1405-ENG-0009
Manufacturing Report
& QC Data
650 MHz Single Cell Cavities

Part #: 1405G00001-1
S/N's B9AS-AES-001 thru B9AS-AES-006

Approved By:
John W. Rathke
Chief Engineer
4/11/12

Advanced Energy Systems, Inc.

Contents

1.0 Introduction & Overview

This document comprises the quality control data and manufacturing discussion associated with manufacture of six (6) single-cell 650 MHz superconducting RF cavities. These cavities were built using the standard manufacturing techniques that AES has applied to previous fabrication contracts for Fermilab.

1.1 Half-Cell Part Numbering

The part numbering system for the cavity half-cells comes directly from the sheet numbers provided by Fermilab. Material was provided by Fermilab so all certifications reside there.

1.2 Beam Tube Part Numbering

Beam tubes were not individually serialized.

1.3 Non-Conformances

In the course of manufacturing these cavities there were three cases of non-conformances, each of which is discussed further in the following paragraphs. Material Reports for these non-conformances are as follows:

MR-11-0009 – One beam tube came out shorter than the design length due to the blank slipping in the draw tooling causing a skewed draw. This was repaired by EB Welding a short extension to the tube. This tube is part of cavity B9AS-AES-006.

MR-12-0001 – One half-cell (#4) was inadvertently trimmed by twice the intended amount due to an error in the NC programming. It was used as-is and is part of cavity B9AS-AES-002.

MR-12-0002 – The equator weld on cavity B9AS-AES-001 formed two holes on the weld pass. After consultation with Fermilab this was repaired by inserting niobium plugs and rewelding.

2.0 Cavity Fabrication Discussion

2.1. Cell Forming and Water Jet Cutting

Cell forming and water jet cutting was performed at Aerotrades Manufacturing, Inc. in Mineola, NY under direct supervision of AES manufacturing personnel. The blanks for hydroforming the cells and for deep drawing the beam tubes were water jet cut. The end flanges were water jet cut from flat plate.

Half-cell forming went well with no issues. Two test forms were made for measurement by Fermilab. Measurements at AES using a CNC cut template and CMM measurements by Fermilab indicated a slightly under-formed condition from spring-back of the angled face of the cell. Based upon this we elected to re-cut the male punch to over-form that angle by about .016” at the iris. This may have been slightly more than necessary but resulted in a better form than the original die shape.

2.2. Beam Tube Manufacturing

The beam tubes were made by deep drawing the flat sheet through a progression of dies using a vertical press. This process went without difficulty except in one case where the blank shifted in the press causing a skewed draw. The tube came out perfectly fine but it was a little bit short after trimming. This was repaired by welding a short extension piece on the end. The weld can be seen upon visual inspection on the inside diameter but it is completely behind the Nb-Ti flange so cannot be observed from the outside. This beam tube was welded to half-cell #14 and is part of cavity B9AS-AES-006.

2.3. Electron Beam Welding – Iris to Beam Tube

This EB weld was performed from both sides with approximately 80% penetration from the outside and 20% penetration form the inside. There were no issues with these welds.

2.4. Equator Weld Prep Machining

The equator weld preps were machined after receiving the required trim lengths from Fermilab (see section 3.0). Due to a glitch in the NC programming of the equator cut one half-cell, S/N 4, was inadvertently trimmed by a value that was twice the desired amount. That cell was ultimately used in cavity B9AS-AES-002

All cells machined fine but exhibited the typical issue of run-out due to the slightly out-of-round condition of the cell forms. This did not cause any serious issues.

2.5. Electron Beam Welding - Equators

Equator welding had issues due to the shortage of appropriate test pieces for parameter development. The weld prep itself is nominally the same as the ILC cavities with a thickness at the weld of .079”. However due to the much larger thickness of the adjacent material (0.157” vs.0.110”) we did expect the equator weld to require more power to achieve the cosmetic under bead. Because we only had one test cavity for an equator trial we performed pre-testing on pairs of flat plates approximately 3 inches wide and 12 inches long with the .079” weld prep at the joint. After more than one dozen of these tests we had a parameter that we thought was good for the cavity test.

The first cavity weld test was performed with the seal pass at 18 mA and the weld pass at 21 mA. Both seal and weld were done at 100 kV and 10 inches/minute. The result was a weld that was noticeably cold with an irregular under bead. After welding, the cavity was cut in half preserving the weld area. Figure 1 shows areas that are good as well as areas that are too narrow (cold).

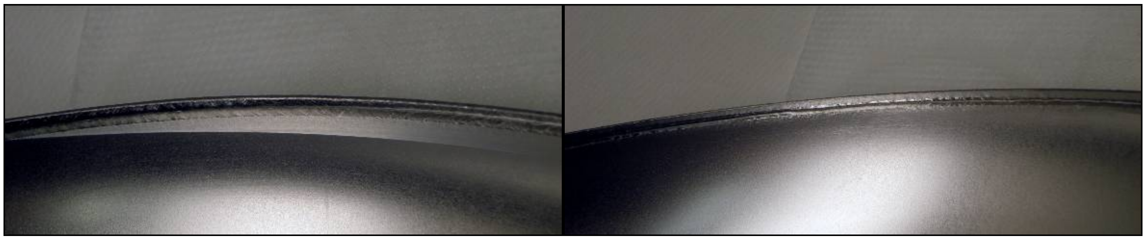

Figure 1 – Test Weld #1, Good Region (L), Thin (Cold) Region (R)

For the second test weld we remachined the weld preps on the test cavity and increased the seal pass and weld pass by 1 mA each so the seal was at 19 mA and the weld was at 22 mA. As before both passes were at 100 kV and 10 inches/minute. This weld resulted in three small melt-thru holes. Again, after the weld we cut the cavity in half preserving the weld zone. Figure 2 shows both an area near the holes and a long section of very nice under bead. Note that the holes closed quickly and did not form a series of holes as typically happens when the beam is not turned off. In this case the bead returned to being excellent almost immediately. This indicated to us that we were very close.

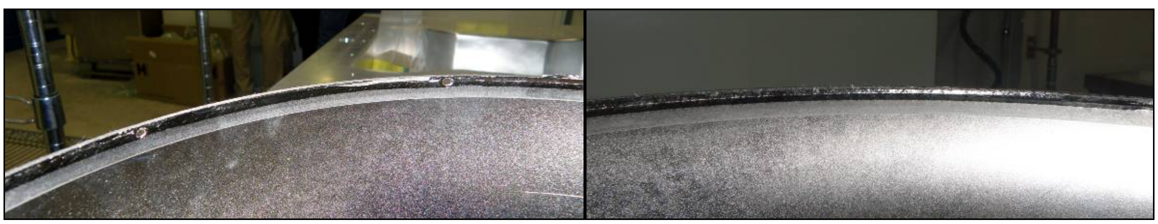

Figure 2 – Test Weld #2, Small Holes (L), Good Region (R)

For the third test weld we again remachined the weld preps on the test cavity and took one mA off of the weld pass. So this weld was performed with a seal at 19 mA and a weld at 21 mA. This resulted in a very nice, well behaved weld that had the appearance of being slightly on the cold side but we elected to declare that this was the parameter for the production cavities. This is the condition of the test cavity as it was delivered to Fermilab. What can be easily noticed, and what we noted at the time, was that having remachined this cavity twice the weld zone was now into the curve of the cell so the geometry was a bit different than a brand new equator. What we could not assess at the time was that this difference was enough to cause very different behavior in a real cavity.

The first production cavity, B9AS-AES-001, was welded using the parameter from test #3 and the result was two widely spaced holes (fig 3), the first of which occurred almost 3 minutes into the weld pass. As with test weld #2 the holes closed up immediately and the balance of the weld was very nice. After consultation with Fermilab the decision was made to repair the weld using small niobium plugs sized to be flush on the inside and slightly proud on the outside. The plugs were first blushed over locally with a 17 mA, 100 kV beam run manually to melt the plugs into the weld on the top surface. We then ran a full seal and weld cycle, increasing the weld pass by 10% over a normal weld. This is a standard rule-of-thumb when rewelding over an existing bead.

Therefore the parameters were 19 mA seal pass and 22 mA weld pass, the 22 being 10% over 20 mA which was now the parameter for a new cavity.

Figure 3 – Holes in B9AS-AES-001 (L), Repair Plugs Installed (R)

The results were very nice (fig 4). The locations of the holes were marked prior to the repair for reference. Location #1 was the first hole to form. One can also note that this cavity came out shorter than the target length due to increased weld shrinkage.

Figure 4 – Cavity B9AS-AES-001 After Equator Weld Repair

Cavities number 002 through 006 were all welded using 19 mA for the seal and 20 mA for the weld. All welds came out very nice.

Worthy of note is the fact that a standard ILC equator weld, which is the same .079” thick at the weld, is performed with a seal pass of 10 mA and a weld pass of 18 mA.

3.0 <u>Inspection and RF Testing Data</u>

After welding of the beam tube assemblies to the half-cells we measured the frequency and the overall length. This data was reported to Fermilab for calculation of the required trim length for the equator weld prep. Figure 5 shows a half-cell during RF measurement. Table 1 presents the dimensional data, frequency data, and trim data for the half-cell assemblies. Note the final three columns that present the expected trimmed length, actual trimmed length, and deviation. Assembly #4 that was over trimmed is highlighted. Also note that due to an oversight, half-cell assemblies #1 and #2 did not have final length measured.

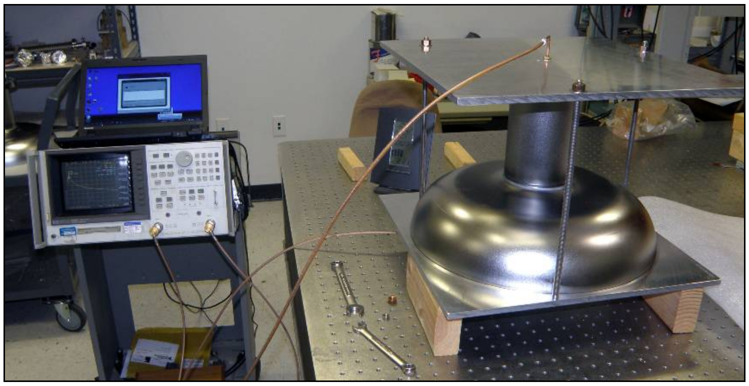

Figure 5 – Half Cell Tune Check

Once complete the cavities were returned to the RF test setup for measurement of the final frequency (figure 6). Final frequency and dimensional data is reported in Table 2.

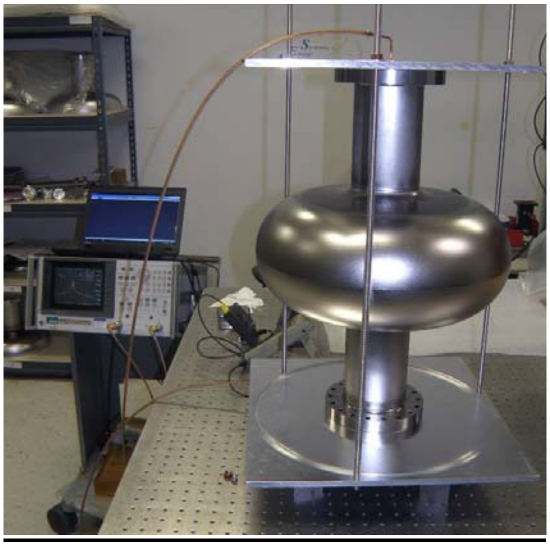

Figure 6 – Complete Cavity Tune Check

The graph with table 2 clearly shows the effects of the weld repair and associated weld shrinkage in cavity B9AS-AES-001. Also clear is the effect of the over trimmed equator on half-cell #4 in cavity B9AS-AES-002. The remaining cavities all fall within a reasonably tight frequency band of 196 kHz.

Cell #	Tair [C]	RH [%]	BP [inHg]	Tcav [C]	Freq [MHz]	Q	Overall Length [in]	L, mm	Fvac, MHz	F at 2K	dF, at 2K	dL trim, mm	dL trim, "	**CUT**	Cell #	Expected Length After Trim (in)	Actual Length After Trim (in)	ΔL (in)
1	24	24	30.03	23	645.265	4222	11.2378	285.4401	645.0852	646.0076	-0.542376	1.86	0.0732	**0.0657**	1	11.1721	N/A	N/A
2	24	24	30.03	23.2	645.293	4223	11.2354	285.3792	645.114	646.0365	-0.513483	1.83	0.0722	**0.0647**	2	11.1707	N/A	N/A
3	24	24	30.03	23.3	645.134	4748	11.2394	285.4808	644.9555	645.8778	-0.672237	1.97	0.0775	**0.0700**	3	11.1694	11.16854	-0.0009
4	24	24	30.03	23.3	645.35	4110	11.2438	285.5925	645.1714	646.094	-0.455988	1.79	0.0703	**0.0628**	4	11.1810	11.11754	-0.0634
5	24	24	30.03	23.3	645.449	4523	11.2479	285.6967	645.2704	646.1931	-0.356874	1.70	0.0670	**0.0595**	5	11.1884	11.18529	-0.0031
6	24	24	30.03	23.2	645.419	4707	11.2511	285.7779	645.24	646.1627	-0.387338	1.73	0.0680	**0.0605**	6	11.1906	11.19054	0.0000
7	24	24	30.03	23.3	645.475	4570	11.2482	285.7043	645.2964	646.2192	-0.330844	1.68	0.0662	**0.0587**	7	11.1895	11.1878	-0.0017
8	24	24	30.03	23.4	645.434	4508	11.2493	285.7322	645.2558	646.1785	-0.371463	1.71	0.0675	**0.0600**	8	11.1893	11.18696	-0.0023
9	24	24	30.03	23.3	645.753	4708	11.2454	285.6332	645.5743	646.4975	-0.052524	1.45	0.0570	**0.0495**	9	11.1959	11.20112	0.0052
10	24	24	30.03	23.1	645.513	4833	11.2437	285.59	645.3335	646.2563	-0.29366	1.65	0.0649	**0.0574**	10	11.1863	11.18546	-0.0008
11	24	24	30.03	23.3	645.603	4605	11.2515	285.7881	645.4243	646.3473	-0.202697	1.57	0.0619	**0.0544**	11	11.1971	11.19653	-0.0005
14	24	24	30.03	23.4	645.458	4588	11.244	285.5976	645.2798	646.2026	-0.347435	1.69	0.0667	**0.0592**	14	11.1848	11.18631	0.0015

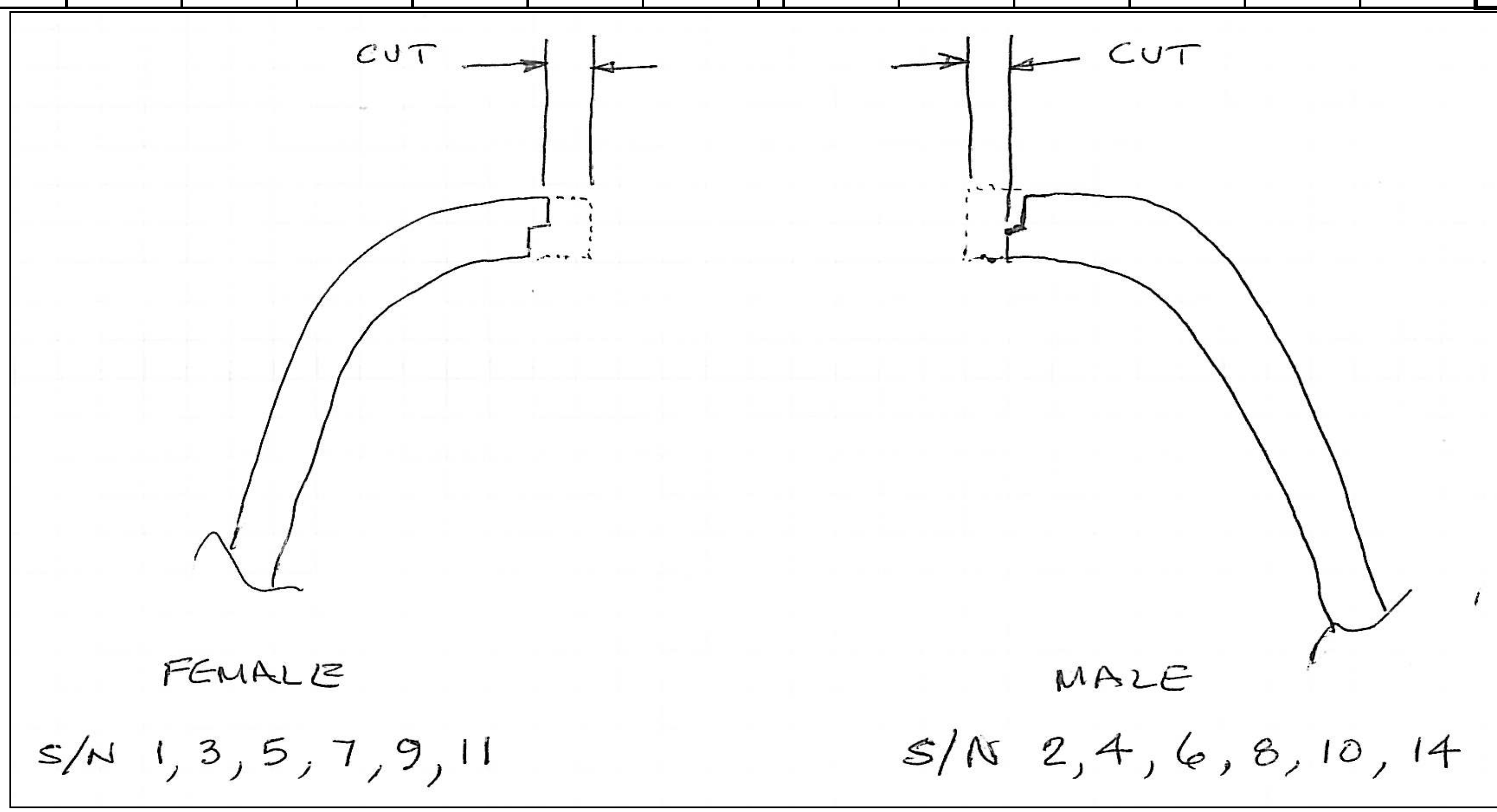

Table 1 – Dimensional Inspection and RF Tuning Data for Half-Cell Assemblies

Cavity No	Half #1 S/N	Half #2 S/N	Length Half #1 (in)	Length Half #2 (in)	Pre-Weld Cavity Length (in)	Post-Weld Cavity Length (in)	Weld Shrinkage (in)	Final Cavity Frequency 20C Vacuum (MHz)
B9AS-AES-001	1	2	N/A	N/A	N/A	22.253	N/A	646.821
B9AS-AES-002	3	4	11.16854	11.11754	22.27108	22.238	-0.03308	647.041
B9AS-AES-003	5	6	11.18529	11.19054	22.36083	22.325	-0.03583	646.162
B9AS-AES-004	7	8	11.1878	11.18696	22.35976	22.3245	-0.03526	646.358
B9AS-AES-005	9	10	11.20112	11.18546	22.37158	22.3295	-0.04208	646.237
B9AS-AES-006	11	14	11.19653	11.18631	22.36784	22.332	-0.03584	646.275

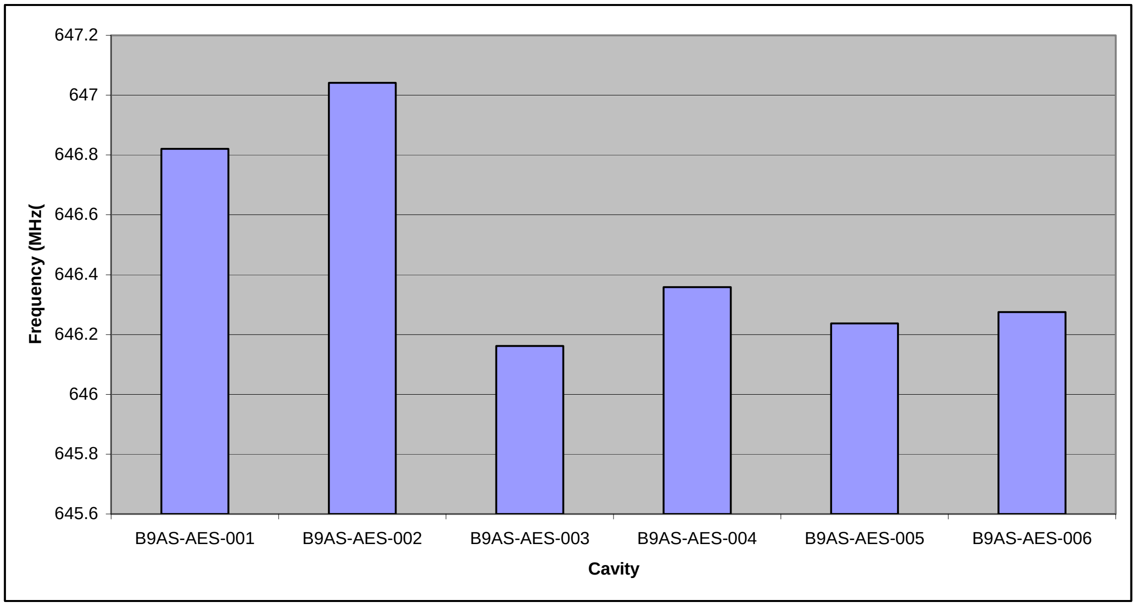

Table 2 – Dimensional Inspection and RF Tuning Data for Complete Cavities

Section 4.0

Vacuum Leak Test Reports

Advanced Energy Systems, Inc.
Leak Test Report

TEST REPORT NUMBER (1)	1405-ENG-0003
TEST PLAN NUMBER (2)	AES-ENG-0001
PROJECT NAME	650MHZ Single cell Cavity
TEST ARTICLE PART NUMBER	1405G00001-1
TEST ARTICLE DESCRIPTION	650MHZ Single cell Cavity
TEST ARTICLE SERIAL NUMBER	B9AS-AES-002
ALLOWABLE LEAK RATE	No Single Point Leak; > 2X10e-10 scc/s
MSLD MODEL NO.	VSMD0301
MSLD SERIAL NO.	LLD00021
CALIBRATED LEAK ID	s/n SC-10D
CALBRATED LEAK VALUE SCC/S	6.4 x 10e-10

TEST RESULTS: No leak detected

COMMENTS:

DATE	**3/6/12**	**TEST PERFORMED BY**	**Jack Ditta**

Notes:

(1) The Leak Test Report number may be obtained from the Project Folder Document Log. Numbering shall be consistent with AES-Q-0003.
(2) A more specific test plan may used in lieu of AES-ENG-0001
(3) This report shall be filed in PDF format in the associated Project Folder and maintained by the Project Leader.

Advanced Energy Systems, Inc.
Leak Test Report

TEST REPORT NUMBER (1)	1405-ENG-0004
TEST PLAN NUMBER (2)	AES-ENG-0001
PROJECT NAME	650MHZ Single cell Cavity
TEST ARTICLE PART NUMBER	1405G00001-1
TEST ARTICLE DESCRIPTION	650MHZ Single cell Cavity
TEST ARTICLE SERIAL NUMBER	B9AS-AES-003
ALLOWABLE LEAK RATE	No Single Point Leak; > 2X10e-10 scc/s
MSLD MODEL NO.	VSMD0301
MSLD SERIAL NO.	LLD00021
CALIBRATED LEAK ID	s/n SC-10D
CALBRATED LEAK VALUE SCC/S	6.4 x 10e-10

TEST RESULTS: No leak detected

COMMENTS:

DATE	**3/6/12**	**TEST PERFORMED BY**	**Jack Ditta**

Notes:

(1) The Leak Test Report number may be obtained from the Project Folder Document Log. Numbering shall be consistent with AES-Q-0003.
(2) A more specific test plan may used in lieu of AES-ENG-0001
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Advanced Energy Systems, Inc.
Leak Test Report

TEST REPORT NUMBER [1]	1405-ENG-0005
TEST PLAN NUMBER [2]	AES-ENG-0001
PROJECT NAME	650MHZ Single cell Cavity
TEST ARTICLE PART NUMBER	1405G00001-1
TEST ARTICLE DESCRIPTION	650MHZ Single cell Cavity
TEST ARTICLE SERIAL NUMBER	B9AS-AES-004
ALLOWABLE LEAK RATE	No Single Point Leak; > 2X10e-10 scc/s
MSLD MODEL NO.	VSMD0301
MSLD SERIAL NO.	LLD00021
CALIBRATED LEAK ID	s/n SC-10D
CALBRATED LEAK VALUE SCC/S	6.4 x 10e-10

TEST RESULTS: No leak detected

COMMENTS:

DATE	**3/6/12**	**TEST PERFORMED BY**	**Jack Ditta**

Notes:

(1) The Leak Test Report number may be obtained from the Project Folder Document Log. Numbering shall be consistent with AES-Q-0003.
(2) A more specific test plan may used in lieu of AES-ENG-0001
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Advanced Energy Systems, Inc.
Leak Test Report

TEST REPORT NUMBER [(1)]	1405-ENG-0006
TEST PLAN NUMBER [(2)]	AES-ENG-0001
PROJECT NAME	650MHZ Single cell Cavity
TEST ARTICLE PART NUMBER	1405G00001-1
TEST ARTICLE DESCRIPTION	650MHZ Single cell Cavity
TEST ARTICLE SERIAL NUMBER	B9AS-AES-005
ALLOWABLE LEAK RATE	No Single Point Leak; > 2X10e-10 scc/s
MSLD MODEL NO.	VSMD0301
MSLD SERIAL NO.	LLD00021
CALIBRATED LEAK ID	s/n SC-10D
CALBRATED LEAK VALUE SCC/S	6.4 x 10e-10

TEST RESULTS: No leak detected

COMMENTS:

DATE	**3/9/12**	**TEST PERFORMED BY**	**Jack Ditta**

Notes:

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Advanced Energy Systems, Inc.
Leak Test Report

TEST REPORT NUMBER [1]	1405-ENG-0007
TEST PLAN NUMBER [2]	AES-ENG-0001
PROJECT NAME	650MHZ Single cell Cavity
TEST ARTICLE PART NUMBER	1405G00001-1
TEST ARTICLE DESCRIPTION	650MHZ Single cell Cavity
TEST ARTICLE SERIAL NUMBER	B9AS-AES-006
ALLOWABLE LEAK RATE	No Single Point Leak; > 2X10e-10 scc/s
MSLD MODEL NO.	VSMD0301
MSLD SERIAL NO.	LLD00021
CALIBRATED LEAK ID	s/n SC-10D
CALBRATED LEAK VALUE SCC/S	6.4 x 10e-10

TEST RESULTS: No leak detected

COMMENTS:

DATE	**3/6/12**	**TEST PERFORMED BY**	**Jack Ditta**

Notes:

(1) The Leak Test Report number may be obtained from the Project Folder Document Log. Numbering shall be consistent with AES-Q-0003.
(2) A more specific test plan may used in lieu of AES-ENG-0001
(3) This report shall be filed in PDF format in the associated Project Folder and maintained by the Project Leader.

Advanced Energy Systems, Inc.
Leak Test Report

TEST REPORT NUMBER [1]	1405-ENG-0008
TEST PLAN NUMBER [2]	AES-ENG-0001
PROJECT NAME	650MHZ Single cell Cavity
TEST ARTICLE PART NUMBER	1405G00001-1
TEST ARTICLE DESCRIPTION	650MHZ Single cell Cavity
TEST ARTICLE SERIAL NUMBER	B9AS-AES-001
ALLOWABLE LEAK RATE	No Single Point Leak; > 2X10e-10 scc/s
MSLD MODEL NO.	VSMD0301
MSLD SERIAL NO.	LLD00021
CALIBRATED LEAK ID	s/n SC-10D
CALBRATED LEAK VALUE SCC/S	6.4 x 10e-10

TEST RESULTS:

COMMENTS:

DATE	**3/9/12**	**TEST PERFORMED BY**	**Jack Ditta**

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