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May 1964

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PRODUCTION ENGINEERING MEASURE
FOR A
K α -BAND INVERTED COAXIAL MAGNETRON

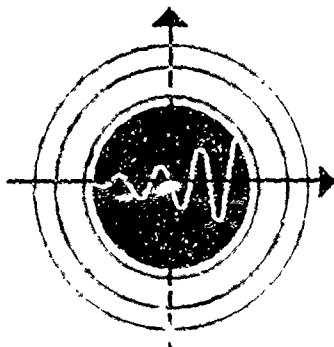
Report No. 4

Fourth Quarterly Progress Report
covering the period
7 February 1964 through 6 May 1964

Contract DA 36-039 AMC-01472(E)

Order No. 21047-PP-63

Industrial Preparedness
U.S. Army Electronic Materiel Agency
225 South Eighteenth Street
Philadelphia, Pennsylvania



S • F • D laboratories, inc.

Union, New Jersey

S·F·D laboratories, inc.

PRODUCTION ENGINEERING MEASURE
for a
Ka-BAND INVERTED COAXIAL MAGNETRON

Fourth Quarterly Progress Report
covering the period
7 February 1964 through 6 May 1964

Object: To conduct a program for a Production Engineering Measure in accordance with Steps I and II of Signal Corps Industrial Preparedness Procurement Requirement No. 15 for an Inside Out Circular Electric Mode Magnetron

Contract DA 36-039 AMC-01472(E)

Order No. 21047-PP-63

Report prepared by: P. du Fosse
G. Glenfield

Report approved by: W. R. Lundberg

ABSTRACT

During this report period, thirteen model tubes were built and evaluated, the results of which are presented.

Initial life test results are reported as are the results of the completed heater cycle life tests. The results of the anode evaluation program, which yielded high Q_u , broad band, low voltage anodes, are discussed.

Tubes which meet the primary electrical specifications and were delivered as the fifth and sixth engineering samples are described.

PURPOSE OF CONTRACT

The purpose of this contract is to conduct a program for a Production Engineering Measure (PEM) in accordance with Steps I and II of Signal Corps Industrial Preparedness Procurement Requirements No. 15 for an Inside Out Circular Electric Mode Magnetron.

This PEM program, to be performed by S-F-D laboratories' Microwave Tube Division, consists of three prime divisions of effort:

- Part I - Tube Development, Product Engineering and Manufacturing (Delivery of six each engineering samples)
- Part II - Establishment of Production Line (Delivery of four each preproduction samples)
- Part III - Production Run (Delivery of twenty each production units)

The objective specification for this program shall be in accordance with Signal Corps Technical Requirement SCS-171, dated 4 December 1962, a copy of which was included in the First Quarterly Progress Report.

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1.0 TECHNICAL INFORMATION AND PROGRESS

1.1 Phase II

1.1.1 General Description

Phase II of this contract deals with the procurement and prove in of the required test equipment. Included are the cold test station, a combined aging and final test set, a life test set, a special high sensitivity spectrum analyzer and a mismatch introducer. Areas not yet reported as being complete are reported below.

1.1.2 Spectrum Analyzer

A LaVoie, Model 18MY-2, high sensitivity spectrum analyzer was received in early April. This analyzer was obtained in order to provide the necessary sensitivity (better than 60 dbm at 35 Gc) while offering a 100 Mc dispersion for the purpose of analyzing 0.1 μ sec pulses. The unit is completely satisfactory.

1.2 Phase III

1.2.1 General Description

This phase covers all of the engineering and evaluation required to meet or to exceed the technical and performance specifications of the contract.

1.2.2 Anode Evaluation Program

The anode evaluation program has continued with prime interest in the areas of high Q_u and broad bandwidth. The early low voltage design anodes made late in the last quarter exhibited low overall Q_u 's. The increase in the number of resonators to 140 seemed to be the major reason for the low Q_u . As the number of resonators is increased while maintaining the same cavity diameter and vane tip diameter, the capacitance

per resonator increases as a function of $1/d$, d being the distance between vanes. This affects the L/C ratio and hence the resonator impedance, since L (the resonator inductance) is essentially unchanged. It is felt that this change results in reduced resonator coupling to the stabilizing cavity and thus lowers the Q_u . The coupling slots between resonators and cavity were then shortened by 0.010 inch to correct this condition and to again obtain the coupling coefficient used on the 120 vane resonator anodes. This met with considerable success and Q_u 's of greater than 2000 were obtained at the best frequency in the band.

In order that the operating models exhibit satisfactory magnetron operation across the entire frequency band of 33.9 Gc to 35.9 Gc, it is well understood that Q_u 's of greater than 1500 must be realized across that band. The early 140 resonator anodes fell far short of this criterion but the most recent anodes are very nearly meeting it. Figure 1 is a comparison of the Q_u 's obtained on the early and current 140 resonator anodes.

1.2.3 Tube Evaluation

During this report period, thirteen tubes were built and evaluated, two of which were shipped as engineering samples. The evaluation results are stated below in order of date of construction and are also tabulated in the interest of clarity in Table I.

Tube B9F - This tube was built with end hats of a different material than that employed in previous tubes. The purpose of the test was to establish whether or not the more thermally rugged molybdenum was equal to titanium with regard to leakage in a positively pulsed magnetron. Unfortunately, electrical evaluation revealed that a competing mode prevented satisfactory operation and thereby made end hat evaluation tests impossible.

Tube B20F - This tube was an engineering test vehicle to evaluate a modified magnetic pole tip configuration. This modification consisted of a pole tip outer diameter change of 0.022 inch which was designed to increase magnetic field uniformity and hence increase the

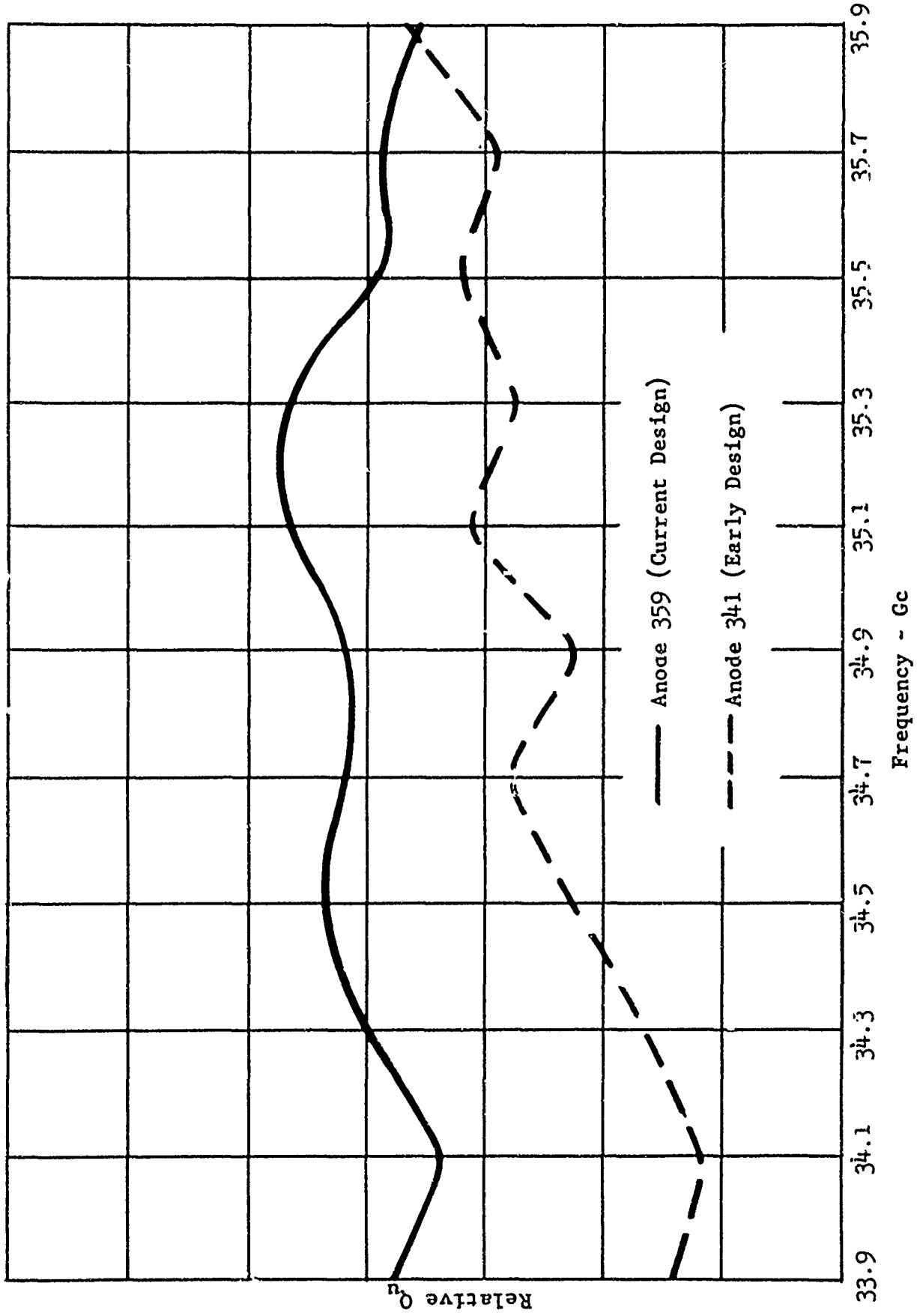


FIGURE 1 COMPARISON OF Q_u 's OBTAINED ON EARLY AND CURRENT 140 RESONATOR ANODES

Tube No.	t_p	D_u	E_{py}	P_o	Eff	f_o	Tuning Band	Results and Disposition
	μsec		kv	kw	%	Gc	Gc	
B9F	-	-	-	-	-	-	-	Mode competition prevented satisfactory operation
B20F	0.9	0.00048	19.1	74	18.7	35.02	-	Improved pole piece tip design yielded higher electronic efficiency
B22F	0.9	0.0005	17.0	20	15.0	34.9	-	Double absorber engineering test vehicle; essentially no improvement over single absorber
B36F	0.9	0.001	14.0	31	16.0	34.9	2.0	First 140 vane anode; good low voltage operation
C20F	1.0	0.0005	14.8	50	21.0	35.0	1.0	Second 140 vane anode; satisfactory low voltage operation
	0.09	0.0005	14.9	42	19.4	35.0		
C26F	0.83	0.0005	19.2	24	20.6	35.2	-	Off-center cathode
C42F	0.96	0.0004	17.5	75	21.0	34.9	-	Last high voltage anode
D4F	0.9	0.001	14.0	39	20.2	34.9	2.0	Fifth engineering sample
	0.1	0.0005	14.0	28	17.0	34.9	1.8	
D8F	0.9	0.0005	14.5	50	23.0	34.9	2.0	Good tube; possible vibration sample
D12F	0.9	0.001	13.6	41	22.0	34.9	2.0	Sixth engineering sample
	0.10	0.0005	14.9	44	21.0	34.9	2.0	
D18F	0.9	0.0005	15.0	46	25.0	34.9	2.0	Absorber broke at 0.001 duty factor
D29F	0.9	0.0005	13.9	35	20.0	35.8	2.0	Poor cathode emission
D38F	0.9	0.0005	12.5	30	18.6	34.7	1.6	End-hatless tube; possible life test sample

TABLE I SUMMARY OF TUBE EVALUATION DATA

electronic efficiency. Since this tube employed an anode of lower Q_u than most current models, the circuit efficiency obtainable was somewhat low. However, this did not prevent a valid evaluation of the engineering change. Although the overall efficiency of this tube was low owing to the lower than normal circuit efficiency, the electronic efficiency was calculated as nearly ten percentage points higher than that of previous tubes. In addition, the magnetic field uniformity derived from the pole tip change lowered the starting jitter. Tests performed at 1.0 μ sec nominal pulse length yielded the following data. At a duty cycle of 0.00048 the peak output power was 74 kw, the efficiency was 18.7% (the electronic efficiency was 40%), the operating voltage was 19.1 kv and the operating frequency was 35.02 Gc.

Tube B22F - This tube was built as a test vehicle to evaluate new competing mode inhibition techniques. Two mode absorbers were used instead of one. The absorber locations were selected to reduce the TE_{011} cavity mode loading while presenting substantially increased loading to the slot mode. The slot mode, if not sufficiently inhibited, causes starting jitter at short pulse lengths of 0.10 μ sec or less especially when the tube is presented with a high rate of rise of voltage (greater than 150 kv/ μ sec). Electrical evaluation of this test vehicle showed that either one or two mode absorbers can be used to inhibit slot mode; however, no benefit is derived when two are used. From a fabrication standpoint, the use of two absorbers is less desirable. This tube could not be operated at power levels greater than 20 kw at which level severe arcing occurred. A low Q_u anode was used for this experiment and, therefore, tunable operation was not possible over more than 350 Mc at mid-band.

Tube B36F - This tube was the first test vehicle built employing a low voltage design anode. This anode, being the first 140 resonator anode made, did not exhibit Q_u 's as high as was desired but did meet the minimum criterion of 1500 over most of the frequency

band. Initial evaluation revealed that the cathode-anode concentricity was incorrect and testing was suspended. The tube was rebuilt after cathode eccentricity was verified optically. The rebuilt tube yielded the following results. At 0.90 μ sec and a 0.001 duty factor, 31 watts average output power was generated. Although the efficiency was only 16% at mid-band, the significant attribute was the low operating voltage of 14 kv. Power output across the 2 Gc band from 33.9 Gc to 35.9 Gc was 22 kw at the ends and 31 kw at the center. All data were taken at a 0.001 duty factor.

The low efficiency is the only thing which prevented this tube from being a full power specification sample. An efficiency of 22% is necessary for this.

Tube C20F - This tube was the second test vehicle made employing a low voltage design anode. In view of the efficiency degradation which has been noted with increased operating time at high duty cycles, low duty cycle evaluation was performed initially. At the mid-band frequency of 35.0 Gc, this tube generated 50 kw at 25 watts at a 1.0 μ sec pulse duration. The operating voltage was 14.8 kv and the efficiency was 21%. While tuning over a 1 Gc band (34.5 Gc to 35.5 Gc) the power output remained above 40 kw while the input power was held constant. The efficiency at these band edges was 17%.

The duty cycle was increased to 0.001 and power versus frequency data were taken from 33.9 Gc to 35.9 Gc; however, to prevent anode damage from high average power dissipation, the input current was maintained at 9.0 milliamperes. Power output across the frequency range varied from a maximum of 26 kw to a minimum of 20 kw at the band edges.

While operating at the short pulse condition of 0.10 μ sec nominal, the following operation was demonstrated at 35.0 Gc. The tube generated 42 kw at 19 watts at a pulse length of 0.09 μ sec. The operating voltage was 14.9 kv and the efficiency was 19.4%. However,

the jitter measured was 5 to 10 nsec at a 160 kv/ μ sec rate of rise of voltage and 10 to 20 nsec at a 230 kv/ μ sec rate of rise of voltage.

Tube C26F - This tube exhibited excessive mode competition at all test conditions except the high duty cycle condition of 0.001 at a pulse length of 1.0 μ sec. It is felt that the cathode-anode concentricity could be inexact and therefore could cause this condition. Since this tube employs a 128 vane anode (a high voltage design), no effort was expended to rebuild this model.

Tube C42F - This tube was built employing an anode of the higher voltage design. Initial tests revealed that high peak powers at reasonably good efficiencies could be obtained without exceeding an 18 kv operating voltage. At a frequency of 34.9 Gc, a peak output power of 75 kw was generated while operating at a voltage of 17.5 kv and a duty cycle of 0.0004. The pulse length was 0.96 μ sec and the efficiency was 21%. No extensive tunable evaluation was performed since all the subsequent tubes were to be of the low voltage design.

Tube D4F - This tube was the third test vehicle made employing an anode of the low voltage design. In addition, this anode differed from the two previous samples of similar design only in that it incorporated a 0.0005 inch vane length reduction which raised the resonator frequency about 300 Mc. This change yielded high Q_u 's over a broader band of frequencies. The more important test results are cited below. While operating at 0.90 μ sec, 0.001 duty factor and 14 kv, the power output and efficiency at mid-band (34.9 Gc) were respectively 39 kw and 20.2%. At 33.9 Gc, the power output was 27 kw and at 35.9 Gc it was 38 kw. The power output versus frequency characteristic is not symmetrical about 34.9 Gc but steps have been taken to adjust this in the following tubes built. The minor lobes were better than 7.4 db down from the major lobe across the entire frequency band. This value was obtained using a 1.2 VSWR adjusted to the phase of maximum spectrum degradation. At the short pulse condition of 0.10 μ sec and

0.0005 duty factor, operation over a 1.8 Gc band from 33.9 Gc to 35.7 Gc was attainable. The maximum input power allowable (limited by internal arcing) limited the output power to 28 kw at 34.9 Gc.

Tube D8F - This tube operated at 14.5 kv with an efficiency of 23% at mid-band. The power output at 1.0 μ sec and a duty factor of 0.0005 was 50 kw. These results established conclusively that anodes designed for low voltage operation can be manufactured with good repeatability and do, in fact, yield tubes of performance equal to or better than the high voltage anode types.

Tube D12F - This tube exhibited the best electrical operation of any model built to date. Although this tube was made the same as D4F and D8F, the power output and efficiency across the band from 33.9 Gc to 35.9 Gc were the most uniform of any tube yet built on the program. This excellent operation is felt to be related to the uniformity of both the circuit efficiency and Q_u as a function of frequency. However the anode used is mechanically identical to most present anodes. Figure 2 is a plot of peak power output as a function of frequency for tube D12F.

Tube D18F - This tube was of a quality similar to D12F but exhibited a marked drop in power above 35.5 Gc when operated at a 0.001 duty factor. This power drop did not occur at a 0.0005 duty factor which then related power drop to an average power phenomenon. Possibly thermal expansions introduce a shift in operating characteristic due to mechanical asymmetries. Figure 3 is a comparison of the power versus frequency of Tube D18F at the 0.001 and 0.0005 duty factors.

This tube suffered a broken mode absorber while being operated at the 0.001 duty factor.

Tube D29F - This tube operated well across the entire frequency band but owing to a poor cathode (one lacking in emission) could not be driven to the proper operating current level. At a frequency of 35.2 Gc, an output power of 35 kw could be obtained before pulse depletion was exhibited.

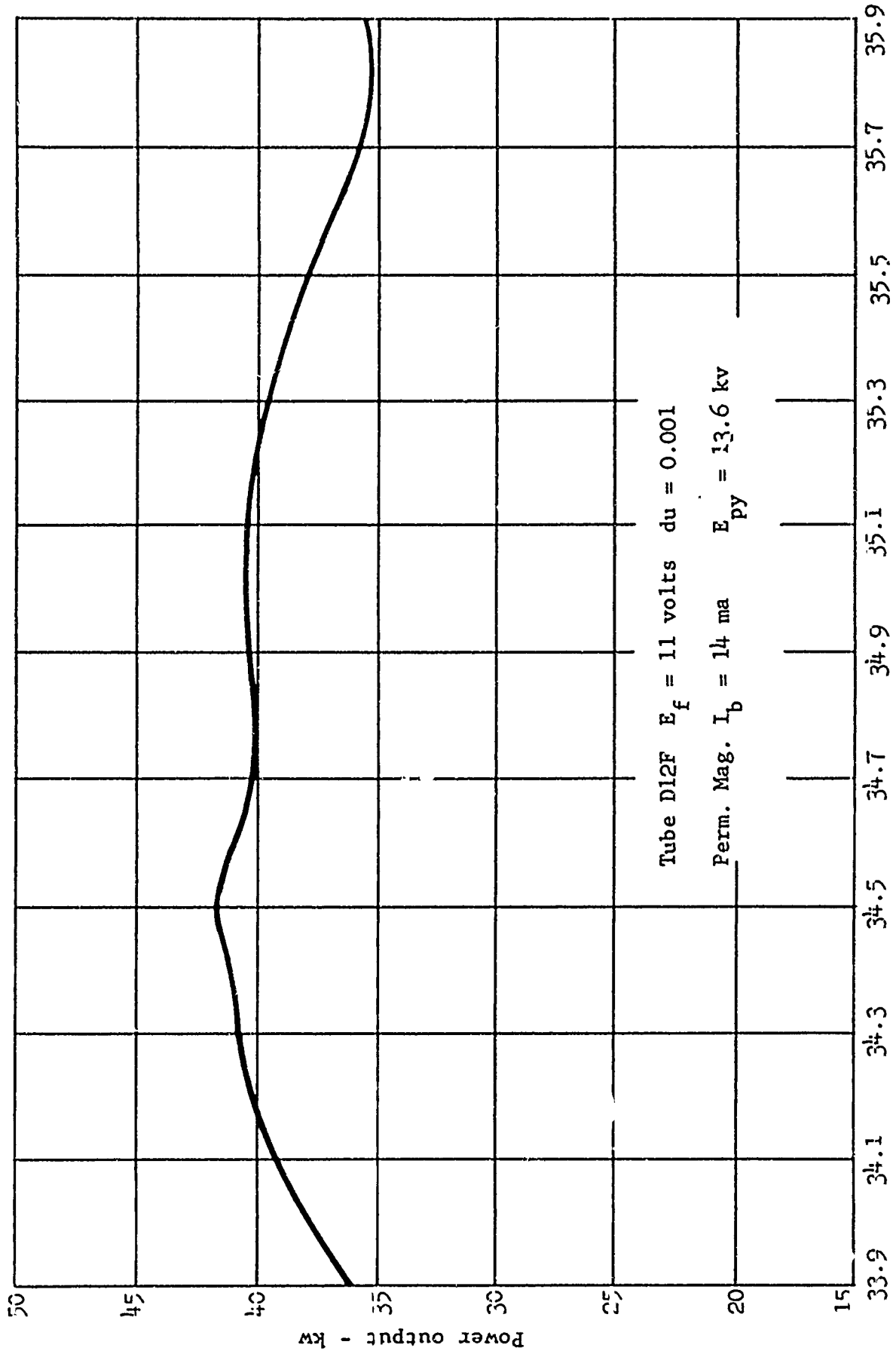


FIGURE 2 POWER OUTPUT VERSUS FREQUENCY FOR TUBE D12F

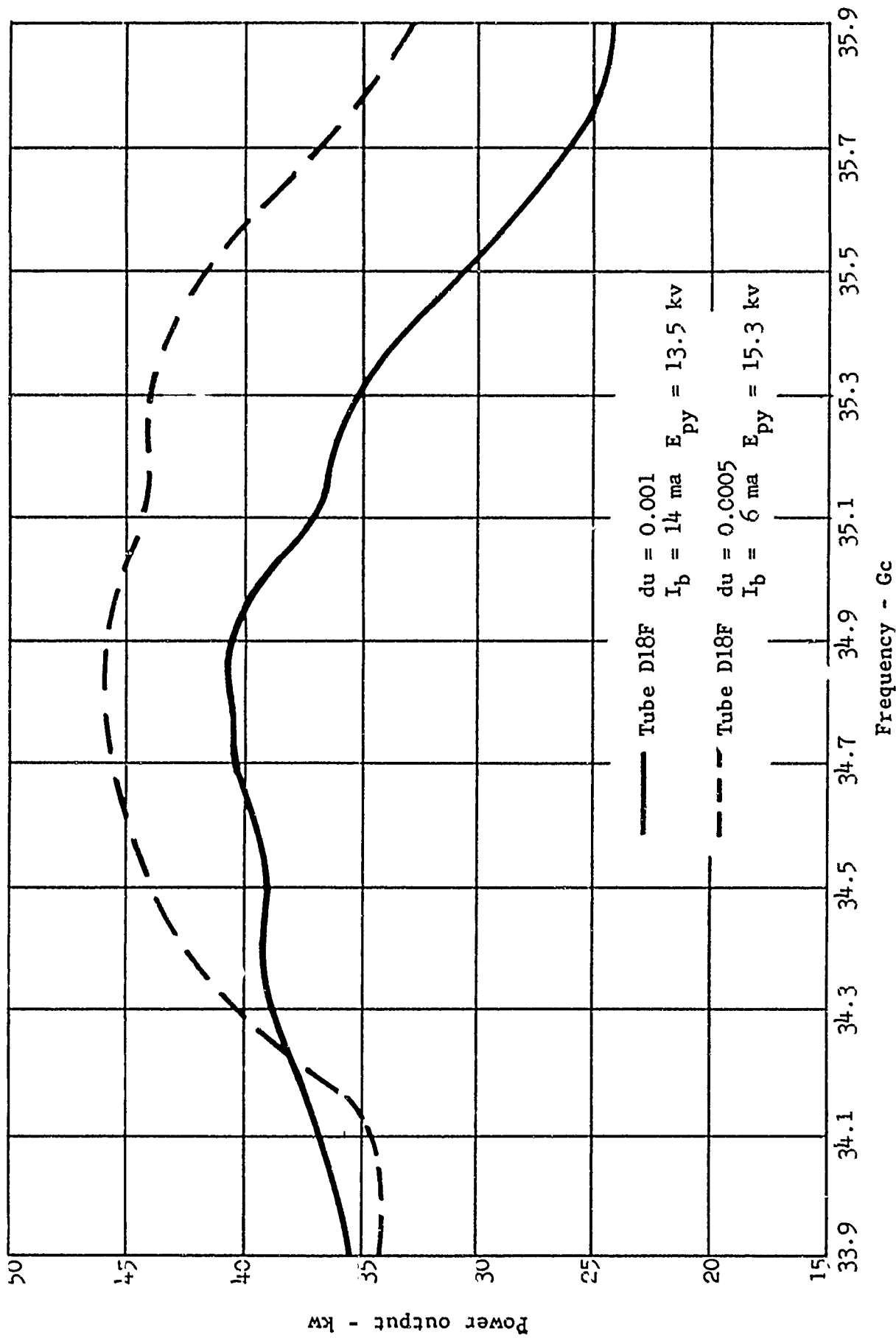


FIGURE 3 COMPARISON OF POWER OUTPUT VERSUS FREQUENCY FOR 0.0005 DUTY FACTOR AND 0.001 DUTY FACTOR FOR TUBE D18F.

Tube D38F - This tube was an experimental vehicle to evaluate the possibility of constructing tubes without end hats. As is discussed in the life test section of this report, end hat erosion is an ever-present problem area. Not only on this program but on similar programs, much effort has been devoted to this area. However, only in a positively pulsed tube is it possible to use the pole piece tip to provide the electrostatic focusing which makes the end hats necessary in a negatively pulsed tube. One deleterious effect which could result is a decrease in electronic efficiency owing to the reduction in confining forces on the electrons.

Satisfactory operation was exhibited across a 1.6 Gc band with the expected decrease in efficiency. At a frequency of 34.7 Gc, 30 kw of peak power output was generated at a 0.9 μ sec pulse length and a duty factor of 0.0005. The input voltage and current were 12.5 kv and 7.0 ma, respectively, which yielded an efficiency of 18.6%.

At present, this vehicle is being considered for life testing to establish the full merit of such an approach to the end hat erosion problem.

1.2.4 Life Testing

As reported in the third quarterly report, tube L46E, although not a specification tube, was placed on a life test program in late January. The tube was being cycled for 5 minutes standby, 45 minutes radiate and ten minutes off. It was further reported that after 146 hours of life testing, the peak output power had increased from 36 kw to 44 kw. At that time it was not clearly understood how this could take place but subsequent failure and internal inspection revealed the cause.

After 462 hours of life testing, the tube was removed from life testing since the power output had fallen to 30 kw. Upon opening the tube, it was found that the end hats had warped considerably and

and hence had materially increased the axial spacing between their inside diameters. In addition, the end hat nearest the output pole piece was severely eroded. This was immediately attributable to an axial misalignment of anode and cathode during the pulsed input condition.

The detection of two latent defects in this design through this particular life test sample permitted corrective action which has been incorporated in all subsequent models.

Figures 4 and 5 are photographs of the eroded end hats.

1.2.5 Heater Cycle Life Testing

The cycled heater life test program initiated during the third quarterly report period was operated for 350 hours at a 60 cycle line frequency. At that time, the line frequency was changed to 400 cycles to provide the necessary information for airborne systems which is one of the primary applications for this positively-pulsed lightweight magnetron.

After a total of 650 hours of heater cycling (350 hours at 60 cycles and 300 hours at 400 cycles) the test was concluded without failure.

The test cycle consisted of application of 16 volts to the heater for 50 minutes and then removal of voltage for a 10 minute cooling off period.

1.2.6 Engineering Samples

In accordance with the contract, the fifth and sixth engineering samples were delivered in the month of April. These two samples incorporate the latest design low voltage anodes and both exhibit near specification operation.

Copies of the test data sheets supplied with the samples are being included in this report as Figures 6 and 7.

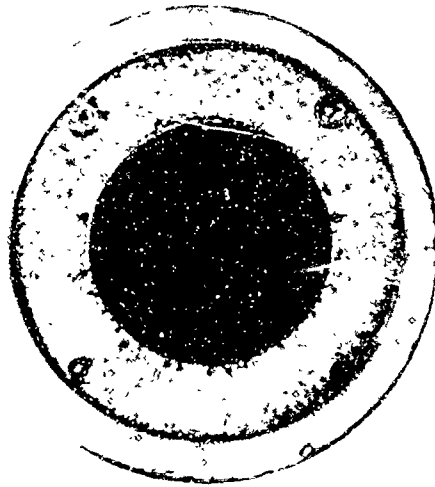


FIGURE 4 PHOTOGRAPH ILLUSTRATING END HAT EROSION - TOP VIEW



FIGURE 5 PHOTOGRAPH ILLUSTRATING END HAT EROSION - FRONTAL VIEW

DATA SHEET

SFD-330

Date 30 April 1964

Serial No. D12F

E_f (Standby) - 16.0 v

I_f (Standby) - 4.5 amps

OSC. 1

OSC. 2

	33.9 Gc	34.9 Gc	35.9 Gc	33.9 Gc	34.9 Gc	35.9 Gc
E_f (volts)	*	*	*	16.0	16.0	16.0
t_p (μ sec)	0.90	0.90	0.90	0.10	0.10	0.10
Duty factor	0.001	0.001	0.001	0.0005	0.0005	0.0005
E_{py} (kv)	13.6	13.6	13.9	14.8	14.9	15.0
I_b (ma)	14.0	14.0	14.0	8.0	8.0	8.0
P_o (kw)	36.0	41.0	35.0	37.0	44.0	38.0
**Pulling (Mc)	8.0	6.0	7.0	8.0	6.0	7.0
**Minor lobes (-db)	8.2	9.8	10.4	-----Not measured-----		
rrv (kv/ μ sec)	Osc. 1 <u>150</u>			Osc. 2 <u>190</u>		
Cooling	30 cfm					
Load VSWR	1.10 max					

*heater reduction schedule supplied

**tests performed using 1.2 VSWR

FIGURE 6

DATA SHEET

SFD-330

Date 30 April 1964

Serial No. D4F

E_f (Standby) - 16.0 v

I_f (Standby) - 4.5 amps

	<u>OSC. 1</u>			<u>(OSC. 2</u>		
	33.9 Gc	34.9 Gc	35.9 Gc	33.9 Gc	34.9 Gc	35.9 Gc
E_f (volts)	*	*	*	16.0	16.0	16.0
t_p (μ sec)	0.90	0.90	0.90	0.10	0.10	0.10
Duty factor	0.001	0.001	0.001	0.0005	0.0005	0.0005
E_{py} (kv)	13.8	13.9	14.1	15.0	15.1	15.2
I_b (ma)	14.0	14.0	14.0	6.0	6.0	6.0
P_o (kw)	27.0	39.0	38.0	15.0	28.0	32.0
**Pulling (Mc)	8.0	6.0	7.0	8.0	7.0	7.0
**Minor lobes (-db)	7.4	9.2	9.3	-----Not measured-----		
rrv (kv/ μ sec)	sc. 1 <u>150</u>			Osc. 2 <u>19</u>		
Cooling	30 cfm					
Load VSWR	1.10 max					

*heater reduction schedule supplied

**tests performed using 1.2 VSWR

FIGURE 7

2.0 CONCLUSIONS

- (1) Phase II of the contract has been completed.
- (2) As a result of an intensive anode evaluation program, low voltage (12-15 kv) anodes have been made which exhibit good Q_u 's across the desired frequency band.
- (3) Tubes have been made with the low voltage design anodes which nearly meet the specification and which are equal to and, in some cases, better than the tubes of a high voltage design.
- (4) Thirteen tubes were constructed and evaluated in this quarterly report period, seven of which were of the low voltage design.
- (5) Power outputs of greater than 40 kw across a 1.8 Gc frequency band have been demonstrated.
- (6) A life test sample completed 462 hours of cycled life testing.
- (7) Heater cycled life testing was concluded after 650 hours of testing without failure.
- (8) The fifth and sixth engineering samples were delivered.

3.0 PROGRAM FOR NEXT QUARTER

- (1) The performance specification will be written using the results of tube evaluation as a guide.
- (2) A description of the preproduction facilities will be submitted for approval.
- (3) A quality control manual will be submitted for approval.
- (4) Assemble and evaluate frozen design tubes.
- (5) Complete environmental tests will be performed on frozen design tubes.
- (6) Initiate life test program using frozen design tubes.

4.0 HOURS EXPENDED DURING QUARTER

Listed below are the hours expended in the performance of the contract by the principal engineering and technical personnel:

	<u>Hours This period</u>
P. du Fosse	367
A. Durner	332
G. Glenfield	8
M. Liscio	435
W. R. Lundberg	24

rtu

GEORGE. E. CLENFIELD

EDUCATION: Boston University 1952
Massachusetts Institute of Technology 1954
Newton College, Massachusetts 1956

EXPERIENCE: S-F-D laboratories, inc. - Senior Mechanical Engineer B

Responsible for coordinating the mechanical engineering effort on K_a and C-band CEM[®] Coaxial Magnetrons and positively and negatively pulsed K_a-band ICEM[®] Magnetrons. Member of the S-F-D Standards Committee. Responsible for the mechanical design and production of an environmentally rugged, 3 Gc tunable, 150 kw, 1000-hr. life, K_a-band ICEM Coaxial Magnetron.

1950-1963 Raytheon Company, Waltham, Massachusetts
Senior Mechanical Designer

Responsible for the mechanical design, development and fabrication of microwave power tubes including magnetrons, "M" type BWO, TWT's, reflex klystrons, Amplitrons and beacon tubes.

Additional responsibilities included: special machining and packaging fixtures, high temperature brazing jigs, high vacuum exhaust systems, heliarc welding stations, bakeout ovens, RF brazing stations, high temperature furnaces, hydraulic lifting and closing devices, gauss probes, lapping machines for klystron grids, hydraulic and mechanical tuning devices for microwave power tubes.

Authored a manual on high temperature brazing, established assembly methods, procedures and process specifications, and cost reduction studies.

Holder of two patents: 1) Ceramic base cathode.
2) Shipping sphere for microwave tubes for space applications.

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