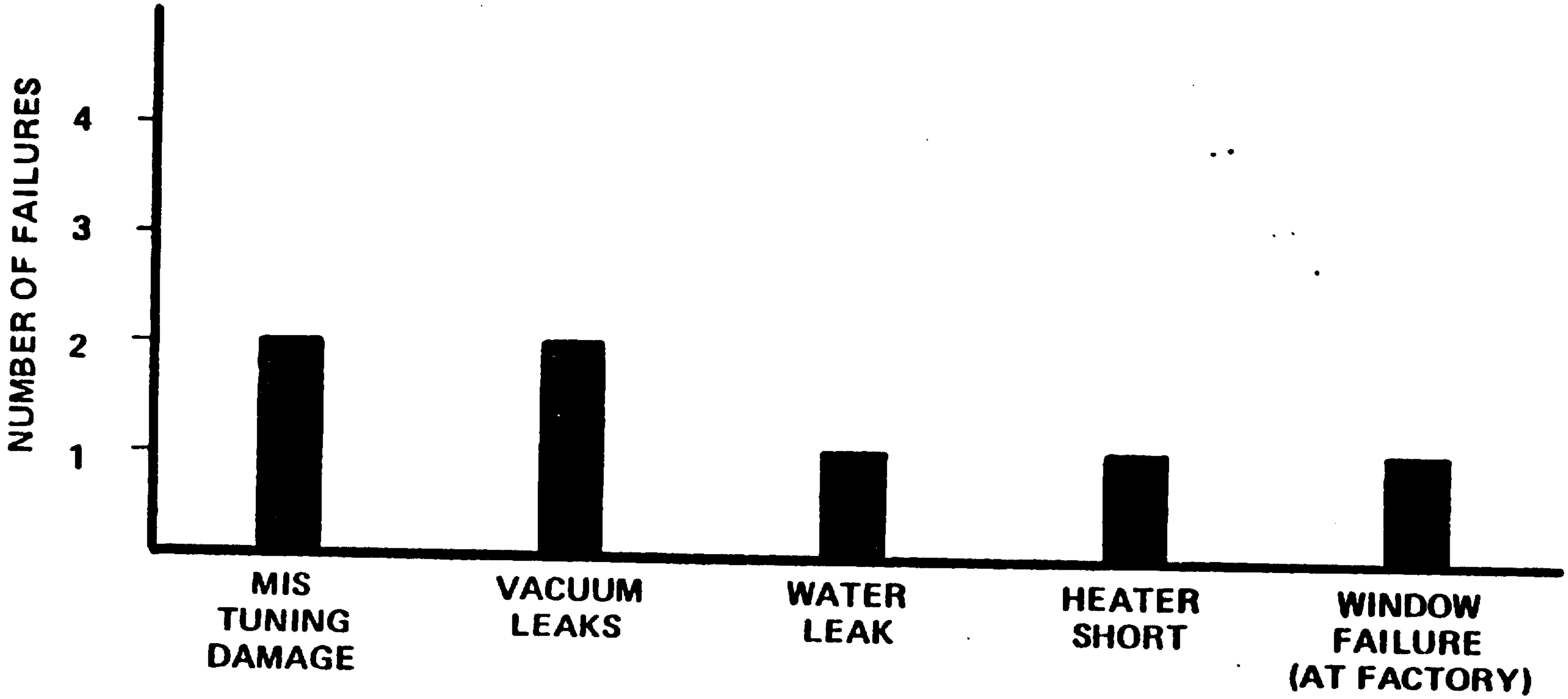

FIGURE II-10.X-3060 DAMAGE SUMMARY

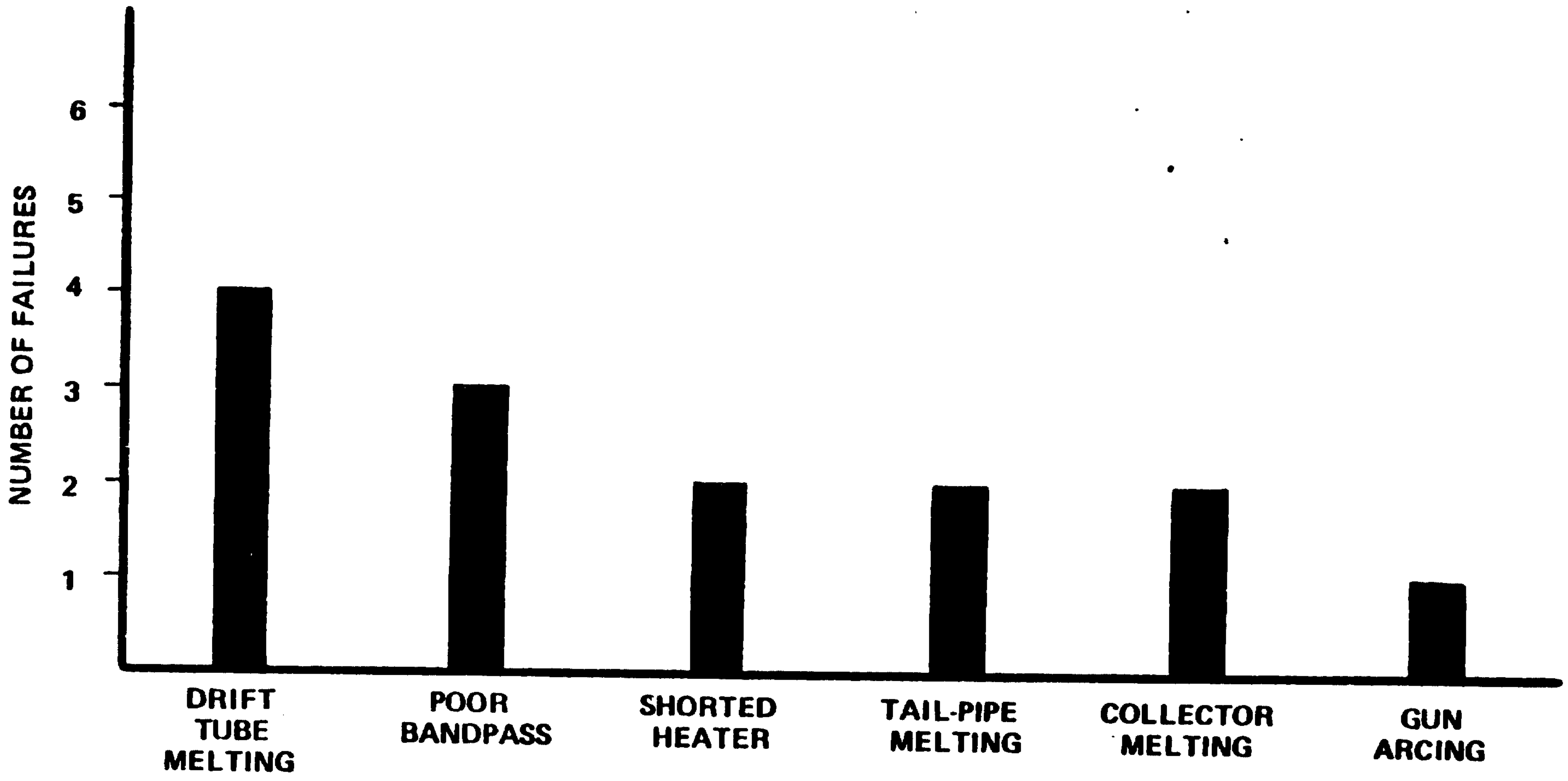

FIGURE II-11. X-3075 DAMAGE SUMMARY

F. DESIGN EVALUATION SUMMARY AND RECOMMENDATIONS

Tables II-5 and II-6 present in summary the design evaluations and recommendations discussed in the preceding paragraphs.

It is the author's conclusion that if the redesign recommendations are implemented, improved and reliable performance can be achieved in both the X-3060 and X-3075 klystrons.

TABLE II-5
X-3060
DESIGN EVALUATION SUMMARY

PARAMETER	RATING/COMMENTS	RECOMMENDATIONS
A. ELECTRON GUN		
1. CATHODE/FILAMENT	GOOD	MAINTAIN
2. CATHODE LOADING	EXCELLENT	MAINTAIN
3. VOLTAGE GRADIENTS	FAIR	RE-DESIGN
4. MODULATING ANODE	UNNECESSARY	ELIMINATE
B. KLYSTRON BODY		
1. TAIL PIPE	UNACCEPTABLE	RE-DESIGN
2. TUBE/MAGNET ALIGNMENT	MARGINAL	RE-DESIGN (ACCOMPLISHED)
3. TUNERS	DISADVANTAGEOUS	RE-DESIGN
4. HIGHER EFFICIENCY	PRACTICAL	RE-DESIGN
5. R.F. DESIGN PARAMETERS	FAIR	RE-DESIGN
6. MECHANICAL RIGIDITY	MARGINAL	RE-DESIGN
C. MAGNET		
1. TUBE/MAGNET ALIGNMENT	MARGINAL	RE-DESIGN (ACCOMPLISHED)
2. INDIVIDUAL CONTROL OF COILS		RECOMMENDED
3. MAGNET ASSEMBLY	NOT COMPATIBLE (NEW TAILPIPE DESIGN)	RE-DESIGN

TABLE II-6

X-3075

DESIGN EVALUATION SUMMARY

PARAMETER	RATING/COMMENT	RECOMMENDATION
A. ELECTRON GUN		
1. CATHODE/FILAMENT	FAIR	RE-DESIGN
2. CATHODE LOADING	EXCELLENT	MAINTAIN
3. VOLTAGE GRADIENTS	HIGH	RE-DESIGN
4. MODULATING ANODE	UNNECESSARY	ELIMINATE
B. KLYSTRON BODY		
1. TAILPIPE	UNACCEPTABLE	RE-DESIGN
2. MECHANICAL TUBE RIGIDITY	MARGINAL	RE-DESIGN
3. TUBE/MAGNET ALIGNMENT	ACCEPTABLE	MAINTAIN
4. RF DESIGN PARAMETERS	EXCELLENT	MAINTAIN
C. COLLECTOR		
1. COLLECTOR ASSEMBLY	NOT COMPATIBLE (NEW TAIL PIPE DESIGN)	RE-DESIGN
2. POWER DENSITY	MARGINAL	RE-DESIGN
D. MAGNET		
1. TUBE/MAGNET ALIGNMENT	ACCEPTABLE	MAINTAIN
2. INDIVIDUAL CONTROL OF COILS		RECOMMENDED
3. MAGNET ASSEMBLY	NOT COMPATIBLE (NEW TAIL PIPE DESIGN)	RE-DESIGN

III. NEW TECHNOLOGY

No reportable items of new technology have been identified.

IV. PHASES II, III AND IV COST ESTIMATES

A. X-3060 KLYSTRON

1. Phase II Design Improvement

Estimated price: $55,000

Length of program: 6 months

2. Phase III Electron Gun and Beam Analyzer Evaluation

Estimated price: $60,000

Length of program: 6 months

3. Phase IV Klystron Prototype Fabrication and Delivery

Estimated price: $225,000

Length of program: 15 months

B. X-3075 KLYSTRON

1. Phase II Design Improvement

Estimated price: $60,000

Length of program: 6 months

2. Phase III Electron Gun and Beam Analyzer Evaluation

Estimated price: $60,000

Length of program: 6 months

3. Phase IV Klystron Prototype Fabrication and Delivery

Estimated price: $325,000

Length of program: 16 months