RF TECHNICAL NOTE

Measurements of RF Power Radiated From Open WR2300 Waveguide Flanges

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7/3/05

A full-height WR2300 waveguide test apparatus was assembled to measure the power density of 351.927MHz rf field radiation escaping from unbolted and gapped waveguide flanges. A drawing and photo of the waveguide test apparatus are shown in Figure 1 and Figure 2 respectively.

Figure 1 – Photo of the waveguide flange leakage test apparatus. *Note the unbolted and gapped flange in the approximate middle of the apparatus.*

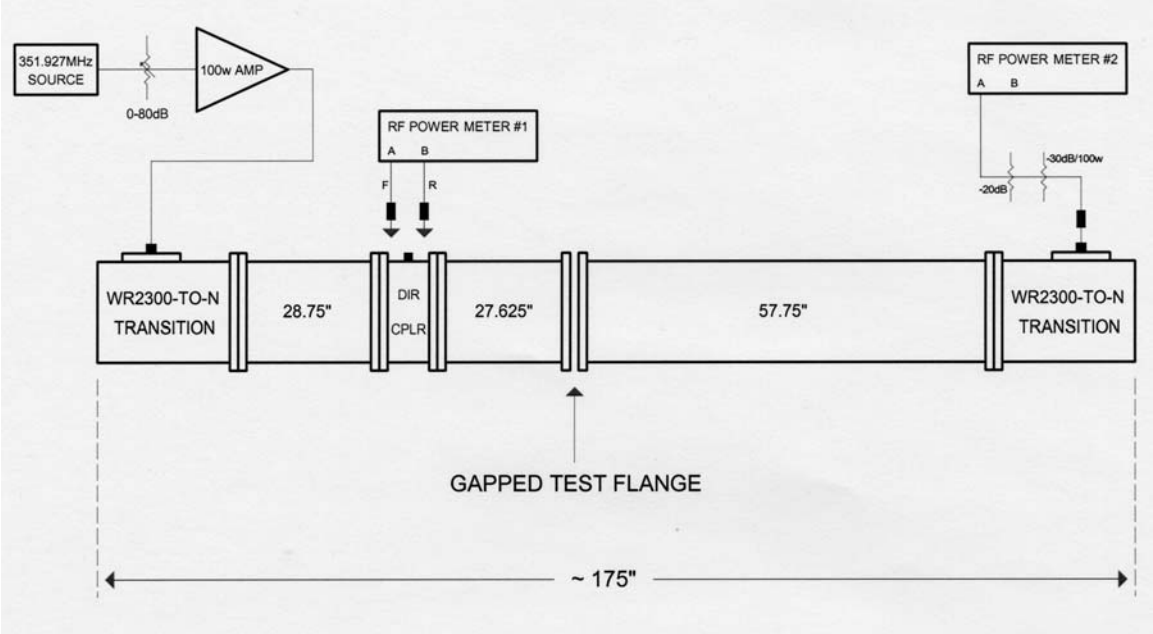

Figure 2 – Drawing of the waveguide flange leakage test apparatus.

Description of the Test Apparatus

The apparatus consists of an assembly of straight WR2300 waveguide pieces and a directional coupler, terminated on each end with a WR2300-to-N transition. One end of the waveguide assembly is connected to a 100-watt CW rf power source at 351.927MHz, and the opposite end is connected to a series of two rf attenuators to absorb excess power and an rf power meter used to measure the rf power exiting the waveguide system downstream of the gapped flange. As shown in Figure 2, a waveguide flange at the approximate center of the test apparatus, referred to as the “gapped flange”, will allow rf power to escape the waveguide. The power density of the rf radiation from the gapped flange will then be measured under controlled conditions. There is an additional rf power meter used to measure the forward and reflected rf power in the waveguide for a confirmation of the termination power readings.

As shown in Figure 2, RF Power Meter #1 is used to measure the forward and reflected rf power in the waveguide upstream from the gapped flange. Information on RF Power Meter #1 is shown in Table

1. Figures 3 and 4 show the connection of RF Power Meter #1 to the waveguide directional coupler.

Table 1: RF Power Meter #1

HP 438A s/n 2743A04606 -- *calibration due on 8/19/05*

"A" Power Head – HP8482A s/n 3318A24570 -- *calibration due on 8/19/05*

"B" Power Head – HP8482A s/n 37290964 -- *calibration due on 8/19/05*

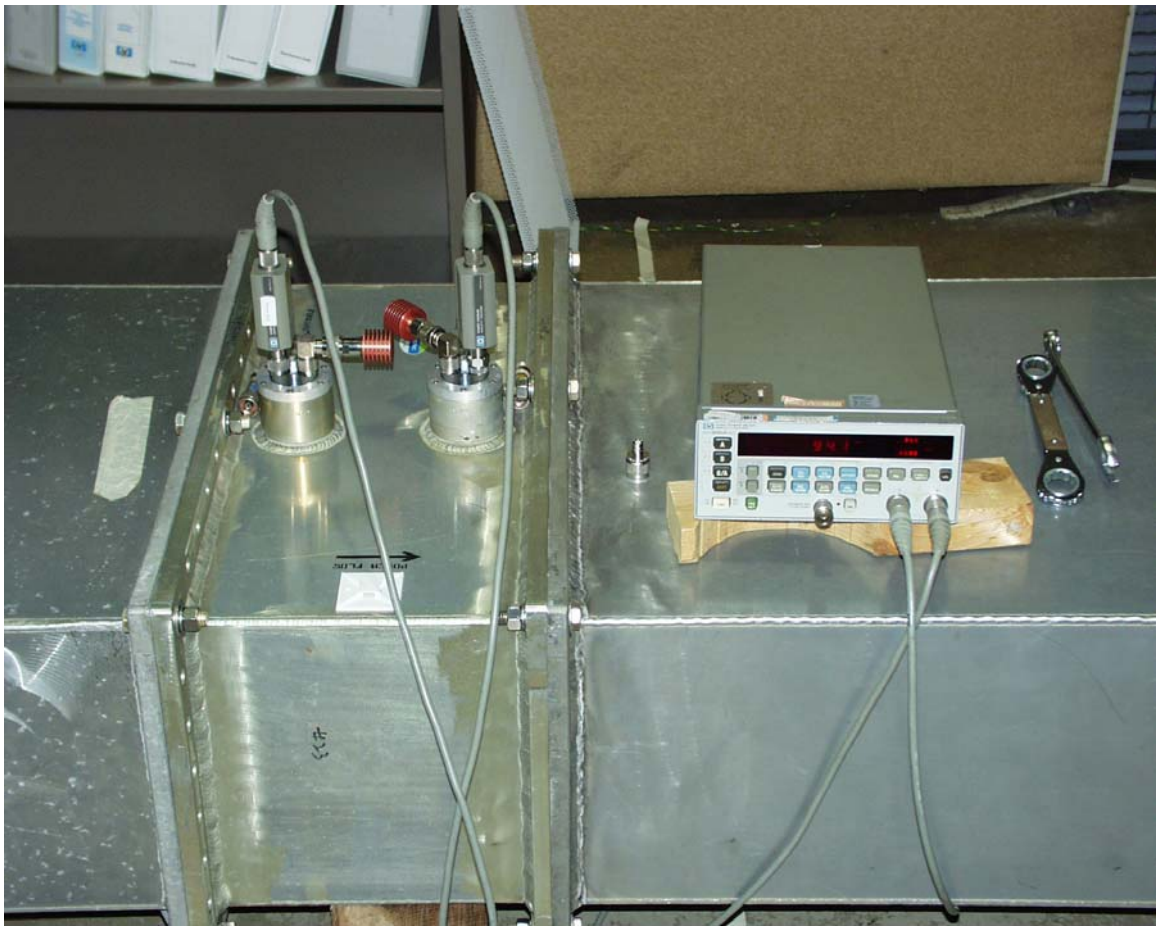

Figure 3 – RF Power Meter #1 connection to the waveguide directional coupler.

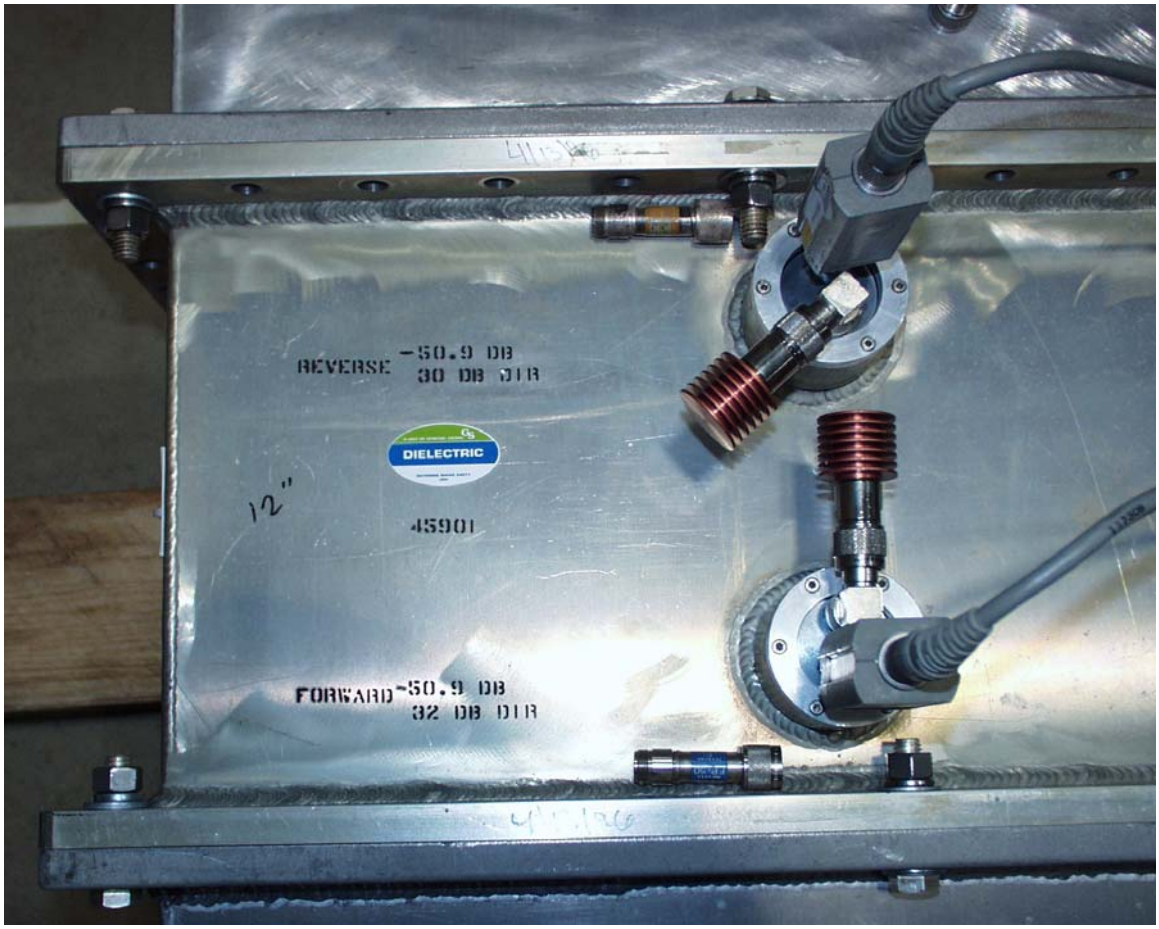

Figure 4 – RF Power Meter #1 connections to the waveguide directional coupler. *Note that no additional attenuators were added between the power heads and the coupler outputs.*

As shown in Figure 2, RF Power Meter #2 is used to measure the rf power exiting the waveguide system downstream of the gapped flange. Information on RF Power Meter #2 is shown in Table 2. Figure 5 shows the connection of RF Power Meter #2 to the downstream end of the waveguide system.

Table 2: RF Power Meter #2

HP 438A s/n 2634A03783 -- *calibration due on 8/17/05*

"A" Power Head – Agilent 8482A s/n US37295323-- *calibration due on 8/17/05*

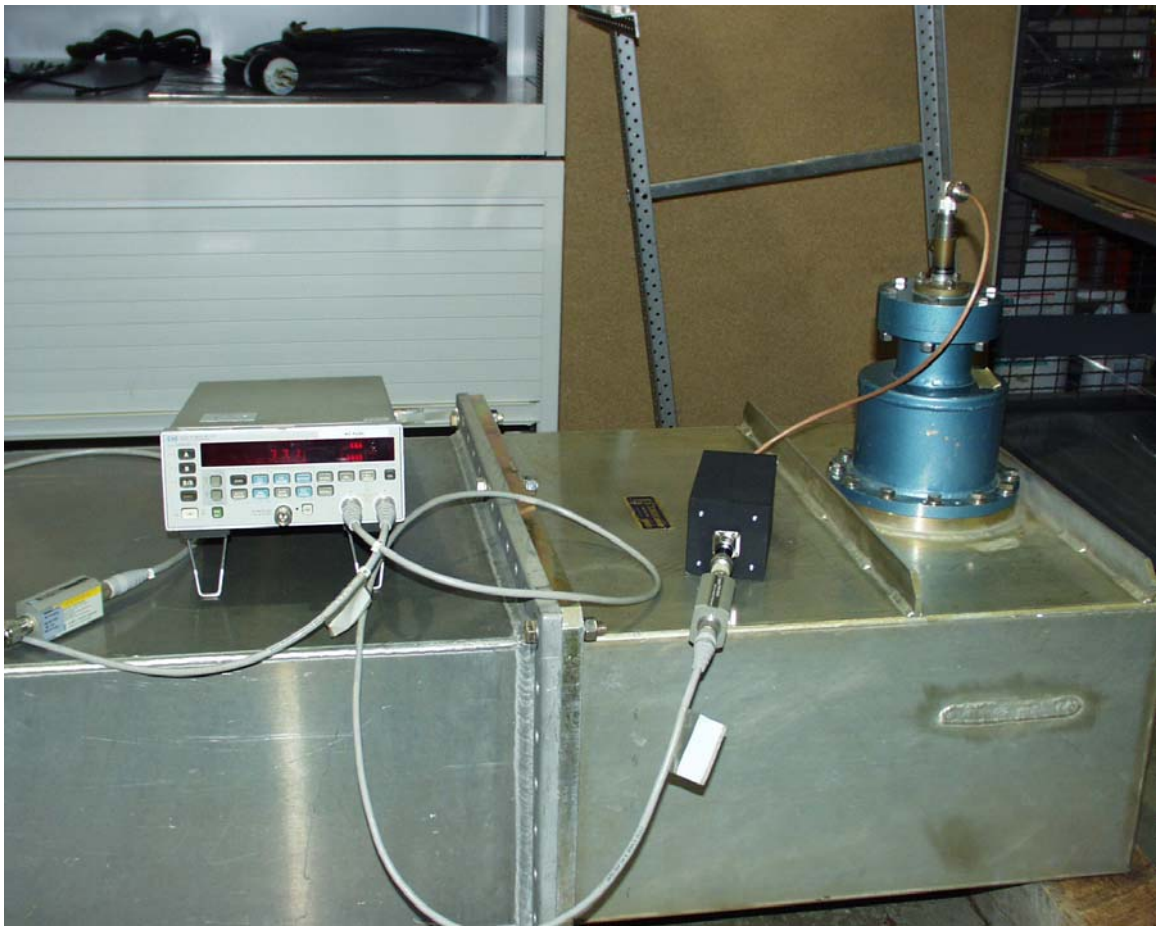

Figure 5 -- The connection of RF Power Meter #2 to the downstream end of the waveguide system. *The combined attenuation of the fixed attenuators and the cable was measured and found to be –50.64dB.*

Figure 6 shows the connection of the 351.927MHz rf source and 100-watt Kalmus amplifier to the input of the waveguide system. A 0-100dB/0.1dB-resolution step attenuator was installed between the rf source and the Kalmus amplifier input to provide calibrated control of the amplifier rf power output.

Figure 6 -- The connection of the 351.927MHz rf source and 100-watt Kalmus amplifier to the input of the waveguide system.

A Narda Model 8712 Survey Meter was used to measure the power density of the rf field radiating from the gapped waveguide flange. Information on the Narda meter is shown in Table 3, and a Figure 7 is a photo of the positioning of the Narda Survey Meter probe when the measurements were made.

Table 3: The Narda Survey Meter

Narda Model 8712 Survey Meter s/n 18009 -- *calibration due on 10/15/05*

Narda E-Field Equivalent RF Power Density Probe, model 8761D,
20mW/square-cm maximum s/n 05014-- *calibration due on 10/15/05*

Note: The correction factor for this probe at 300MHz is 1.10

Figure 7 -- Positioning of the Narda Survey Meter probe on the broad wall of the waveguide, at a distance of 3" from the gapped flange for rf power density measurements. *Note: The metal ruler was pulled a minimum of 36" away when the actual measurements were made.*

The Measurements

The initial measurements on the test system were made with the gapped test flange closed and bolted at the corners and at mid-positions on the side walls. The results of this measurement are shown in Table 4 below. There was no measurable rf leakage from the test apparatus with the gapped flange closed.

Table 4: System RF Power Measurements with a Closed Gapped Flange

- Kalmus rf amplifier power output ≈ 109 watts (read from front panel meter).

- Power Meter #1, Channel A – Forward Waveguide RF Power = 104.3 watts

- Power Meter #1, Channel B – Reflected Waveguide RF Power = 0.976 watts

- Power Meter #2, Channel A – Forward RF Power out of waveguide system = 83.3 watts.

RF Measurements from a Gapped Flange Opened to 0.082"

The gapped flange was opened to a thickness of "one washer", which was measured with a digital caliper as 0.082" (see Figures 8 and 9).

Figure 8 – "One washer" gap measurement.

Figure 9 – Flange gap at 0.082” with one-washer spacers at each corner of the flange.

The rf power density of the field radiated from the 0.082” gapped flange is shown in Table 5 below:

Table 5: System RF Power Measurements on the Broad Wall with a 0.082” Gapped Flange

Probe distance from flange	Narda meter reading	X 1.10 correction	Scaled to 1MW waveguide pwr
3”	0.03mW/sq-cm	0.033mw/sq-cm	330mW/sq-cm
6”	0.01mW/sq-cm	0.011mW/sq-cm	110mW/sq-cm
9”	no reading	no reading	no reading
12”	no reading	no reading	no reading

Power meter #1 reads 104.3w forward/0.727w reflected
Power meter #2 reads 83.3w
There was no measurable rf radiation from the flange on the narrow wall.

The rf electric field power density over the length of the broad wall flange is shown in Figure 10 below. The peak of the reading is in the center of the broad wall flange, and the radiated electric field polarization is demonstrated by the orientation of a separate pickup antenna positioned relative to the gapped flange, as shown in Figure 11 and Figure 12.

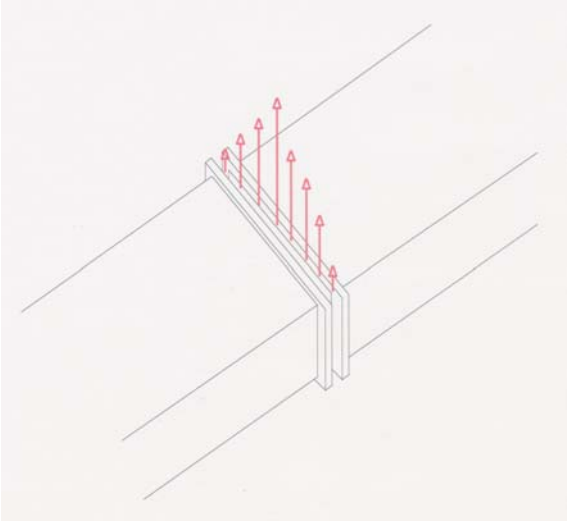

Figure 10 – RF electric field intensity pattern radiating from the gapped broad wall flange.

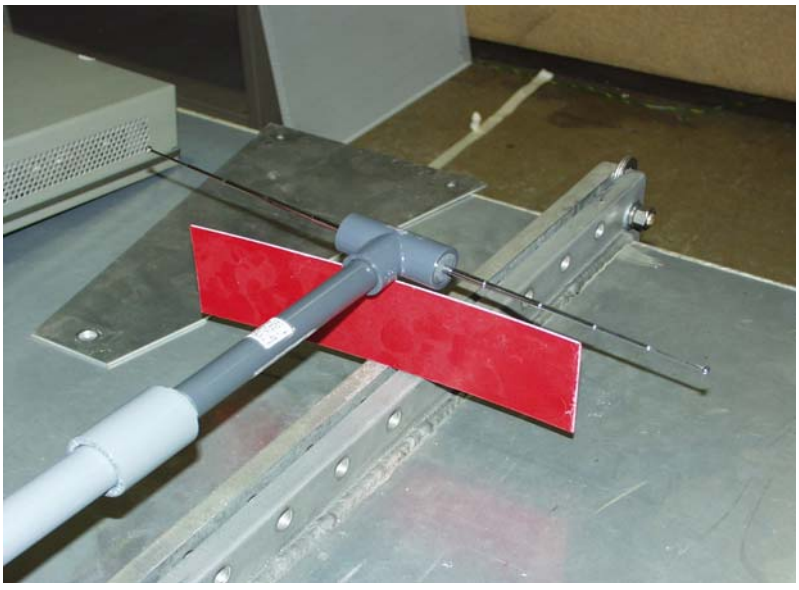

Figure 11 – Antenna orientation for maximum pickup.

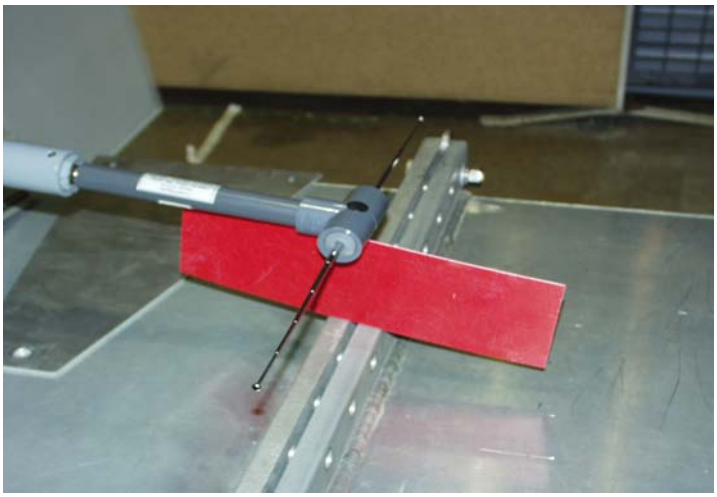

Figure 12 – Antenna orientation for minimum pickup.

RF Measurements from a Gapped Flange Opened to 0.160”

The gapped flange was opened to a thickness of “two washers”, which was measured with a digital caliper as 0.160” (see Figures 13 and 14).

Figure 13 – The “two washer” gap.

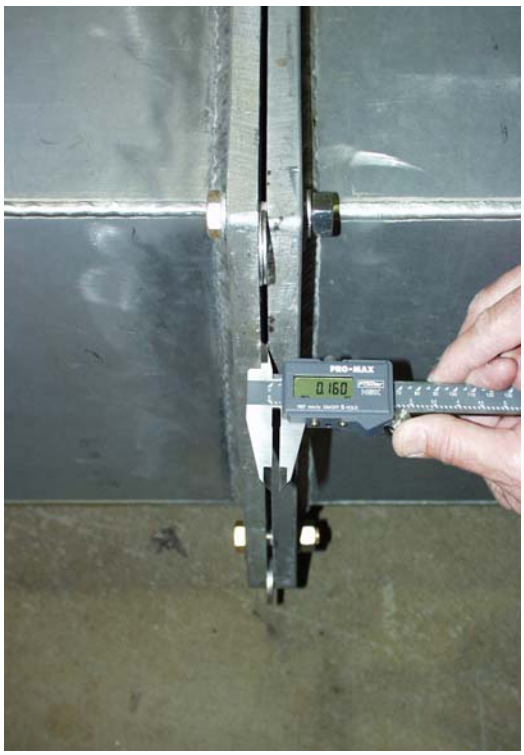

Figure 14 – Measurement of the 0.160” gap

Table 6: System RF Power Measurements on the Broad Wall with a 0.160" Gapped Flange

Probe distance from flange	Narda meter reading	X 1.10 correction	Scaled to 1MW waveguide pwr
3"	0.12mW/sq-cm	0.132mw/sq-cm	1.32W/sq-cm
6"	0.07mW/sq-cm	0.077mW/sq-cm	770mW/sq-cm
9"	0.03mW/sq-cm	0.033mW/sq-cm	330mW/sq-cm
12"	0.01mW/sq-cm	0.011mW/sq-cm	110mW/sq-cm

- Power meter #1 reads 100.7w forward/0.710w reflected
- Power meter #2 reads 80.8w
- *There was no measurable rf radiation from the flange on the narrow wall.*

RF Measurements from a Gapped Flange Opened to 0.239"

The gapped flange was opened to a thickness of "three washers", which was measured with a digital caliper as approximately 0.235" (see Figures 15 and 16).

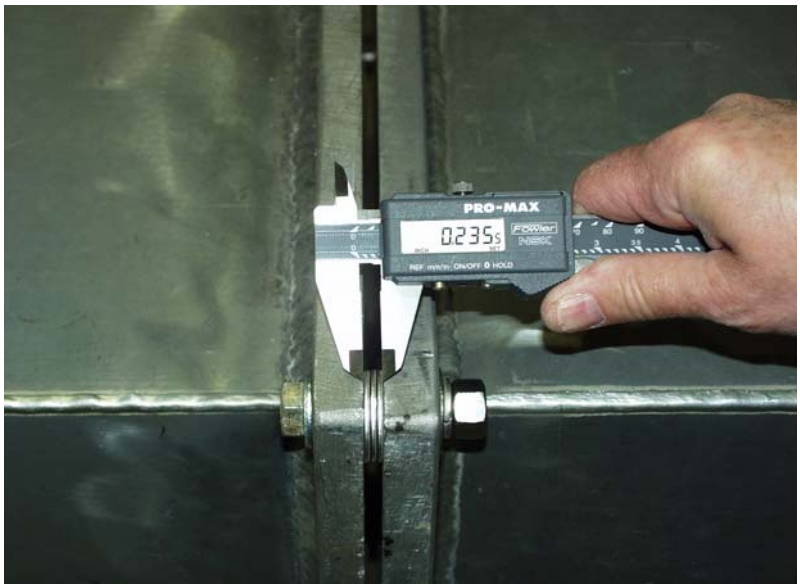

Figure 15 – The "three washer" gap.

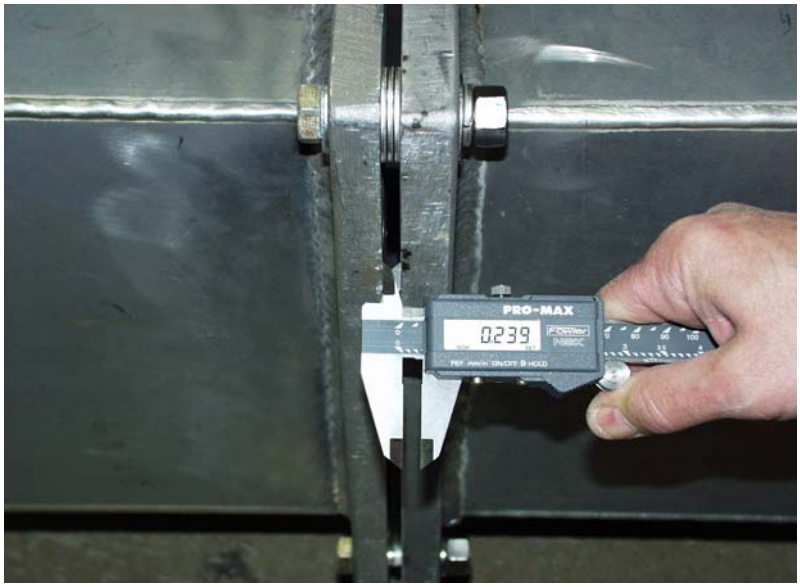

Figure 16 – Measurement of the 0.239” gap.

Table 7: System RF Power Measurements on the Broad Wall with a 0.239” Gapped Flange

Probe distance from flange	Narda meter reading	X 1.10 correction	Scaled to 1MW waveguide pwr
3”	0.28mW/sq-cm	0.308mw/sq-cm	3.08W/sq-cm
6”	0.13mW/sq-cm	0.143mW/sq-cm	1.43W/sq-cm
9”	0.06mW/sq-cm	0.066mW/sq-cm	660mW/sq-cm
12”	0.04mW/sq-cm	0.044mW/sq-cm	440mW/sq-cm

- Power meter #1 reads 104.1w forward/0.723w reflected
- Power meter #2 reads 82.6w
- *There was no measurable rf radiation from the flange on the narrow wall.*

RF Measurements from a Gapped Flange Opened to 1.0”

The gapped flange was opened to a thickness of one inch (1.0”), with no bolts connecting the two sections of the waveguide system together. This arrangement is shown in Figure 17 and Figure 18.

Figure 17 – The 1” gapped flange with no bolts connecting the two sections of the waveguide system together.

Figure 18 – Measurement of the 1” gap.

Table 8: System RF Power Measurements on the Broad Wall with a 1.0" Gapped Flange Without Bolts

Probe distance from flange	Narda meter reading	X 1.10 correction	Scaled to 1MW waveguide pwr
3"	0.47mW/sq-cm	0.517mw/sq-cm	5.17W/sq-cm
6"	0.25mW/sq-cm	0.275mW/sq-cm	2.75W/sq-cm
9"	0.18mW/sq-cm	0.198mW/sq-cm	1.98W/sq-cm
12"	0.13mW/sq-cm	0.143mW/sq-cm	1.43W/sq-cm

- Power meter #1 reads 104.2w forward/0.366w reflected
- Power meter #2 reads 79.9w

There was measurable radiation detected from the narrow wall with a 1" gap without bolts. The rf electric field power density over the length of the narrow wall flange is shown in Figure 19 below. The peak readings are located at the ends of the narrow-wall flange, and the null reading is located at the center of the narrow-wall flange.

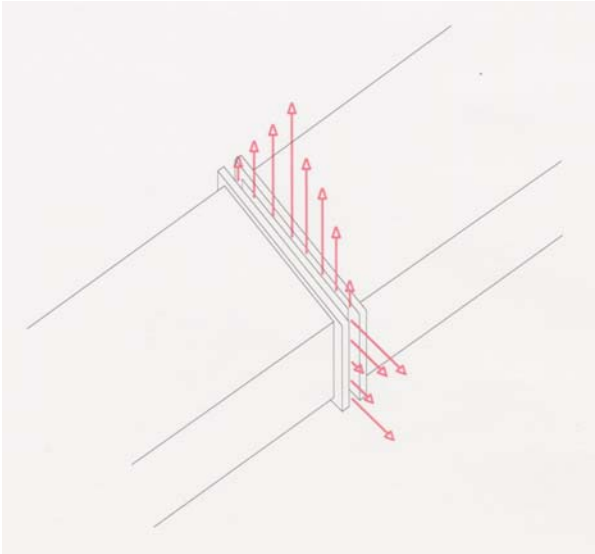

Figure 19 -- RF electric field intensity pattern radiating from the 1" gapped narrow-wall flange without bolts.

Table 9: System RF Power Measurements on the Narrow Wall with a 1.0" Gapped Flange Without Bolts

Probe distance from flange	Narda meter reading	X 1.10 correction	Scaled to 1MW waveguide pwr
3"	0.17mW/sq-cm	0.187mw/sq-cm	1.87W/sq-cm
6"	0.04mW/sq-cm	0.044mW/sq-cm	440mW/sq-cm
9"	no reading	no reading	no reading
12"	no reading	no reading	no reading

- Power meter #1 reads 104.2w forward/0.366w reflected
- Power meter #2 reads 79.9w

An interesting effect was noticed in the case of the 1" gapped flange when bolts were inserted in the flange corner holes (see Figure 20). The rf field power density along the broad wall of the gapped flange was increased dramatically.

Figure 20 – 1" gapped flange with bolts inserted in corner holes.

Table 10: System RF Power Measurements on the Broad Wall With a 1.0" Gapped Flange With Corner Bolts

Probe distance from flange	Narda meter reading	X 1.10 correction	Scaled to 1MW waveguide pwr
3"	2.8mW/sq-cm	3.08mw/sq-cm	30.8W/sq-cm
6"	0.75mW/sq-cm	.825mW/sq-cm	8.25W/sq-cm
9"	0.40mW/sq-cm	.440mW/sq-cm	4.4W/sq-cm
12"	0.25mW/sq-cm	.275mW/sq-cm	2.75W/sq-cm

- Power meter #1 reads 104.1w forward/1.72w reflected
- Power meter #2 reads 77.6w

Table 11: System RF Power Measurements on the Narrow Wall With a 1.0" Gapped Flange With Corner Bolts

Probe distance from flange	Narda meter reading	X 1.10 correction	Scaled to 1MW waveguide pwr
3"	0.07mW/sq-cm	0.077mw/sq-cm	770mW/sq-cm
6"	0.03mW/sq-cm	.033mW/sq-cm	330mW/sq-cm
9"	no reading	no reading	no reading
12"	no reading	no reading	no reading

- Power meter #1 reads 104.1w forward/1.72w reflected
- Power meter #2 reads 77.6w

RF Measurements from a Gapped Flange Opened to 0.185"

The gapped flange was opened to a thickness of 0.185", utilizing calibrated spacers to separate the flanges. This is shown in Figure 21 and 22. The 0.185" gap thickness was derived from measurements taken on the APS 350MHz waveguide system, and represents the minimum waveguide flange gap that will result in a trip of the RF Personnel Safety System on a waveguide air pressure fault.

Figure 21 – Thickness measurement on one of the calibrated 0.185” flange gap spacers.

Figure 22 – Measurement of 0.185” gapped flange separated by a calibrated spacer at each corner of the flange.

Table 12: System RF Power Measurements on the Broad Wall with a 0.185" Gapped Flange

Probe distance from flange	Narda meter reading	X 1.10 correction	Scaled to 1MW waveguide pwr
3"	0.15mW/sq-cm	0.165mw/sq-cm	1.65W/sq-cm
6"	0.05mW/sq-cm	0.055mW/sq-cm	550mW/sq-cm
9"	0.02mW/sq-cm	0.022mW/sq-cm	220mW/sq-cm
12"	0.01mW/sq-cm	0.011mW/sq-cm	110mW/sq-cm

- Power meter #1 reads 104.2w forward/0.628w reflected
- Power meter #2 reads 84.6w
- *There was no measurable rf radiation from the flange on the narrow wall.*