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MASTER

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PERFORMANCE OF PULSED 805-MHZ, 1.25-MW KLYSTRONS INTO MISMATCHED LOADS

by

R. A. Jameson, R. S. Mills, and R. L. Cady

ABSTRACT

High-power 805-MHz klystrons are being used in an accelerator application as pulsed amplifiers at 12% duty factor. These amplifiers drive resonant loads in a dynamically controlled mode where output field must be held to 1% in amplitude and 1° in phase despite 20-30% load disturbances. Because high efficiency is desired, operation occurs in the nonlinear region near saturation. The power-transfer characteristics of the klystron are studied into mismatched loads of complex reflection coefficients up to 0.75. Data are presented as a function of rf drive in the form of two- and three-dimensional Rieke diagrams and as power-transfer and dynamic-gain curves. Appendixes cover tube characteristics, experimental and data reduction techniques, and error analysis.

The Los Alamos, New Mexico, Clinton P. Anderson Meson Physics Facility (LAMPF) has a proton linear accelerator of unprecedented beam intensity. The rf (radio frequency) power system for the 805-MHz portion of this accelerator requires 44 amplifiers, each capable of producing 1.25 MW of peak power and 150-kW average power. The load presented to the amplifier is resonant with an unloaded Q of about 20 000. The klystron itself is an imperfectly matched generator with complicated internal dynamics. The pulse sequence is 120 pps of 1000- μ s duration. During the pulse, the accelerator field must be continuously controlled to 1% in amplitude and 1° in phase; therefore the klystron must run below saturation in a modulating mode. Both phase and amplitude modulation are accomplished by modulating the rf drive to the klystron. When the accelerator beam is turned on, the load impedance changes and the klystron must supply more power. However, to achieve as high overall efficiency as

possible, the klystron should be operated as close to saturation as possible, forcing operation to occur over a nonlinear region.

The combination of these factors results in highly complex system interactions. We therefore decided to investigate the actual characteristics at full power during the development program. The bulk of this work was done from 1967 through late 1970. Further details of the accelerator requirements and the procedures and instrumentation used to obtain the data are reported in Refs. 1-4 and especially 5; they will not be repeated here.

The purpose of this report is to present a body of representative visual data (refer to Data Sets 1-5) for several different tubes at various operating conditions, and to detail in the Appendixes the procedures used to reduce and display the information. The results are true operating performance; only certain known instrumentation influences were removed from the raw data. The experiments and

data-reduction were conducted with great care, with resulting accuracy of $\pm 5\%$ or better in delivered power measurement. Thus, the information forms a data base for comparing various models. The actual data base is in digital form, allowing extensive manipulation.

Because the klystron output is modulated via the rf drive, the drive power was chosen as the independent variable. The power reflected at the klystron rf input, the klystron beam current intercepted in the tube itself, the power delivered to the load, and the dynamic gain of the tube are investigated as functions of drive power and load impedance. The drive pulse to the tube is ramped, and the output is connected through a directional coupler to an E-H tuner and a water load. At each operating condition the E-H tuner is set at 56 different load impedances covering the Smith Chart to VSWR's (Voltage Standing-Wave Ratio) of 7:1, and oscillographs are taken of the variables as a function of rf-drive power. Transparencies are made of the photographs; and the information, using a projection reader, is put on punched cards for computer processing.

Information is presented for five tubes, three from one vendor, two from another, with internal configurations as outlined in Appendix A. The LAMPF accelerator, now operational, uses 44 production tubes on-line. The five tubes tested were procured during the development program under the specification included in Appendix A.

The operating characteristics are displayed in several formats. First, two-dimensional contour maps are plotted on the Smith Chart load impedance plane at 0.5-W drive intervals until tube saturation. Then, three-dimensional displays are given, with the Smith Chart as the base; input reflection coefficient, intercepted current, and delivered power are plotted vertically. These formats are presented for two different tubes at one operating condition each. They serve primarily as a visual orientation to the processes occurring as the drive power changes. The contour information is available for all tubes and operating conditions studied.

The delivered power has a characteristic mountain shape with maximum power delivered to the load at

a certain (complex) load reflection coefficient. This readily demonstrated⁶ property of the interaction of loads and generators with complex impedances has an interesting aspect in this case: the peak moves as a function of drive level. Thus, one useful compression of the data is to plot the position and magnitude of this peak as a function of drive power. Any proposed system model would have to demonstrate this feature. The derivative of the resulting power transfer curve is the dynamic gain of the "equivalent generator" along the maximum-power-transfer trajectory. This information is presented separately for each operating condition detailed; also, the results for all operating conditions for one tube are plotted on the same graph.

Finally, the input-output power-transfer curves and the dynamic-gain curves are given for the 56-load impedance points measured at each operating condition. These points are taken at load VSWR = 1.0:1 and at roughly equally spaced points on load VSWR circles of 1.5, 2.0, 3.0, 4.5 and 7.0. Data for each circle are plotted on the same graph. The power transfer curves are plotted both linearly and logarithmically, and the dynamic gain is plotted in decibels against the rf drive on a linear scale.

The data sets are arranged in the following hierarchical manner.

(1) The performance of each tube over all the operating conditions studied is summarized in terms of the magnitude, slope, and location of the maximum-power-transfer point as a function of rf drive. The term "equivalent generator characteristic" is used for this condensation of the tube performance.

(2) For each operating condition the following information is given:

- (a) Two-dimensional contours (2 cases only),
- (b) Three-dimensional displays (2 cases only),
- (c) Equivalent generator characteristics,
- (d) Input-output characteristics on VSWR circles.

The appendixes cover the characteristics of the tubes studied, the data reduction procedures followed, and the computer programs used.

DATA SET 1

**TUBE: VENDOR 1
 SERIAL NO. 212**

EQUIVALENT GENERATOR DYNAMIC GAIN

EQUIVALENT GENERATOR REFLECTION COEFFICIENT, MAGNITUDE

EQUIVALENT GENERATOR REFLECTION COEFFICIENT, ANGLE

SUMMARY OVER ALL OPERATING CONDITIONS

TUBE: VENDOR 1
SERIAL NO. 212

EQUIVALENT GENERATOR AVAILABLE POWER

The characteristics at the load impedance where maximum power transfer occurs are plotted as a function of rf drive level. Reflection coefficient angle is in guide wavelengths at 805 MHz.

TWO-DIMENSIONAL CONTOURS ARE PLOTTED ON THE LOAD IMPEDANCE PLANE (SMITH CHART) AT RF-DRIVE INTERVALS OF 0.5 W, FOR CONSTANT:

1. INPUT REFLECTION COEFFICIENT; INTERVALS OF 0.1 FROM 0.0 TO 0.9.
2. INTERCEPTED CURRENT; INTERVALS OF 0.8 A FROM 0.0 TO 8.0 A.
3. DELIVERED POWER; INTERVALS OF 100 kW FROM 0 TO 1800 kW.
4. DYNAMIC GAIN; INTERVALS OF 5 dB, FROM 30 to 70 dB.

TUBE

VENDOR 1
SERIAL NO. 212

OPERATING
CONDITION

CATHODE VOLTAGE = 86 kV
COLLECTOR CURRENT = 28.7 A
MODULATING ANODE RESISTANCE = 20 k Ω
FOCUS MAGNET CURRENT = 14 A

IDENTIFICATION	CONTOUR VALUE
A-----A	0.000
B-----B	100
C-----C	200
D-----D	300
E-----E	400
F-----F	500
G-----G	600
H-----H	700
I-----I	800
J-----J	900

IDENTIFICATION	CONTOUR VALUE
A-----A	0.000
B-----B	.000
C-----C	1.000
D-----D	2.000
E-----E	3.000
F-----F	4.000
G-----G	4.000
H-----H	5.000
I-----I	6.000
J-----J	7.000
K-----K	8.000

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE : 5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = .5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE : 1.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 1.0 W

IDENTIFICATION	CONTOUR VALUE
A-----A	0 000
B-----B	100 000
C-----C	200 000
D-----D	300 000
E-----E	400 000
F-----F	500 000
G-----G	600 000
H-----H	700 000
I-----I	800 000
J-----J	900 000
K-----K	1000 000
L-----L	1100 000
M-----M	1200 000
N-----N	1300 000
O-----O	1400 000
P-----P	1500 000
Q-----Q	1600 000
R-----R	1700 000
S-----S	1800 000

IDENTIFICATION	CONTOUR VALUE
A-----A	30 000
B-----B	35 000
C-----C	40 000
D-----D	45 000
E-----E	50 000
F-----F	55 000
G-----G	60 000
H-----H	65 000
I-----I	70 000

DELIVERED POWER CONTOURS

DRIVE = .5 W

DYNAMIC GAIN CONTOURS

DRIVE = .5 W

DELIVERED POWER CONTOURS

DRIVE = 1.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 1.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 1.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 1.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 2.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 2.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 2.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 2.5 W

DELIVERED POWER CONTOURS

DRIVE = 1.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 1.5 W

DELIVERED POWER CONTOURS

DRIVE = 2.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 2.0 W

DELIVERED POWER CONTOURS

DRIVE = 2.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 2.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 3.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 3.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 3.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 3.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 4.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 4.0 W

DELIVERED POWER CONTOURS

DRIVE = 3.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 3.0 W

DELIVERED POWER CONTOURS

DRIVE = 3.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 3.5 W

DELIVERED POWER CONTOURS

DRIVE = 4.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 4.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 4.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 4.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 5.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 5.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 5.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 5.5 W

DELIVERED POWER CONTOURS

DRIVE = 4.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 4.5 W

DELIVERED POWER CONTOURS

DRIVE = 5.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 5.0 W

DELIVERED POWER CONTOURS

DRIVE = 5.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 5.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 6.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 6.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 6.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 6.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 7.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 7.0 W

DELIVERED POWER CONTOURS

DRIVE = 6.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 6.0 W

DELIVERED POWER CONTOURS

DRIVE = 6.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 6.5 W

DELIVERED POWER CONTOURS

DRIVE = 7.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 7.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 7.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 7.5 W

DELIVERED POWER CONTOURS

DRIVE = 7.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 7.5 W

THREE-DIMENSIONAL DISPLAYS ARE PLOTTED ON THE LOAD-IMPEDANCE PLANE AT
RF-DRIVE INTERVALS OF 0.5 W, FOR:

1. INPUT REFLECTION COEFFICIENT
2. INTERCEPTED CURRENT
3. DELIVERED POWER

TUBE

VENDOR 1
SERIAL NO. 212

OPERATING
CONDITION

CATHODE VOLTAGE = 86 kV
COLLECTOR CURRENT = 28.7 A
MODULATING ANODE RESISTANCE = 20 k Ω
FOCUS MAGNET CURRENT = 14 A

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = .5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = .5 W

DELIVERED POWER CONTOURS

DRIVE = .5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 1.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 1.0 W

DELIVERED POWER CONTOURS

DRIVE = 1.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 1.6 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 1.6 W

DELIVERED POWER CONTOURS

DRIVE = 1.6 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 2.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 2.0 W

DELIVERED POWER CONTOURS

DRIVE = 2.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 2.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 2.5 W

DELIVERED POWER CONTOURS

DRIVE = 2.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 3.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 3.0 W

DELIVERED POWER CONTOURS

DRIVE = 3.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 3.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 3.5 W

DELIVERED POWER CONTOURS

DRIVE = 3.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 4.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 4.0 W

DELIVERED POWER CONTOURS

DRIVE = 4.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 4.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 4.5 W

DELIVERED POWER CONTOURS

DRIVE = 4.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 5.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 5.0 W

DELIVERED POWER CONTOURS

DRIVE = 5.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 5.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 5.5 W

DELIVERED POWER CONTOURS

DRIVE = 5.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 6.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 6.0 W

DELIVERED POWER CONTOURS

DRIVE = 6.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 6.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 7.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 6.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 7.0 W

DELIVERED POWER CONTOURS

DRIVE = 6.5 W

DELIVERED POWER CONTOURS

DRIVE = 7.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 7.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 7.5 W

DELIVERED POWER CONTOURS

DRIVE = 7.5 W

TUBE: VENDOR 1
SERIAL NO. 212

DELIVERED POWER AT LOAD VSWS OF 1.0 AND 1.5

EQUIVALENT GENERATOR CHARACTERISTICS

DELIVERED POWER AT LOAD VSWS OF 1.0 AND 1.5

DYNAMIC GAIN AT LOAD VSWS OF 1.0 AND 1.5

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 28.7 A
Modulating Anode Resistance = 20 k Ω
Focus Magnet Current = 14 A

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DYNAMIC GAIN AT LOAD VSWR OF 2.0

DYNAMIC GAIN AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 4.6

VENDOR 1
SERIAL NO. 212

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 28.7 A
Modulating Anode Resistance = 20 k Ω
Focus Magnet Current = 18 A

DELIVERED POWER AT LOAD VSWR OF 4.6

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.6

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.6

DYNAMIC GAIN AT LOAD VSWR OF 7.0

VENDOR 1
SERIAL NO. 212

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 28.7 A
Modulating Anode Resistance = 20 kΩ
Focus Magnet Current = 22 A

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DYNAMIC GAIN AT LOAD VSWR OF 2.0

DYNAMIC GAIN AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

TUBE: VENDOR 1
SERIAL NO. 212

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

EQUIVALENT GENERATOR CHARACTERISTICS

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

DYNAMIC GAIN AT LOAD VSWRS OF 1.0 AND 1.5

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 30.9 A
Modulating Anode Resistance = 15 kΩ
Focus Magnet Current = 14 A

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DYNAMIC GAIN AT LOAD VSWR OF 2.0

DYNAMIC GAIN AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 4.6

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.6

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.6

DYNAMIC GAIN AT LOAD VSWR OF 7.0

TUBE: VENDOR 1
 SERIAL NO. 212

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

EQUIVALENT GENERATOR CHARACTERISTICS

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

DYNAMIC GAIN AT LOAD VSWRS OF 1.0 AND 1.5

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 30.9 A
Modulating Anode Resistance = 15 kΩ
Focus Magnet Current = 18 A

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DYNAMIC GAIN AT LOAD VSWR OF 2.0

DYNAMIC GAIN AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

TUBE: VENDOR 1
SERIAL NO. 212

DELIVERED POWER AT LOAD VSWS OF 1.0 AND 1.5

EQUIVALENT GENERATOR CHARACTERISTICS

DELIVERED POWER AT LOAD VSWS OF 1.0 AND 1.5

DYNAMIC GAIN AT LOAD VSWS OF 1.0 AND 1.5

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 30.9 A
Modulating Anode Resistance = 15 kΩ
Focus Magnet Current = 22 A

DELIVERED POWER AT LOAD VSIR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

DATA SET 2

**TUBE: VENDOR 1
SERIAL NO. 103**

EQUIVALENT GENERATOR DYNAMIC GAIN

EQUIVALENT GENERATOR REFLECTION COEFFICIENT, MAGNITUDE

EQUIVALENT GENERATOR REFLECTION COEFFICIENT, ANGLE

SUMMARY OVER ALL OPERATING CONDITIONS

TUBE: VENDOR 1
SERIAL NO. 103

EQUIVALENT GENERATOR AVAILABLE POWER

The characteristics at the load impedance where maximum power transfer occurs are plotted as a function of rf drive level. Reflection coefficient angle is in guide wavelengths at 805 MHz.

TWO-DIMENSIONAL CONTOURS ARE PLOTTED ON THE LOAD-IMPEDANCE PLANE (SMITH CHART) AT RF-DRIVE INTERVALS OF 0.5 W, FOR CONSTANT:

1. INPUT REFLECTION COEFFICIENT; INTERVALS OF 0.1 FROM 0.0 TO 0.9.
2. INTERCEPTED CURRENT; INTERVALS OF 1.0 A FROM 0.0 TO 10.0 A.
3. DELIVERED POWER; INTERVALS OF 100 kW FROM 0 TO 1800 kW.
4. DYNAMIC GAIN; INTERVALS OF 5 dB, FROM 30 TO 70 dB.

TUBE

VENDOR 1
SERIAL NO. 103

OPERATING
CONDITION

CATHODE VOLTAGE = 86 kV
COLLECTOR CURRENT = 33.2 A
MODULATING ANODE RESISTANCE = 15 k Ω
FOCUS MAGNET CURRENT = 14 A

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 10 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 10 W

IDENTIFICATION	CONTOUR VALUE
1	0 000
2	100 000
3	200 000
4	300 000
5	400 000
6	500 000
7	600 000
8	700 000
9	800 000
10	900 000
11	1000 000
12	1100 000
13	1200 000
14	1300 000
15	1400 000
16	1500 000
17	1600 000
18	1700 000
19	1800 000

IDENTIFICATION	CONTOUR VALUE
1	20 000
2	30 000
3	40 000
4	50 000
5	60 000
6	70 000

DELIVERED POWER CONTOURS

DRIVE = 5 W

DYNAMIC GAIN CONTOURS

DRIVE = 5 W

DELIVERED POWER CONTOURS

DRIVE = 10 W

DYNAMIC GAIN CONTOURS

DRIVE = 10 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 1.5 w

INTERCEPTED CURRENT CONTOURS

DRIVE = 1.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 2 0 0

INTERCEPTED CURRENT CONTOURS

DRIVE = 20 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 2.5 V

INTERCEPTED CURRENT CONTROLS

DRIVE = 2 5 W

DELIVERED POWER CONTOURS

DRIVE = 1.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 1.5 W

DELIVERED POWER CONTOURS

DRIVE = 2.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 2.0 W

DELIVERED POWER CONTOURS

DRIVE = 2.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 2.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 3.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 3.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 3.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 3.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 4.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 4.0 W

DELIVERED POWER CONTOURS

DRIVE = 30 W

DYNAMIC GAIN CONTOURS

DRIVE = 30 W

DELIVERED POWER CONTOURS

DRIVE = 35 W

DYNAMIC GAIN CONTOURS

DRIVE = 35 W

DELIVERED POWER CONTOURS

DRIVE = 40 W

DYNAMIC GAIN CONTOURS

DRIVE = 40 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 4.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 4.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 5.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 5.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 5.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 5.5 W

DELIVERED POWER CONTOURS

DRIVE = 4.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 4.5 W

DELIVERED POWER CONTOURS

DRIVE = 5.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 5.0 W

DELIVERED POWER CONTOURS

DRIVE = 5.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 5.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 6.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 6.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 6.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 6.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 7.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 7.0 W

DELIVERED POWER CONTOURS

DRIVE = 6.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 6.0 W

DELIVERED POWER CONTOURS

DRIVE = 6.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 6.5 W

DELIVERED POWER CONTOURS

DRIVE = 7.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 7.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 7.6 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 7.6 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 8.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 8.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 8.6 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 8.6 W

DELIVERED POWER CONTOURS

DRIVE = 7.6 W

DYNAMIC GAIN CONTOURS

DRIVE = 7.6 W

DELIVERED POWER CONTOURS

DRIVE = 8.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 8.0 W

DELIVERED POWER CONTOURS

DRIVE = 8.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 8.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 9.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 9.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 9.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 9.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 10.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 10.0 W

DELIVERED POWER CONTOURS

DRIVE = 9.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 9.0 W

DELIVERED POWER CONTOURS

DRIVE = 9.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 9.5 W

DELIVERED POWER CONTOURS

DRIVE = 10.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 10.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 10.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 10.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 11.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 11.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 11.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 11.5 W

DELIVERED POWER CONTOURS

DRIVE = 10.6 W

DYNAMIC GAIN CONTOURS

DRIVE = 10.6 W

DELIVERED POWER CONTOURS

DRIVE = 11.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 11.0 W

DELIVERED POWER CONTOURS

DRIVE = 11.6 W

DYNAMIC GAIN CONTOURS

DRIVE = 11.6 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 12.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 12.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 12.6 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 12.6 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 13.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 13.0 W

DELIVERED POWER CONTOURS

DRIVE = 12.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 12.0 W

DELIVERED POWER CONTOURS

DRIVE = 12.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 12.5 W

DELIVERED POWER CONTOURS

DRIVE = 13.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 13.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 13.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 13.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 14.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 14.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 14.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 14.5 W

DELIVERED POWER CONTOURS

DRIVE = 13.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 13.5 W

DELIVERED POWER CONTOURS

DRIVE = 14.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 14.0 W

DELIVERED POWER CONTOURS

DRIVE = 14.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 14.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 15.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 15.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 15.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 15.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 16.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 16.0 W

DELIVERED POWER CONTOURS

DRIVE = 15.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 15.0 W

DELIVERED POWER CONTOURS

DRIVE = 15.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 15.5 W

DELIVERED POWER CONTOURS

DRIVE = 16.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 16.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 16.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 16.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 17.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 17.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 17.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 17.5 W

DELIVERED POWER CONTOURS

DRIVE = 16.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 16.5 W

DELIVERED POWER CONTOURS

DRIVE = 17.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 17.0 W

DELIVERED POWER CONTOURS

DRIVE = 17.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 17.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 18.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 18.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 18.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 18.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 19.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 19.0 W

DELIVERED POWER CONTOURS

DRIVE = 18.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 18.0 W

DELIVERED POWER CONTOURS

DRIVE = 18.5 W

DYNAMIC GAIN CONTOURS

DRIVE = 18.5 W

DELIVERED POWER CONTOURS

DRIVE = 19.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 19.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 19.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 19.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 20.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 20.0 W

DELIVERED POWER CONTOURS

DRIVE = 19.6 W

DYNAMIC GAIN CONTOURS

DRIVE = 19.6 W

DELIVERED POWER CONTOURS

DRIVE = 20.0 W

DYNAMIC GAIN CONTOURS

DRIVE = 20.0 W

THREE-DIMENSIONAL DISPLAYS ARE PLOTTED ON THE LOAD-IMPEDANCE PLANE AT
RF-DRIVE INTERVALS OF 0.5 W, FOR:

1. INPUT REFLECTION COEFFICIENT
2. INTERCEPTED CURRENT
3. DELIVERED POWER

TUBE

VENDOR 1
SERIAL NO. 103

OPERATING
CONDITION

CATHODE VOLTAGE = 86 kV
COLLECTOR CURRENT = 33.2
MODULATING ANODE RESISTANCE = 15 k Ω
FOCUS MAGNET CURRENT = 14 A

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = .5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = .5 W

DELIVERED POWER CONTOURS

DRIVE = .5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 1.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 1.0 W

DELIVERED POWER CONTOURS

DRIVE = 1.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 1.5 W

INTERCEPTED CURRENT CONTOURS

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 2.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 1.5 W

DELIVERED POWER CONTOURS

DRIVE = 2.0 W

DELIVERED POWER CONTOURS

DRIVE = 1.5 W

DRIVE = 2.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 2.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 2.5 W

DELIVERED POWER CONTOURS

DRIVE = 2.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 3.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 3.0 W

DELIVERED POWER CONTOURS

DRIVE = 3.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 3.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 4.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 3.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 4.0 W

DELIVERED POWER CONTOURS

DRIVE = 3.5 W

DELIVERED POWER CONTOURS

DRIVE = 4.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE : 4.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE : 5.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE : 4.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE : 5.0 W

DELIVERED POWER CONTOURS

DRIVE : 4.5 W

DELIVERED POWER CONTOURS

DRIVE : 5.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 5.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 6.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 5.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 6.0 W

DELIVERED POWER CONTOURS

DRIVE = 5.5 W

DELIVERED POWER CONTOURS

DRIVE = 6.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 6.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 7.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 6.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 7.0 W

DELIVERED POWER CONTOURS

DRIVE = 6.5 W

DELIVERED POWER CONTOURS

DRIVE = 7.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 7.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 8.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 7.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 8.0 W

DELIVERED POWER CONTOURS

DRIVE = 7.5 W

DELIVERED POWER CONTOURS

DRIVE = 8.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 8.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 9.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 8.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 9.0 W

DELIVERED POWER CONTOURS

DRIVE = 8.5 W

DELIVERED POWER CONTOURS

DRIVE = 9.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 9.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 10.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 9.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 10.0 W

DELIVERED POWER CONTOURS

DRIVE = 9.5 W

DELIVERED POWER CONTOURS

DRIVE = 10.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 10.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 11.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 10.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 11.0 W

DELIVERED POWER CONTOURS

DRIVE = 10.5 W

DELIVERED POWER CONTOURS

DRIVE = 11.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 11.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 12.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 11.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 12.0 W

DELIVERED POWER CONTOURS

DRIVE = 11.5 W

DELIVERED POWER CONTOURS

DRIVE = 12.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 12.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 13.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 12.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 13.0 W

DELIVERED POWER CONTOURS

DRIVE = 12.5 W

DELIVERED POWER CONTOURS

DRIVE = 13.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 13.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 14.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 13.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 14.0 W

DELIVERED POWER CONTOURS

DRIVE = 13.5 W

DELIVERED POWER CONTOURS

DRIVE = 14.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 14.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 15.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 14.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 15.0 W

DELIVERED POWER CONTOURS

DRIVE = 14.5 W

DELIVERED POWER CONTOURS

DRIVE = 15.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 15.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 16.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 15.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 16.0 W

DELIVERED POWER CONTOURS

DRIVE = 15.5 W

DELIVERED POWER CONTOURS

DRIVE = 16.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 16.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 16.5 W

DELIVERED POWER CONTOURS

DRIVE = 16.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 17.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 17.0 W

DELIVERED POWER CONTOURS

DRIVE = 17.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 17.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE = 18.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 17.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE = 18.0 W

DELIVERED POWER CONTOURS

DRIVE = 17.5 W

DELIVERED POWER CONTOURS

DRIVE = 18.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE : 18.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE : 19.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE : 18.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE : 19.0 W

DELIVERED POWER CONTOURS

DRIVE : 18.5 W

DELIVERED POWER CONTOURS

DRIVE : 19.0 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE : 19.5 W

INTERCEPTED CURRENT CONTOURS

DRIVE : 19.5 W

DELIVERED POWER CONTOURS

DRIVE : 19.5 W

INPUT REFLECTION COEFFICIENT CONTOURS

DRIVE : 20.0 W

INTERCEPTED CURRENT CONTOURS

DRIVE : 20.0 W

DELIVERED POWER CONTOURS

DRIVE : 20.0 W

TUBE: VENDOR 1
SERIAL NO. 103

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 33.0 A
Modulating Anode Resistance = 15 k Ω
Focus Magnet Current = 14 A

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DYNAMIC GAIN AT LOAD VSWR OF 2.0

DYNAMIC GAIN AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

TUBE: VENDOR 1
SERIAL NO. 103

EQUIVALENT GENERATOR CHARACTERISTICS

DELIVERED POWER AT LOAD VSWS OF 1.0 AND 1.5

DELIVERED POWER AT LOAD VSWS OF 1.0 AND 1.5

DYNAMIC GAIN AT LOAD VSWS OF 1.0 AND 1.5

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 33.0 A
Modulating Anode Resistance = 15 kΩ
Focus Magnet Current = 18 A

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

TUBE: VENDOR 1
SERIAL NO. 103

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

EQUIVALENT GENERATOR CHARACTERISTICS

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 33.0 A
Modulating Anode Resistance = 15 kΩ
Focus Magnet Current = 22 A

DYNAMIC GAIN AT LOAD VSWRS OF 1.0 AND 1.5

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DYNAMIC GAIN AT LOAD VSWR OF 2.0

DYNAMIC GAIN AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

TUBE: VENDOR 1
SERIAL NO. 103

EQUIVALENT GENERATOR CHARACTERISTICS

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 30.4 A
Modulating Anode Resistance = 20 k Ω
Focus Magnet Current = 14 A

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

DYNAMIC GAIN AT LOAD VSWRS OF 1.0 AND 1.5

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DYNAMIC GAIN AT LOAD VSWR OF 2.0

DYNAMIC GAIN AT LOAD VSWR OF 3.0

TUBE: VENDOR 1
SERIAL NO. 103

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

EQUIVALENT GENERATOR CHARACTERISTICS

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

DYNAMIC GAIN AT LOAD VSWRS OF 1.0 AND 1.5

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 30.5
Modulating Anode Resistance = 20 kΩ
Focus Magnet Current = 18 A

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

TUBE: VENDOR 1
SERIAL NO. 103

DELIVERED POWER AT LOAD VSWS OF 1.0 AND 1.5

EQUIVALENT GENERATOR CHARACTERISTICS

DELIVERED POWER AT LOAD VSWS OF 1.0 AND 1.5

DYNAMIC GAIN AT LOAD VSWS OF 1.0 AND 1.5

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 30.2 A
Modulating Anode Resistance = 20 kΩ
Focus Magnet Current = 22 A

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

DATA SET 3

**TUBE: VENDOR 1
 SERIAL NO. 105**

EQUIVALENT GENERATOR DYNAMIC GAIN

EQUIVALENT GENERATOR REFLECTION COEFFICIENT, MAGNITUDE

EQUIVALENT GENERATOR REFLECTION COEFFICIENT, ANGLE

SUMMARY OVER ALL OPERATING CONDITIONS

TUBE: VENDOR 1
SERIAL NO. 105

EQUIVALENT GENERATOR AVAILABLE POWER

The characteristics at the load impedance where maximum power transfer occurs are plotted as a function of rf drive level. Reflection coefficient angle is in guide wavelengths at 805 MHz.

TUBE: VENDOR 1
SERIAL NO. 105

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

EQUIVALENT GENERATOR CHARACTERISTICS

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

OPERATING CONDITION

Cathode Voltage = 86 kV

Collector Current = 32.3 A

Modulating Anode Resistance = 15 k Ω

Focus Magnet Current = 14 A

DYNAMIC GAIN AT LOAD VSWRS OF 1.0 AND 1.5

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DYNAMIC GAIN AT LOAD VSWR OF 2.0

DYNAMIC GAIN AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

TUBE: VENDOR 1
SERIAL NO. 105

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

EQUIVALENT GENERATOR CHARACTERISTICS

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

DYNAMIC GAIN AT LOAD VSWRS OF 1.0 AND 1.5

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 32.3 A
Modulating Anode Resistance = 15 k Ω
Focus Magnet Current = 18 A

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DYNAMIC GAIN AT LOAD VSWR OF 2.0

DYNAMIC GAIN AT LOAD VSWR OF 3.0

TUBE: VENDOR 1
SERIAL NO. 105

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

EQUIVALENT GENERATOR CHARACTERISTICS

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

DYNAMIC GAIN AT LOAD VSWRS OF 1.0 AND 1.5

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 32.3 A
Modulating Anode Resistance = 15 kΩ
Focus Magnet Current = 22 A

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

TUBE: VENDOR 1
SERIAL NO. 105

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 29.4 A
Modulating Anode Resistance = 20 kΩ
Focus Magnet Current = 14 A

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DYNAMIC GAIN AT LOAD VSWR OF 2.0

DYNAMIC GAIN AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

TUBE: VENDOR 1
SERIAL NO. 105

OPERATING CONDITION

Cathode Voltage = 86 kV

Collector Current = 29.4 A

Modulating Anode Resistance = 20 k Ω

Focus Magnet Current = 18 A

DELIVERED POWER AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 2.0

DYNAMIC GAIN AT LOAD VSWR OF 3.0

DYNAMIC GAIN AT LOAD VSWR OF 2.0

TUBE: VENDOR 1
SERIAL NO. 105

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

EQUIVALENT GENERATOR CHARACTERISTICS

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

DYNAMIC GAIN AT LOAD VSWRS OF 1.0 AND 1.5

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 29.4 A
Modulating Anode Resistance = 20 kΩ
Focus Magnet Current = 22 A

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

TUBE: VENDOR 1
SERIAL NO. 105

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 29.4 A
Modulating Anode Resistance = 25 k Ω
Focus Magnet Current = 18 A

DATE SET 4

TUBE: VENDOR 2
SERIAL NO. 2006

SUMMARY OVER ALL OPERATING CONDITIONS

TUBE: VENDOR 2
SERIAL NO. 2006

The characteristics at the load impedance where maximum power transfer occurs are plotted as a function of rf drive level. Reflection coefficient angle is in guide wavelengths at 805 MHz.

TUBE: VENDOR 2
SERIAL NO. 2006

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

EQUIVALENT GENERATOR CHARACTERISTICS

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

DYNAMIC GAIN AT LOAD VSWRS OF 1.0 AND 1.5

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 30.3 A
Modulating Anode Resistance = 10 kΩ
Focus Magnet Current = 14 A

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DYNAMIC GAIN AT LOAD VSWR OF 2.0

DYNAMIC GAIN AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

TUBE: VENDOR 2
SERIAL NO. 2006

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 33.0 A
Modulating Anode Resistance = 6 kΩ
Focus Magnet Current = 14 A

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

DATA SET 5

**TUBE: VENDOR 2
 SERIAL NO. 2007**

SUMMARY OVER ALL OPERATING CONDITIONS

TUBE: VENDOR 2
SERIAL NO. 2007

The characteristics at the load impedance where maximum power transfer occurs are plotted as a function of rf drive level. Reflection coefficient angle is in guide wavelengths at 805 MHz.

In curves 1-6, an additional cavity, located between main cavities three and four, and tuned to the second harmonic (1610 MHz) is active. In curves 7 and 8, this cavity is detuned.

TUBE: VENDOR 2
SERIAL NO. 2007

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

EQUIVALENT GENERATOR CHARACTERISTICS

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

DYNAMIC GAIN AT LOAD VSWRS OF 1.0 AND 1.5

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 31.4 A
Modulating Anode Resistance = 15 kΩ
Focus Magnet Current = 11.5 A

2nd Harmonic Cavity Active

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

TUBE: VENDOR 2
SERIAL NO. 2007

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

EQUIVALENT GENERATOR CHARACTERISTICS

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

DYNAMIC GAIN AT LOAD VSWRS OF 1.0 AND 1.5

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 31.4 A
Modulating Anode Resistance = 15 kΩ
Focus Magnet Current = 12.5 A

2nd Harmonic Cavity Active

TUBE: VENDOR 2
SERIAL NO. 2007

EQUIVALENT GENERATOR CHARACTERISTICS

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 28.6 A
Modulating Anode Resistance = 20 kΩ
Focus Magnet Current = 11.5 A

2nd Harmonic Cavity Active

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

DYNAMIC GAIN AT LOAD VSWRS OF 1.0 AND 1.5

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DYNAMIC GAIN AT LOAD VSWR OF 2.0

DYNAMIC GAIN AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

TUBE: VENDOR 2
SERIAL NO. 2007

DELIVERED POWER AT LOAD VSWS OF 1.0 AND 1.5

EQUIVALENT GENERATOR CHARACTERISTICS

DELIVERED POWER AT LOAD VSWS OF 1.0 AND 1.5

DYNAMIC GAIN AT LOAD VSWS OF 1.0 AND 1.5

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 28.6 A
Modulating Anode Resistance = 20 k Ω
Focus Magnet Current = 12.5 A

2nd Harmonic Cavity Active

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DYNAMIC GAIN AT LOAD VSWR OF 2.0

DYNAMIC GAIN AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

TUBE: VENDOR 2
SERIAL NO. 2007

DELIVERED POWER AT LOAD VSWS OF 1.0 AND 1.5

EQUIVALENT GENERATOR CHARACTERISTICS

DELIVERED POWER AT LOAD VSWS OF 1.0 AND 1.5

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 26.1 A
Modulating Anode Resistance = 25 kΩ
Focus Magnet Current = 11.5 A

2nd Harmonic Cavity Active

DYNAMIC GAIN AT LOAD VSWS OF 1.0 AND 1.5

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DYNAMIC GAIN AT LOAD VSWR OF 2.0

DYNAMIC GAIN AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

TUBE: VENDOR 2
SERIAL NO. 2007

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 26.1 A
Modulating Anode Resistance = 25 k Ω
Focus Magnet Current = 12.5 A

2nd Harmonic Cavity Active

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DYNAMIC GAIN AT LOAD VSWR OF 2.0

DYNAMIC GAIN AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

TUBE: VENDOR 2
SERIAL NO. 2007

EQUIVALENT GENERATOR CHARACTERISTICS

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 30.4 A
Modulating Anode Resistance = 15 kΩ
Focus Magnet Current = 11.5 A

2nd Harmonic Cavity Detuned

DYNAMIC GAIN AT LOAD VSIRS OF 1.0 AND 1.5

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

TUBE: VENDOR 2
SERIAL NO. 2007

EQUIVALENT GENERATOR CHARACTERISTICS

OPERATING CONDITION

Cathode Voltage = 86 kV
Collector Current = 30.4 A
Modulating Anode Resistance = 15 kΩ
Focus Magnet Current = 12.5 A

2nd Harmonic Cavity Detuned

DELIVERED POWER AT LOAD VS VRS OF 1.0 AND 1.5

DELIVERED POWER AT LOAD VSWRS OF 1.0 AND 1.5

DYNAMIC GAIN AT LOAD VSURS OF 1.0 AND 1.5

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 2.0

DELIVERED POWER AT LOAD VSWR OF 3.0

DYNAMIC GAIN AT LOAD VSWR OF 2.0

DYNAMIC GAIN AT LOAD VSWR OF 3.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DELIVERED POWER AT LOAD VSWR OF 4.5

DELIVERED POWER AT LOAD VSWR OF 7.0

DYNAMIC GAIN AT LOAD VSWR OF 4.5

DYNAMIC GAIN AT LOAD VSWR OF 7.0

APPENDIX A

KLYSTRON CHARACTERISTICS

All of the klystrons tested were essentially configured as sketched in Fig. A-1. Developmental and production models from Varian Associates and Litton Industries were included in the tests.

The klystrons have five cavities and are designed to operate at 86-kV dc and 30-A pulsed beam current. One tube, Serial No. 2007, was fitted with an additional cavity, located between cavities three and four, which could be tuned to resonate at the second harmonic or detuned completely. The modulating anode is used as a switch to pulse the beam on. The output-rf phase and amplitude are regulated by controlling the input-rf phase and amplitude.

The cavity frequencies are chosen to provide the required bandwidth and to present the proper impedance to the beam. Table A-I shows the available characteristics.

The transfer characteristics are more sensitive to cavity-two tuning than to the other cavities. All of the cavities except cavity five have tuners. The tuners of the Litton Industries klystrons are fixed (welded) in one of the final assembly steps. The frequencies of cavity five are 803 ± 3 MHz due to manufacturing tolerances. When the frequency of the output cavity is below 805 MHz, the amplitude variation of the output at the various mismatches is minimized.

Fig. A-1.
Klystron representation.

I. PERFORMANCE SPECIFICATION FOR KLYSTRON AMPLIFIER

The klystron specified below is a sealed-off, fixed-tuned, modulating-anode klystron amplifier that must operate in a Varian VA-1562 solenoid. Table A-II shows the electrical characteristics.

The dynamic gain* must not deviate more than 10 dB over the interval of output power from 500 kW to 1000 kW and must not exceed 60 dB nor be less than 47 dB within this interval. Further, there must be no abrupt, discontinuous changes in the rf-power output when rf drive is changed to produce outputs from 500 kW to full saturation at any time within a 1000- μ sec pulse. The above characteristics will apply when the load VSWR is $\leq 1.5:1$ at any phase angle.

With the tube cold in air and the cathode shorted to the body, the capacity measured from mod-anode to body will be less than 200 pF.

The output power, measured with a 1-kHz-bandwidth spectrum analyzer and with a 1- μ sec pulse length, will be less than 40 dB relative to the fundamental over the 600- to 1200-MHz frequency band (with the exception of a ± 40 -kHz band centered at the fundamental frequency).

Heater voltage will be $18.0 \text{ V} \pm 5\%$. Filament power supply is to be regulated to $\pm 5\%$; warmup time is to be ≤ 10 min, and surge current will be limited to twice operating value.

The collector will be operated at body potential and be capable of withstanding full beam power. (No rf drive for an indefinite time.)

Maximum linearity of the power-in, power-out transfer curve will be a design goal. The power delivered to the accelerator load will be controlled using a fast closed-loop system to maintain the accelerator field at a constant level under various conditions of beam loading.

The tube will be used to power a resonant accelerator load having a Q of approximately 20 000. The steady-state 805-MHz VSWR during the pulse will be 1.1:1 or less at arbitrary phase angle.

The klystron must meet the electrical specification in Table A-II when mounted within a Varian solenoid, Type VA-1562. The focus magnet will have a single input terminal pair. The 11 individual coils will be connected as specified by the seller, and these connections will be the same for all tubes delivered under this contract. The seller will specify the magnet focus current for each tube, and the tube must operate in accordance with this specification for all

*Dynamic gain = $10 \log (\delta p_{\text{out}} / \delta p_{\text{in}})$, all other parameters constant.

TABLE A-I
CAVITY FREQUENCIES, MHZ

Serial No.	Drift Tube Diam [mm (in.)]	Cavities					Output Q
		1	2	3	4	5	
103	50.8 (2.0)	803.4	795.3	815.5	820.2	801.6	37
105	50.8/55.88 (2/2.2)	805.0	798.5	811.5	822.8	---	30
212	50.8/55.88 (2/2.2)	---	---	---	---	804.8	31
2006	31.74 (1.25)	---	---	---	---	---	---
2007	58.42 (2.3)	805.0	804.0	816.0	823.0	---	35

---signifies data not available.

TABLE A-II
ELECTRICAL CHARACTERISTICS

Parameter	Minimum	Nominal	Maximum	Units
Operating frequency		805.0		MHz
Bandwidth (3 dB)	±4.0			MHz
Peak rf incident drive power, with VSWR _g ≤ 1.5			12.5	W
Peak power output	1.25			MW
Cathode to body voltage			86.0	kV
Peak beam current		29.1	33.0	A
Cathode to mod-anode voltage (pulse on)			84.0	kV
Video duty ratio			0.132	
RF pulse length			1000.0	μs
Video pulse length			1100.0	μs
Total focus magnet power			2.0	kW

magnet currents within a 1-A range centered at the specified magnet current. It will be a design objective for all tubes to operate at the same magnet current, but in no event will it exceed 20 A or be less than 14 A.

Power output and phase angle will be controlled by varying rf drive. The following phase-shift characteristics from 700 kW to 1000 kW of output into a load with VSWR 1.15:1 must obtain: phase shift/percent anode voltage of 15° max and a phase shift/dB change in rf drive of 10° max.

In operation, the mod-anode will be used as a switch only.

Table A-III shows the mechanical characteristics of the klystron amplifier.

The rf-power output will be in the WR-975 waveguide provided with a standard flange with the output facing vertically.

The tube is to be mounted vertically, cathode end down. The cathode and mod-anode will be immersed in type-10 transformer oil or equivalent. Electrical gradients around the tube socket will be low enough so that no arcing occurs if the sparking potential of the oil deteriorates to 30 kV when tested as specified in ASTM Standard D877.

All sockets and klystrons delivered under this contract must be completely interchangeable.

X-ray shielding will be provided so that when the tube is running at full power, the radiation level will

not exceed 12.5 mR/h anywhere within a radius of 0.3 m from the tube when measured with a Victoreen 440-RF ionization chamber.

The output window is to be accessible for periodic cleaning.

The cooling water courses will terminate with the following "Snap-Tite" connectors.

Collector supply	VHC24
Collector return	VHN24
Body supply	VHC8
Body return	VNH8

The serial number will be imprinted prominently on an exterior portion of the klystron, visible when the tube is seated in its focusing magnet.

The window air-blower requirements will be a nominal 100 cfm at 2.54-cm static pressure and a maximum of 393 cfm at that pressure.

II. KLYSTRON ACCEPTANCE TESTS

The first klystron and every fifth thereafter must pass all the tests enumerated below in Parts 1 and 2. The remaining klystrons will be subject only to the tests in Part 1. Passing the applicable tests will ensure acceptance for each klystron.

TABLE A-III
MECHANICAL CHARACTERISTICS

<u>Parameter</u>	<u>Nominal</u>	<u>Maximum</u>
Collector water requirement (at 150-kW output)		4.7 //s
Body water requirement		0.63 //s
Pressure drop in any cooling chamber	344.74 KPa	482.64 kPa
Inlet water temperature		43.3°C
Inlet water pressure		689.48 kPa gauge
Tube weight		362.87 kg
Tube height overall		3.048 m
RF-input connector: Type N		
Ion pump size: 8 //s		

A. Part 1

Operate into a matched load ($VSWR \leq 1.5:1$).

Adjust:

1. Cathode voltage ≤ 86 kV. The mod-anode voltage with the beam will be adjustable in 5% steps to a maximum of 84 kV.

2. The rf drive for optimum output.

3. Video pulse length = 1100 μsec .

4. Radio-frequency pulse length = 1000 μsec .

5. Repetition Rate = 120 pps.

Demonstrate:

6. Average rf-power output $\geq 150 \times 10^3$ W.

7. Incident rf-drive power ≤ 1.5 -W average.

8. Plot the power-input, power-output transfer curve from 350-kW peak power output to full saturation.

9. Operate the tube continuously for 3 h at an average power output $\geq 150 \times 10^3$ W. At the end of this heat run, determine that no component of the tube and magnet assembly has exceeded the rated operating temperature.

B. Part 2

In addition, the following tests will be performed on every fifth tube. The tests in this part will be per-

formed with the adjustments cited in numbers 1 through 5 in Part 1.

Operate into a matched load ($VSWR$ 1.5:1).

Demonstrate:

1. The dynamic gain, as indicated on the power-transfer curve cited in number 8, Part 1, will not deviate by more than 10 dB over the interval of output power from 500 kW to 1000 kW and will not exceed 60 dB nor be less than 47 dB within this interval.

2. The output power, measured with a 1-kHz bandwidth spectrum analyzer and with a 1.0-ms rf pulse, will be less than 40 dB relative to the fundamental over the 600- to 1200-MHz frequency band (with the exception of a ± 40 -kHz band centered at the fundamental frequency).

Operate into a load with $VSWR = 1.5:1$ at 6 approximately equally spaced phase angles. An appropriate, tunable transformer will be provided.

Plot the power-input, power-output transfer curve from zero-power output to full saturation. The dynamic gain, as indicated on the above transfer curve, must not deviate by more than 10 dB over the interval of output power from 500 kW to 1000 kW, and will not exceed 60 dB nor be less than 47 dB within this interval.

APPENDIX B EXPERIMENTAL SETUP

The klystron characteristics were recorded as functions of the rf drive and the load impedance. The information recorded was redundant for checking the measuring system. The following variables were measured:

P_{II} , power input, incident;

P_{IR} , power input, reflected;

P_{OI} , power output, incident;

P_{OR} , power output, reflected;

P_{OL} , power output, delivered to the load;

I_b , beam current intercepted in the body of the klystron.

These variables were not always all measured at the same time.

Figure B-1 is a simplified block diagram of the experimental setup.

The rf source consisted of a high-quality, 805-MHz signal generator and an amplifier that could be

Fig. B-1.

Experimental layout block diagram.

ramp modulated from 0 to 40 W. Harmonics and spurious signals were held 60 dB below the fundamental. For these measurements the amplifier was controlled to deliver three of four ramped pulses for

each setting of the E-H tuner. The isolator protected the source against variations of the klystron input impedance.

The signal from each directional coupler port passes through an inner/outer dc block, to remove ground loop errors; a low-pass filter, to screen out harmonics, and on to a crystal detector. The signals were displayed on X-Y oscilloscopes and recorded on photographs.

The logic coupler following the klystron and an acoustical waveguide arc detector were part of the klystron fault protection system. The signals from the logic coupler were permanently coupled to the fault protection logic, but could simultaneously be monitored on an oscilloscope.

The slotted line was used to determine a detuned-open reference plane and occasionally to check the phase and VSWR of the E-H tuner mismatch. The detuned-open reference plane was determined by replacing the water load with a signal generator and locating a VSW minimum at the operating frequency of 805 MHz. It was not necessary to plot a frequency vs minimum position curve, because the minimal positions at 805 MHz were sufficiently clear.

The E-H tuner mismatches were set according to measured positions of the E-H plungers. An attempt was made to choose points where the plunger settings were least critical. The original set of mismatch points was chosen with the E-H tuner mounted one wavelength from the water load. The water load had a VSWR of 1.05; consequently, when a directional coupler was placed between the E-H tuner and the water load, the distance was adjusted to $n\lambda/2$ to maintain the same E-H tuner mismatch settings.

The waveguide slotted-line and directional couplers used to measure output power are discussed in Ref. 4. All the directional couplers and the slotted line were mounted at least one wavelength away from an elbow, the E-H tuner, or the water load. Because an 805-MHz wavelength in the WR974 waveguide is 0.565 m, and the directional couplers and other components are large, the layout required 15 to 20 m from the klystron to the water load.

Other equipment was used in the experiment. A digital voltmeter and precision high-voltage divider were used to monitor the input voltage to the klystron.

The water load was carefully insulated and fitted with precision thermometers and flow meters to calorimetrically check the average power delivered. A time-mark generator was used with the oscilloscope to determine accurately the pulse width and to calculate peak power from the average power measurements.

The crystal detector, oscilloscope, and camera system were calibrated at 10 different power levels using an rf generator, directional couplers, and an rf power meter. A multiple-exposure photograph was taken to record the calibration. The calibration was then checked at one or two points with the crystal detectors mounted in the system. To check the crystal detectors' measuring of reflected power, the directional couplers were reversed.

Intercepted current measurements were made by taking the difference in cathode current and collector current with a pair of pulse transformers. This measurement could be made only on those klystrons having isolated collectors.

APPENDIX C INTERPRETATION OF REFERENCE PLANES

I. THE REFERENCE PLANE

The selection of the reference plane for the load-impedance Smith chart, where data are plotted, must be made from considerations of the klystron generator.

A plane easily observed experimentally is the VSW's minimum position at the design frequency (805 MHz) in the output waveguide external to the klystron with a matched generator driving the klystron output as a load. This is seen in Fig. C-1. This plane is the logical reference plane because:

Fig. C-1.

Experimental measurement of reference plane.

- (1) It can be measured after the tube is assembled and evacuated.

(2) It is used during manufacture to set up the output-cavity and output-coupling networks.

(3) It corresponds to the operating frequency.

(4) It is less subject to errors of interpretation than are the detuned-open or detuned-short planes due to the dispersive nature of the circuit.

(5) The VSW minimum can be measured more accurately than can the VSW maximum.

II. THE KLYSTRON OUTPUT SECTION

The klystron output section consists of the output gap in a tuned output-cavity, a coupling iris into reduced-height waveguide, a quarter-wave transformer to full-height waveguide, and a window. See Fig. C-2.

The klystron designer wants the impedance presented by the output circuit at the gap to be high (typically 2000 Ω) for efficient power transfer. The output cavity is strongly overcoupled to the waveguide. The output-cavity tuning is accomplished during manufacture by achieving a $\lambda g/4$ movement of the VSW minimum in the full-height waveguide, at the operating frequency, when the output gap is alternately opened and then shorted by inserting a rod along the beam line.

The klystron output circuit is usually considered as a parallel resonant circuit driven by a current generator. The procedure of shorting the output gap

Fig. C-2.
Klystron output circuit.

with a rod produces a detuned-short condition in the output cavity. The position of the VSW minimum in the external guide depends on the characteristics of the output circuit. By following the position of the detuned-short VSW minimum as a function of frequency, and matching this movement to that of a theoretical short, the effective length of the reduced-height-waveguide section can be found. This was done, and the length was determined to be essentially $\lambda g/4$ at the operating frequency, with the effective short at the position of the iris. See Fig. C-3.

Measurement with the output gap open would then show a VSW minimum, $\lambda g/4$ away from plane A, at B. Y_B is real and $Y_B \gg Y_0$. Transformation to plane C results in a real Y_C and $Y_C \ll Y_0$; thus the output circuit impedance at the gap is high, as required.

Plane B is the one which can be measured after the tube is assembled. Its position is the same whether or not there is a dc beam present in the klystron. All data are presented for plotting in terms of impedance at plane B, as found externally.

Although beyond the scope of this report, considerably more detailed modeling of the coupling mechanism from output gap to full-height waveguide has been done using equivalent circuit techniques and experimental data. Detailed transformations would be necessary in relating the experimental data presented here to predictions from theoretical klystron models.

Fig. C-3.
Equivalent output circuit.

APPENDIX D RAW DATA TO CALIBRATED DIGITAL DATA

As explained in Appendix B, raw data were in the form of oscillographs of the variables plotted dynamically against the rf-drive power to the klystron. Polaroid prints were taken at each point, showing the scope graticule and the traces of interest.

Transparencies of approximately 1.5 cm x 1.5 cm. were made of each print on 105-mm film. These were projected onto the screen of a digitizing machine, which had x- and y-crosshairs connected to shaft-angle encoders to allow the coordinates of any point, plus 12 switch settings for run identification, to be

punched on a card. The encoders gave resolution of 10 000 units across the x- and y-screen dimensions, and the projected transparencies nearly filled the full screen. Nine points from the oscilloscope grid were digitized as fiducial marks: the center, each corner, and the middle of each side. The traces were then digitized, with the number of points depending on the curvature of the trace; i.e., more points were taken in portions where the curvature was sharper.

A computer program was written to process this raw digital data into engineering units.

I. REMOVAL OF GRID DISTORTION

The first step was to remove any skew or other distortion from the fiducial grid that might have been introduced by the camera or digitizing machine. Each quadrant of the fiducial grid was more finely meshed to 5×5 , giving a 10×10 grid overall. The grid square in which each data point was located was then found, the fractional location within that square determined, and the units converted using 11-point calibration tables made for the x- and y-axes of the oscilloscope.

Several roughly equivalent methods were tried for locating a point in a distorted grid square. The accuracy was tested by digitizing the entire oscilloscope grid and looking at the errors in placing the intermediate points on the engineering-unit grid. The preferred method is given in Ref. 7.

II. INTERPOLATION IN CALIBRATION CURVES

The rf-power data were taken with crystal detectors, whose output voltages vs rf-power input are known to be smooth, monotonic functions. A linear interpolation of the 11-point calibration curve was not considered adequate for the resolution desired. Several other methods were studied extensively with various data, including an Aitken integration (polynomial fitting) routine and spline-fit methods. The available spline routines had the advantages of fits that are smooth to the second derivative and of allowing the optional use of boundary conditions on the first or second derivatives or periodic conditions. The spline could be used directly on the data, or a smoothed spline could be derived by a least-squares approximation before interpolating.

Other interpolation problems will be treated later, but for the crystal calibration curves, the problem is not difficult because the curves are well behaved. A least-squares spline approximation using five knots was chosen, giving a good fit, adequate smoothing of small offsets in the original curve, and quite smooth variation of the first derivative.

III. OUTPUT

The resulting data, in engineering units, were condensed and reformatted on cards for subsequent use in display programs or for comparison to analytical results.

APPENDIX E DISPLAY PROGRAMS

A master program was written with numerous sub-routines for processing and displaying the data in various ways. Two considerations that have some influence on the displays in this report are explored:

(1) Interpolation and calculation of slopes—treated in this appendix.

(2) Correction for errors in the directional couplers used in the measurements—treated in Appendix F.

I. PLOTS VS RF-DRIVE POWER AS ORDINATE

Graphs of the variables of interest as a function of rf-drive power were made for each load impedance point in various formats. It was also useful to find the derivative of some of these curves, particularly in the case of the input-output power transfer characteristic, where the derivative represents the

dynamic gain of the klystron. Certain constraints are placed on the dynamic gain's variation in the operating region, to have effective closed-loop control of the output. One useful format compared the data against the requirements of the specifications and flagged any out-of-tolerance conditions. These uses require interpolation in the original curves.

II. INTERPOLATION IN THE ORIGINAL OSCILLOGRAPH CURVES

The oscillograph curves can have various types of behavior that make interpolation difficult; therefore various interpolation methods were studied.

Linear interpolation is not accurate and is discontinuous in the first derivative. The Aitken method also was discarded because it is not smooth; even the first derivative can be discontinuous.

Least-squares spline smoothing approximations were discarded for two reasons.

(1) The oscillograph curves were very clear on the digitizer, and the relative accuracy of digitized points along the curve is high. Thus, smoothing is not really necessary.

(2) The method is generally very hard to use because the knots must be placed very carefully to get a good fit without oscillation. The difficulty involves the mathematical nature of the available spline routines, which, unlike the stiff draftsman's spline that smooths itself between knot points, had no constraints on the curvature or stiffness.

Spline interpolation without smoothing was chosen, using all the data points along the curve to determine the spline. The first derivative is smooth all along the spline and is returned directly from the interpolation routine. However, some problems still exist. The curves to be interpolated must not be double-valued; but more important, the spline tends to oscillate in the vicinity of a drastic change in slope, because of the mathematical properties mentioned. Wiggles were introduced even on curves that looked smooth, such as the klystron power-transfer curve, especially where the slope changed from a very high value (nearly straight up) to a lower value. The fit is coordinate-system dependent. Coordinate-system rotation did not solve the problem.

A successful approach involved the introduction of a new variable: the distance along the curve from its start. Each data point was converted to its distance along the curve, and the interpolation was done in this space. Curves of the distance functions are well behaved, and interpolation has been satisfactory. The klystron dynamic gain curves given in this report

sensitively show how much wiggle is left in the spline fit to the power-transfer curve. This remaining wiggle was satisfactorily low for most purposes.

III. SMITH CHART DISPLAYS

The klystron load impedance space was mapped using about 56 different settings of an E-H tuner to cover the Smith Chart out to VSWR's of 7:1. One point was taken at VSWR = 1.0:1; the others were taken at arbitrary, unevenly but fairly uniformly spaced angles on constant VSWR circles of 1.5, 2.0, 3.0, 4.5, and 7.0:1. To make contour maps or other comparisons over the whole load impedance plane at a given drive level, each of the 56 curves must be interpolated at that drive level. This was done as explained above.

The program for contour mapping requires an evenly spaced array in radius and angle. A finer grid is desirable for many purposes, so interpolation is again required.

It was decided to accept the measured complex-reflection coefficients of the E-H tuner at the 56 points as sufficiently accurate without further smoothing. This decision was made on the basis of the instrumentation used⁴ and extensive analysis outlined in Appendix F.

The first interpolation is on the angles, because the original data lie on circles of constant VSWR. Two problems had to be considered: the circular (periodic) nature and areas where the klystron was oscillating, causing gaps in the data over a large part of the circle. Spline interpolation was again used, with a knot at every data point. Periodic boundary conditions were tried, but the fit was less satisfactory than when each end was overlapped three points and the boundary conditions were determined by the data. The points where the tube was oscillating were left out during the interpolation; later the boundaries of the oscillating areas were determined, and the included points were set at arbitrary values.

The second interpolation is along the radii. Again a spline is fit, this time from edge to edge across a diameter instead of only from the center out. Points where the tube was oscillating were treated as described above. The boundary conditions at the ends must be considered to keep the spline from oscillating near the points on the VSWR = 7:1 circle. Therefore, points were defined on the VSWR = ∞ circle, the outer edge of the Smith Chart. The delivered power would be zero on this circle. It might be expected that the intercepted current would be

high; therefore the values on the outer circle were arbitrarily set to the value that had been found convenient as the full-scale value on the oscillographs. The conditions for the reflection coefficient at the input and the dynamic gain of the tube are not clear; therefore the values on the outer circle were set to what they were on the VSWR = 7 circle. These boundary conditions keep the spline pointed in approximately the right direction beyond the VSWR = 7 circle.

In this way, the original 56 data points were interpolated every 5° at 43 radii on each diameter, giving a grid of $72 \times 43 = 3096$ points, from which three-dimensional displays and contour maps were made. Except for delivered power, plotting was stopped at the VSWR = 7 circle. Movies, which give a feeling for the dynamic processes involved, were also made.

APPENDIX F CHECKS FOR DIRECTIONAL COUPLER AND OTHER ERRORS

I. DIRECTIONAL COUPLER ERRORS

Even with a great deal of care, it is very difficult to make a directional coupler with an accuracy of a few percent over VSWR's from one to seven at any angle in a high-power system. Using a distributed design and giving very thorough attention to possible sources of error in manufacture, tuning, and calibration,^{4,8} couplers were produced with very good characteristics, but still with errors greater than desired. However, most of the remaining error could be removed from the data as described below.

In high-power work, the power coupled out is very small compared to the power in the main line. A general model is Fig. F-1.

For the stripline coupler used, $S_{43} = S_{34} \approx 1$ and $S_{33} = S_{44} \approx 0 \approx \Gamma_3 = \Gamma_4$, where Γ_3 and Γ_4 are the reflection coefficients of the detectors at the coupled output ports. The remaining error is then due to less-than-perfect directivity, and

$$\frac{b_3}{b_2} = S_{31} + S_{32} \Gamma_L = S_{31} (1 + C \Gamma_L)$$

$$\frac{b_4}{b_2} = \frac{S_{41}}{\Gamma_L} + S_{42} = S_{42} \left(\frac{B}{\Gamma_L} + 1 \right),$$

where Γ_L = load reflection coefficient = a_2/b_2 . In terms of the power detected at the coupled output ports,

$$P_3 = |b_2|^2 |S_{31} (1 + C \Gamma_L)|^2 / R_0 = P_{inc} |1 + C \Gamma_L|^2$$

$$P_4 = |a_2|^2 |S_{42} \left(\frac{B}{\Gamma_L} + 1 \right)|^2 / R_0 = P_{refl} \left| \frac{B}{\Gamma_L} + 1 \right|^2$$

$$\begin{pmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{pmatrix} = \begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{pmatrix}$$

Fig. F-1.
Directional coupler model.

Then the magnitudes of the true and measured load reflection coefficients are related by:

$$|\Gamma_{indicated}| = \left(\frac{P_3}{P_4} \right)^{1/2} \frac{|1 + C \Gamma_L|}{\left| \frac{B}{\Gamma_L} + 1 \right|}$$

This representation applies at the design frequency only. High-power generators also produce power at harmonic frequencies, particularly at the second in the klystron case. Although usually required to be at least 50 dB below the fundamental, the power at the harmonic outputs is still significant and the directional coupler may couple to it much more strongly than it does to the fundamental. Serious errors can be

introduced unless the coupled output signals are carefully filtered so that only the signal at the fundamental frequency is measured.

These directional coupler errors cause distortions in the size, position, and shape of contours of indicated load reflection coefficient magnitude, $|\Gamma_L|$, plotted on the true Γ_L plane, as shown in Fig. F-2.

When Γ_L is small, near the center, the effect of B will be strong and the effect of C negligible. Conversely, the effect of C will dominate as $|\Gamma_L|$ becomes large. The B term will cause the plane to be only shifted with respect to the Γ_L plane, while the C term will cause both a shift and a change in size. However, if contours of constant $|\Gamma_i|$ are plotted on the Γ_L coordinate system, the shape of the contours is complicated.

Data were taken for both incident and reflected power as detected by the directional coupler ahead of the E-H tuner. At a given drive level, $|\Gamma_i|$ could be calculated at each of the 3096 mesh points and contours drawn. The distortions were clearly present, but the separate contributions of B and C are hard to estimate from this presentation.

The true complex Γ_L was known at each original data point from independent measurements using the slotted line; thus the distortions were known to be due to the coupler. In making the contours above, each measured $|\Gamma_i|$ was plotted at its corresponding true (complex) Γ_L . If, however, the $|\Gamma_i|$ is plotted directly along the radius in the Γ_L plane with the correct angle and the points on each measured VSWR circle are connected, a very useful construction results.

Consider the B error, near the center, which produces the loci shown in Fig. F-3.

The cusp now clearly shows the direction of the B offset, and the magnitude of B can be estimated readily. If the B error is removed from the data and the result plotted again, the effect of C is seen as a shift in the outer circles, from which the size and angle of C can be found directly. Or the reciprocal of the data may be plotted, transforming the effect of C to the center of the chart.

When both B and C errors are removed, slight errors in the magnitude of the coupling constants may be exposed by slight uniform oversized or undersized circles.

Coupler errors were removed in this manner from the data sets in this report. An example is shown in Fig. F-4.

Fig. F-2.

Contours of constant $|\Gamma_i|$ where $\Gamma_i = (B + \Gamma_L)(C\Gamma_L + 1)$ and $B = .06 \angle -120$ and $C = .06 \angle -150$.

Fig. F-3.

Effect of one type of directional coupler error.

VENDOR 1 SN 3

VOLTAGE = 86 KV
COLL. CURRENT = 33.2 AMPS

MAG CURRENT = 14 AMPS
NOO ANODE RES = 16 K

DRIVE = 8.5 W

ORIGINAL DATA

BMAG = .08 • BAND = 90 REMOVED
CMAG = .12 • BAND = -110 REMOVED

BMAG = .08 • BAND = 90 REMOVED
CMAG = .12 • BAND = -110 REMOVED

Fig. F-4.
Contours of constant load reflection coefficient.
Referred to cold 805-MHz short plane. Dots are the
true Γ_L measurement points.

II. DELIVERED-POWER ERROR CHECKING

A. Couplers Before and After the E-H Tuner

The E-H tuner positions for the 56 settings measured at each operating condition were found at high-power conditions with a precision slotted line. The coupling factors of the directional couplers were measured using a precision, calorimetric water-load at high power. If done correctly, a calculation of the power delivered to the tuner/load from the measurements at the coupler before the tuner should agree with the measured power at the water load itself. Therefore, data were also taken from a directional coupler between the E-H tuner and the water load. The reflection coefficient of the water load was independently found to remain constant over the range of power to be used.

Using the contour map programs, contour maps of the two determinations of delivered power were made. The difference between the two was calculated also, and contour maps of the errors were made.

As expected, the E-H tuner contributed a small loss to the system, which could be removed from the data after study of the error contours. Some settings had a higher-than-normal loss, probably corresponding to high, local VSWR's in the tuner arms.

Corrections as described above are necessary for both couplers involved. The power that can be deposited in a load of reflection coefficient Γ_L , by a generator that has a given maximum power available and source reflection coefficient Γ_s , is given by

$$P_{\text{delivered}} = P_{\text{available}} \frac{(1 - |\Gamma_L|^2)(1 - |\Gamma_s|^2)}{|1 - \Gamma_L \Gamma_s|^2}$$

The coupler upstream sees all variations of Γ_L as set by the E-H tuner and the dynamic behavior of the klystron Γ_s . The coupler between the tuner and the water load sees a constant Γ_L , but Γ_s takes all the values set into the E-H tuner. Thus, the problem is further complicated by the introduction of Γ_s factors, but at least the B and C terms for a given coupler may be removed. The effective angles of the error terms for the two couplers must be matched to the same reference plane; rotational offsets can be spotted by distinctive patterns in the delivered power error contours.

The differences between the two methods of determining delivered power were calculated over the 3096-point grid; the rms and maximum and minimum errors were found over nine different runs at four drive levels for each run. Expressing the differences

at each drive level in terms of percent of the maximum power delivered at that drive level, the rms deviation over these 36 comparisons was 2.7%, with a maximum of 2.7% and a minimum of -8.8%.

B. Coupler Ahead of the E-H Tuner

A second comparison can be made by subtracting the delivered power calculated from the incident power measurement and the measured load VSWR's from the delivered power, indicated by the difference between the incident and reflected power measurements.

$$P_{\text{delivered}} = (P_{\text{inc}} - P_{\text{refl}}) = P_{\text{inc}}(1 - |\Gamma_L|^2)$$

Coupler corrections again must be taken into account. In this case, comparing over 10 runs at 5 levels on each run, the rms deviation was 2.1%, with maximum of 2.2% and minimum of -9.3%.

C. Repeated Run Comparisons

Several runs were repeated to check the reproducibility of the E-H tuner and to check different types of crystal detectors. Comparing four runs at four drive levels each showed an rms deviation of 1.5% with maximum of 3.3% and minimum of -4.8%.

D. Summary of All Comparisons

Combining all comparisons in proportion to the number of runs for each type, the overall errors from all causes are estimated as 2.6% rms, and $\pm 6.4\%$ maximum.

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