Intel Corporation & Hewlett-Packard Company

Ferrite Clamp/Tube Analysis

Comb Generator Source

CISPR/G/143/CDV

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Ghery S. Pettit, NCE
Intel Corporation
2800 Center Drive
DuPont, Washington 98327
(253) 371-5515

Robert Dockey
Hewlett-Packard Company
18110 SE 34th Street
Camas, Washington 98607
(360) 212-2768

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I. Introduction

CISPR/G/143/CDV proposes amending CISPR Publication 22, 3rd Edition, to include the use of ferrite clamps or tubes on all cables leaving the turntable when performing radiated emissions measurements. The stated purpose of this change is to improve repeatability between different test laboratories.

II. Test Program

The test program reported in this document was designed to provide a more rigorous indication of the effectiveness of placing ferrite clamps or tubes on cables which leave the turntable on reducing measurement uncertainty between laboratories. Tests were performed at three different laboratories by injecting a common mode signal onto a power cord and measuring the resulting radiated emissions at three different laboratories.

The ferrite clamp used for the inter-laboratory comparison testing was a Schaffner INA 726 decoupling clamp. This ferrite clamp is part of the Intel DuPont Site EMC laboratory's IEC 61000-4-6 test system. The MDS 21 and Fischer Custom Communications F-203I-23mm clamps used for the clamp comparison testing belong to the Hewlett-Packard Camas, Washington EMC test facility.

III. Test Facilities and Equipment

Testing was performed at the following EMC laboratories in the states of Washington and Oregon in the United States:

OATS Facilities:

Intel DuPont Site EMC Laboratory, DuPont, Washington

10 meter OATS with a 57 by 67 foot ground plane, elevated about 1 foot above grade. The ground screen is 1/4 inch wire mesh, galvanized after weaving hardware cloth. The ground plane around the turntable area, extending beyond the fiberglass reinforced plastic dome is solid sheet metal, welded periodically at the joints. A Hewlett Packard 8546A receiver is used with an EMCO 3143 Biconilog antenna for measurements up to 1 GHz. Power to the EUT is provided via receptacles mounted to the concrete platform under the center of the turntable. These receptacles are fed from the control building via underground conduits.

Intel Oregon Site EMC Laboratory, Hillsboro, Oregon

10 meter OATS with a 57 by 67 foot ground plane, elevated about 6 inches above grade on one side, with the grade sloping away, resulting in the ground plane being about 30 inches above grade on the other side. The ground screen is 1/4 inch wire mesh, galvanized after weaving

hardware cloth. The ground plane around the turntable area, extending beyond the fiberglass reinforced plastic dome is solid sheet metal, welded periodically at the joints. A Hewlett Packard 8566B spectrum analyzer with a Hewlett Packard 85685A pre-selector and a Hewlett Packard 85650A quasi peak adapter is used with EMCO 3110B and 3146 antennas for measurements up to 1 GHz. Power to the EUT is provided via receptacles mounted to the concrete platform under the center of the turntable. These receptacles are fed from the control building via conduits routed under the ground plane platform.

10 Meter RF Semi-Anechoic Chamber Test Facility

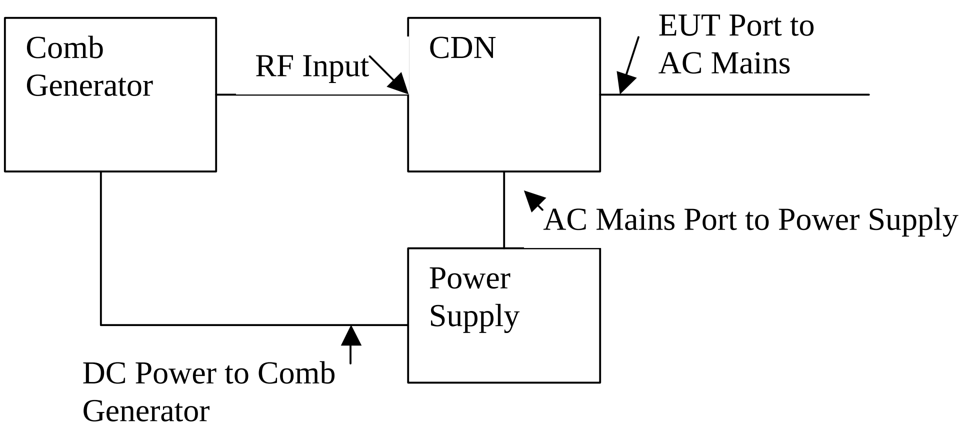
Hewlett-Packard Company, Camas, Washington

10 meter RF semi-anechoic chamber with a 45 by 65.5 foot ground plane. The ground plane is welded steel plate. A Hewlett Packard 8566B spectrum analyzer with a Hewlett Packard 85650A quasi peak adapter is used with a Chase CBL-1112 antenna for measurements up to 1 GHz. Power to the EUT is provided via receptacles mounted in the center of the turntable. Several of these receptacles are fed from flush mounted LISNs which provide a 50 ohm impedance at frequencies up to about 500 MHz. One receptacle is fed via cable from the circuit breaker panel in the turntable pit without passing through an LISN.

All three laboratories are accredited by the American Association for Laboratory Accreditation (A2LA) for emissions testing to CISPR 22 and other standards.

IV. EUT Description

The "EUT" for this round of testing consisted of a comb generator producing harmonics every 5 MHz. This comb generator is a custom made unit belonging to the Hewlett-Packard EMC laboratory in Camas, Washington. The signal from the comb generator was coupled to a power cord using an M2 CDN of the type used for IEC 61000-4-6 immunity testing. Power for the comb generator was taken through the CDN using a power cube type power supply. The mains end of the power cord (connected to the EUT side of the CDN) was plugged into the AC mains at the turntable. Both LISN and non-LISN fed receptacles were tested in the Hewlett-Packard 10 meter chamber. This provided a total of 4 different AC mains conditions for this evaluation (two at Hewlett-Packard and one each at the Intel DuPont and Intel Oregon facilities). A block diagram of the "EUT" is shown below:



The comb generator, CDN and power supply were all placed on the 80 cm high non-conducting table with the CDN mounted on top of the comb generator chassis. The CDN and comb generator were bonded together with copper tape along two sides. The power supply was placed on top of the table in front of the comb generator / CDN combination. The only cable extending below the surface of the table was the power cord connected between the EUT port of the CDN and the power receptacle on the turntable.

Photo #1 shows the "EUT" on the turntable at the Intel DuPont EMC laboratory without a ferrite clamp installed on the power cord. Photo #2 shows the "EUT" at the same location with the ferrite clamp installed.

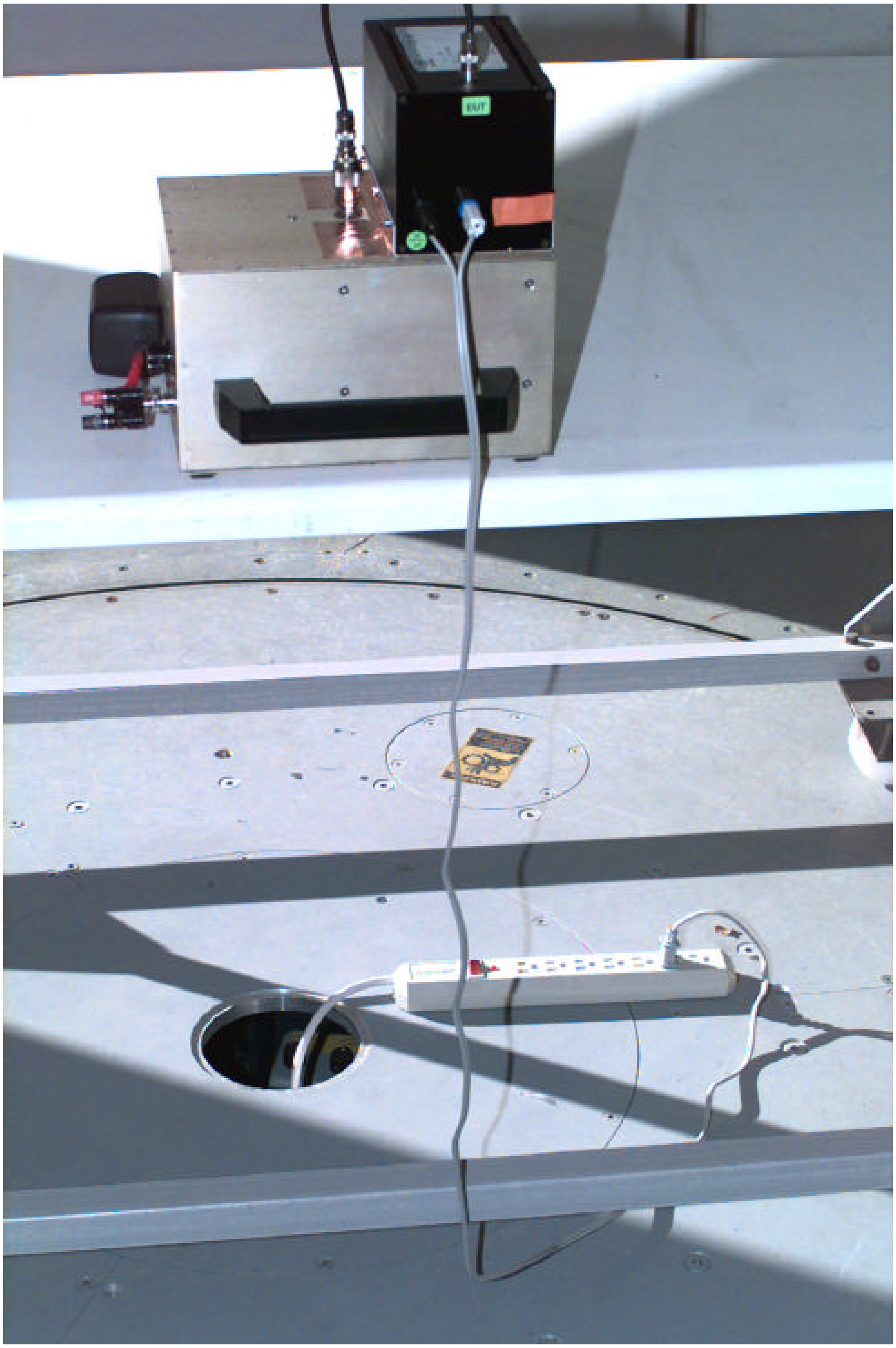


Photo #1 - No Ferrite Clamp on Power Cord

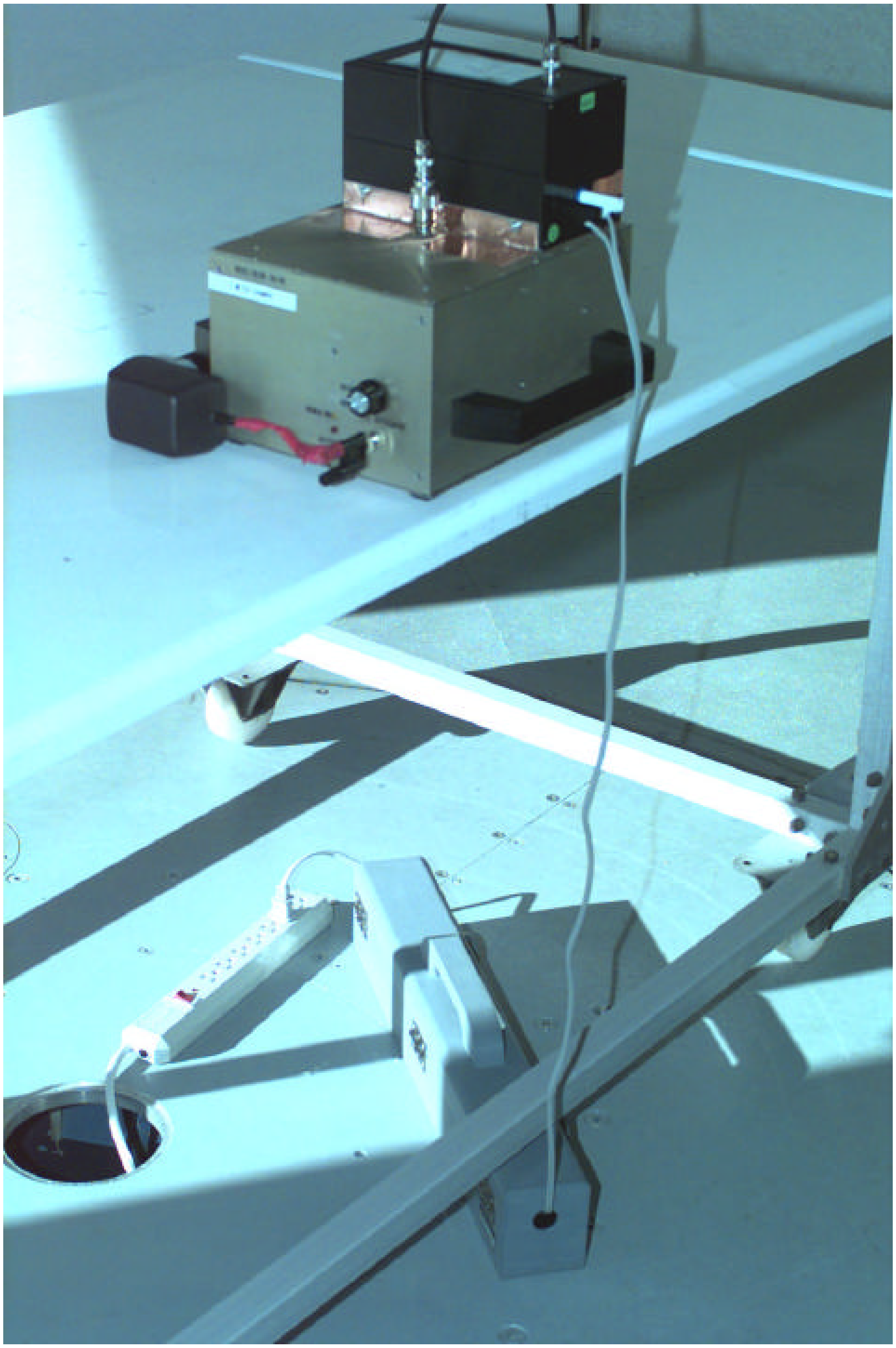


Photo #2 - Ferrite Clamp on Power Cord

V. Test Method

All emissions from the comb generator were measured at 5 MHz steps from 30 MHz to 200 MHz. Only vertical polarization was used as the major emissions were expected to be radiated from the vertically polarized power cord (CDN to floor). The turntable was rotated over a 360 degree range and the receive antenna was scanned from 1 meter to 4 meters above the ground plan to maximize the received signal level. Signals impacted by ambient signals at the two OATS facilities are not included in the analysis. All three facilities maximized first by rotating the turntable and then by scanning the antenna height. All final measurements were taken with a quasi-peak detector. Measurements were taken twice in each configuration, once without the ferrite clamp on the power cord and once with the clamp installed.

In addition to measuring the emissions from the EUT, the impedance characteristics of the Schaffner INA 726 decoupling clamp were also measured. Tests were also performed in the Hewlett-Packard 10 meter RF semi-anechoic chamber on the MDS 21 Absorbing Clamp and the Fischer Custom Communications F-203I-23mm EM Clamp to show how commercial ferrite clamps of different types can vary in their characteristics and effect on test results.

VI. Inter-Laboratory Comparison

The following table shows the data taken at the 3 facilities. No data is shown for the Intel OATS facilities where ambient signals interfered with the readings. The ferrite clamp used for the inter-laboratory comparison was the Schaffner INA 726.

Frequency MHz	HP NEMA No Ferrite	HP NEMA Ferrite	HP LISN No Ferrite	HP LISN Ferrite	Intel DuPont No Ferrite	Intel DuPont Ferrite	Intel Oregon No Ferrite	Intel Oregon Ferrite
30	33.7	27.0	41.2	27.6	33.2	32.1	35.2	31.3
35	37.3	28.3	39.5	27.5	39.0	35.2	41.0	36.7
40	36.6	27.3	36.3	26.5	42.4	35.0	43.0	34.9
45	33.4	30.9	37.4	30.4	39.8	33.0	45.5	39.0
50	37.2	33.4	37.7	33.4	41.5	38.0	41.3	38.4
55	35.4	34.9	36.5	35.2	41.2	41.2		
60	34.0	36.5	36.0	37.4	40.0	42.9	39.1	42.0
65	26.9	37.3	33.9	38.4	36.9	42.1	33.6	40.3
70	38.5	38.5	32.0	39.2	31.6	38.9	36.1	42.7
75	38.8	38.7	28.5	39.3	28.7	39.7	36.5	41.4
80	37.1	39.1	19.6	39.6	31.2	39.8	39.3	41.1
85	40.7	39.5	31.3	39.2	35.8	40.0		
90	39.1	38.9	38.6	38.5	41.2	40.2		
95	41.1	40.4	38.7	39.6				

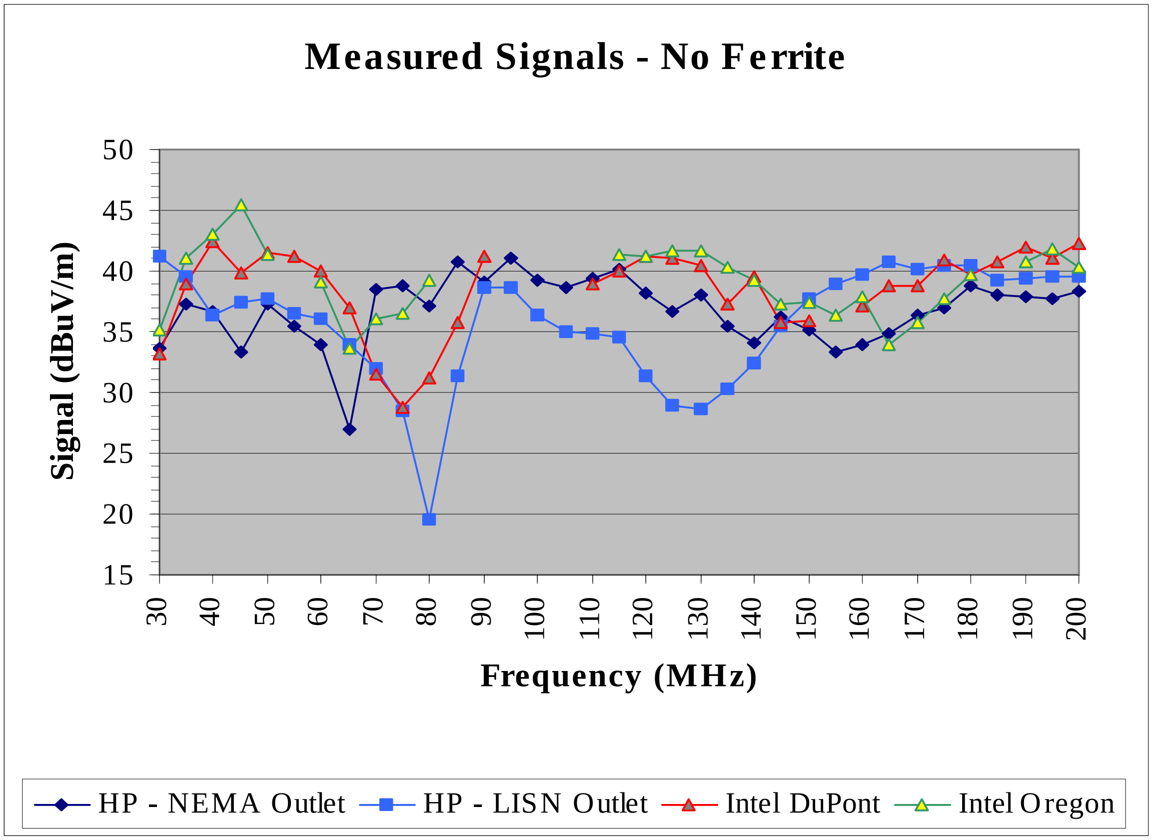
Effect of Ferrite Clamps/Tubes on Radiated Emissions Measurements
Comb Generator Measurements

Frequency MHz	HP NEMA No Ferrite	HP NEMA Ferrite	HP LISN No Ferrite	HP LISN Ferrite	Intel DuPont No Ferrite	Intel DuPont Ferrite	Intel Oregon No Ferrite	Intel Oregon Ferrite
100	39.3	39.6	36.3	39.0				
105	38.7	39.6	35.0	39.2				
110	39.4	40.7	34.9	40.4	39.0	39.7		
115	40.1	41.9	34.5	41.7	40.0	41.0	41.3	41.9
120	38.2	40.8	31.4	40.7	41.3	40.5	41.2	40.8
125	36.7	40.7	29.0	40.6	41.1	38.3	41.7	40.1
130	38.0	40.9	28.6	40.9	40.5	36.5	41.6	41.6
135	35.5	39.5	30.3	39.6	37.3	37.5	40.3	40.6
140	34.1	39.5	32.5	39.4	39.5	39.1	39.2	40.8
145	36.2	40.7	35.5	40.6	35.8	35.7	37.3	39.4
150	35.1	41.1	37.7	41.0	36.0	38.5	37.5	40.8
155	33.4	40.7	38.9	40.7			36.4	40.1
160	33.9	40.8	39.7	40.8	37.1	39.8	37.9	41.2
165	34.9	41.2	40.7	41.2	38.8	40.3	34.0	39.6
170	36.3	40.2	40.1	40.2	38.8	40.6	35.7	39.8
175	37.0	40.5	40.4	40.4	41.0	40.9	37.7	40.1
180	38.8	40.8	40.4	40.6	39.8	39.8	39.7	41.2
185	38.0	40.0	39.2	40.0	40.8	40.4		
190	37.9	39.9	39.4	40.1	42.0	41.0	40.7	41.6
195	37.7	40.0	39.6	40.3	41.1	41.0	41.8	41.1
200	38.3	40.6	39.6	40.5	42.3	42.0	40.3	41.8

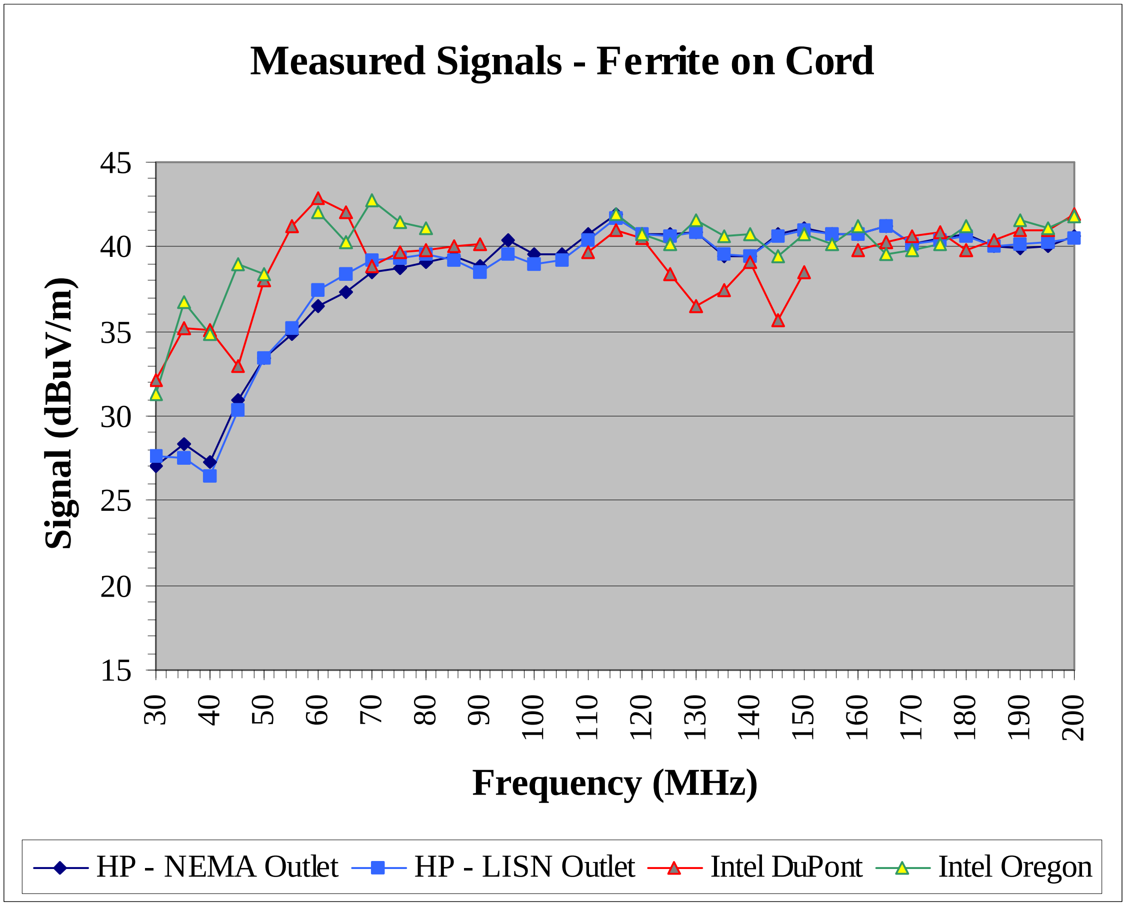
The following table shows the change in spread between the high and low readings at each frequency when the ferrite clamps were added.

Frequency MHz	Spread No Ferrite	Spread With Ferrite	Spread Change by adding Ferrite
30	8.0	5.1	-2.8
35	3.7	9.2	5.5
40	6.7	8.5	1.8
45	12.1	8.6	-3.5
50	4.3	5.0	0.7
55	5.8	6.3	0.5
60	6.0	6.4	0.5
65	10.0	4.8	-5.3
70	7.0	4.2	-2.8
75	10.3	2.7	-7.6
80	19.7	2.0	-17.7
85	9.4	0.8	-8.6
90	2.6	1.7	-0.8
95	2.4	0.8	-1.6
100	3.0	0.6	-2.4
105	3.7	0.4	-3.3
110	4.5	1.0	-3.5
115	6.8	0.9	-5.9
120	9.9	0.3	-9.6
125	12.7	2.4	-10.3
130	13.0	5.1	-7.9
135	10.0	3.1	-6.9
140	7.0	1.8	-5.2
145	1.8	5.0	3.2
150	2.6	2.6	0.0
155	5.5	0.6	-4.9
160	5.8	1.4	-4.4
165	6.7	1.6	-5.1
170	4.4	0.8	-3.6
175	4.0	0.8	-3.2
180	1.6	1.4	-0.2
185	2.8	0.4	-2.4
190	4.1	1.7	-2.4
195	4.1	1.1	-3.0
200	4.0	1.5	-2.6

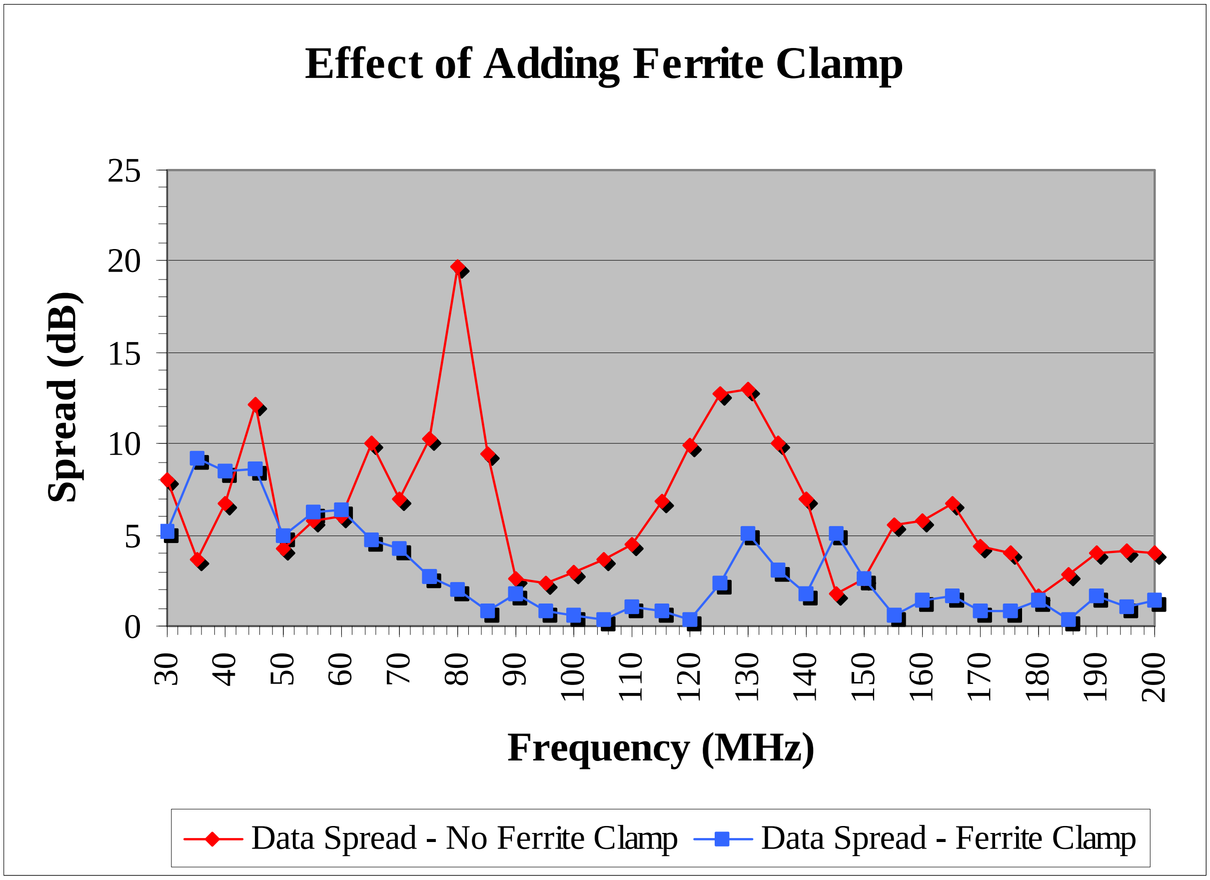
The following graph shows the data taken at the different laboratories without ferrite clamps on the power cord. Notice that the resonance frequencies between 60 and 80 MHz are different in each case. This would appear to be due to the different power distribution schemes for each test. The differences in these resonant frequencies can cause large deviations between results from different labs.



The graph on the next page shows the same comparison between the different laboratories with the Schaffner INA 726 decoupling clamp placed on the power cord. Note that much better agreement is seen between the different labs.


Measured Signals - Ferrite on Cord
Signal (dBuV/m)
45
40
35
30
25
20
15
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
Frequency (MHz)
HP - NEMA Outlet
HP - LISN Outlet
Intel DuPont
Intel Oregon

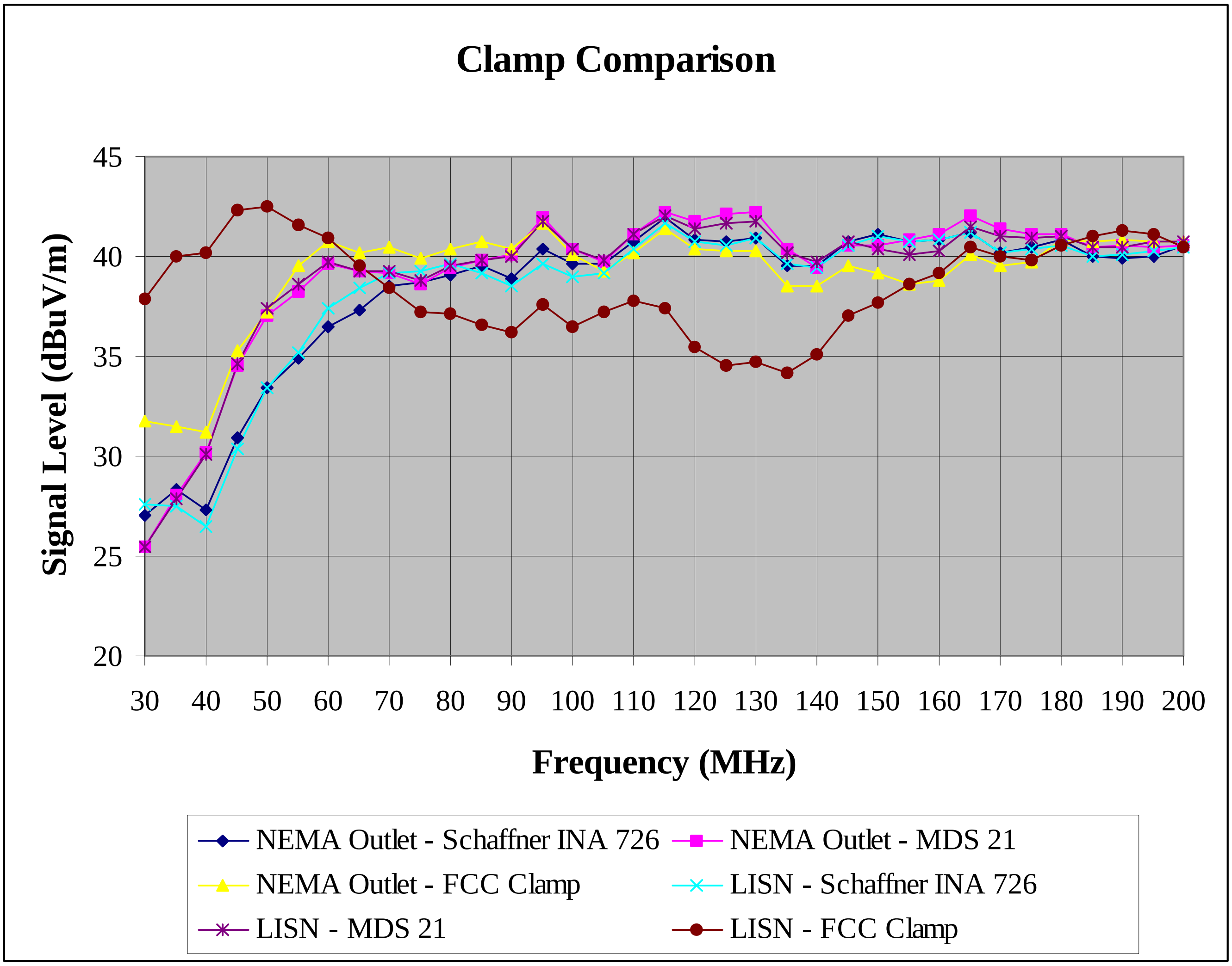
The following graph shows the maximum spread at each frequency, both with and without the ferrite clamps installed on the power cord. This graph clearly shows the improvement provided by adding the ferrite clamp to the power cord.



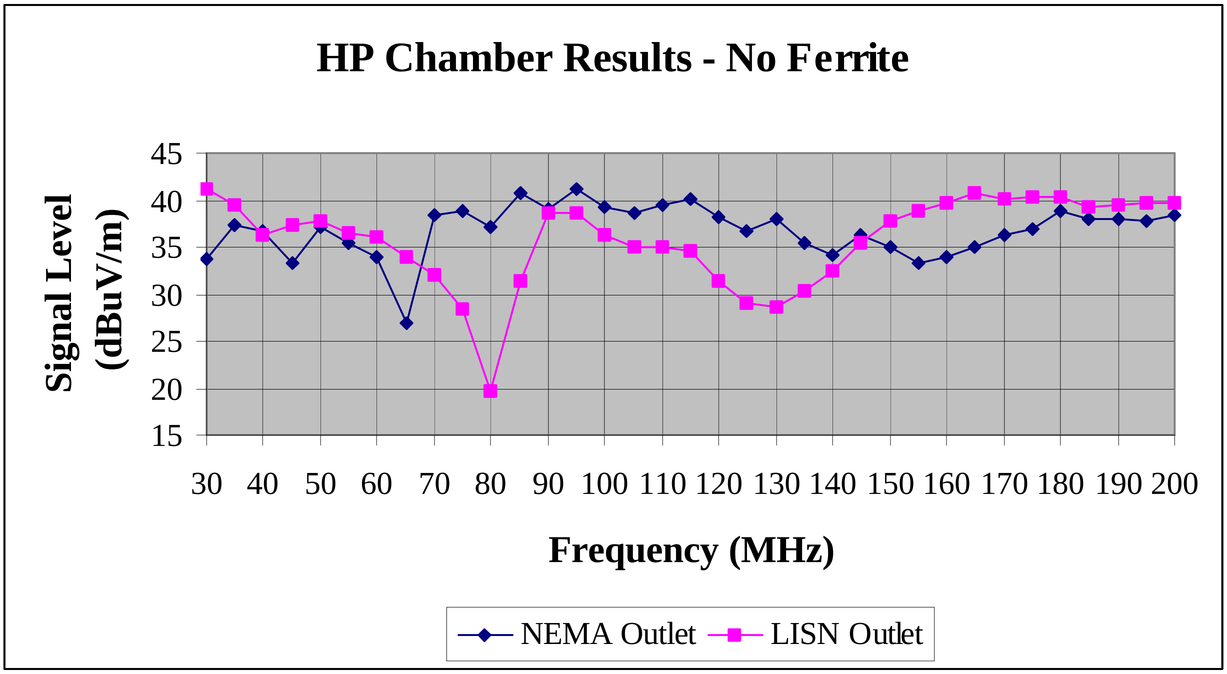
VII. Ferrite Clamp Comparison

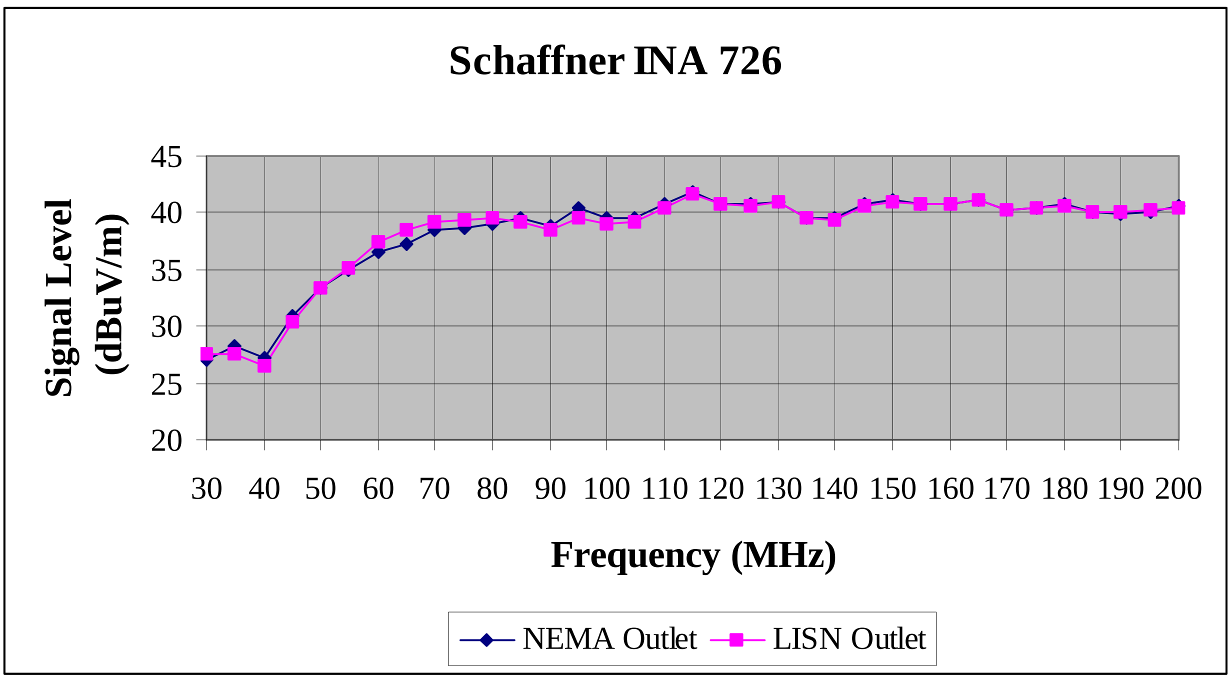
Data was taken at the Hewlett-Packard facility to compare the effectiveness of three commercially available ferrite clamps. The Schaffner INA 726 isolation clamp (used above), the MDS 21 CISPR 22 absorbing clamp and the Fischer Custom Communications F-203I-23mm EM clamp were compared. Testing was performed with the EUT power cord plugged into both the LISN fed and standard NEMA outlets in the face of the turntable in the 10 meter RF semi-anechoic chamber.

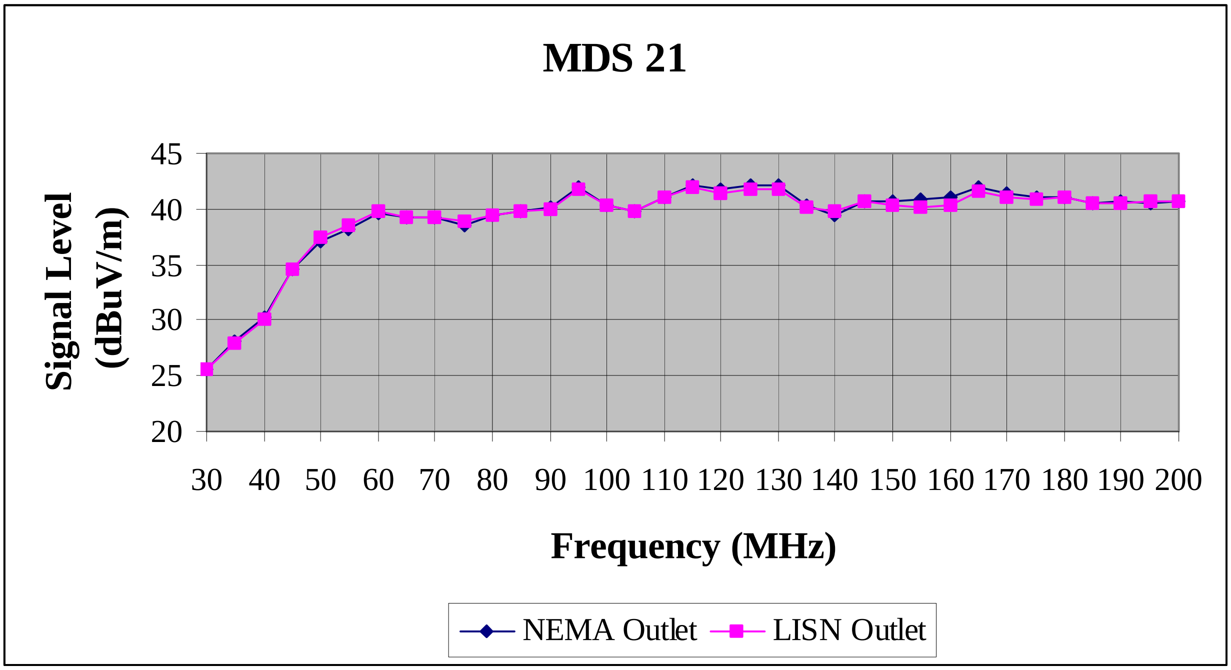
As seen in the graph on the following page, the different clamps have different effects on the results. The Schaffner INA 726 isolation clamp does a good job of reducing the spread between the LISN fed and NEMA outlets. The MDS 21 absorbing clamp also does an excellent job of reducing the spread. The Fischer Custom Communications F-203I-23mm EM clamp, on the other hand, does not do as effective a job. Note also that the Schaffner INA 726 isolation clamp and the MDS 21 absorbing clamp give different results.

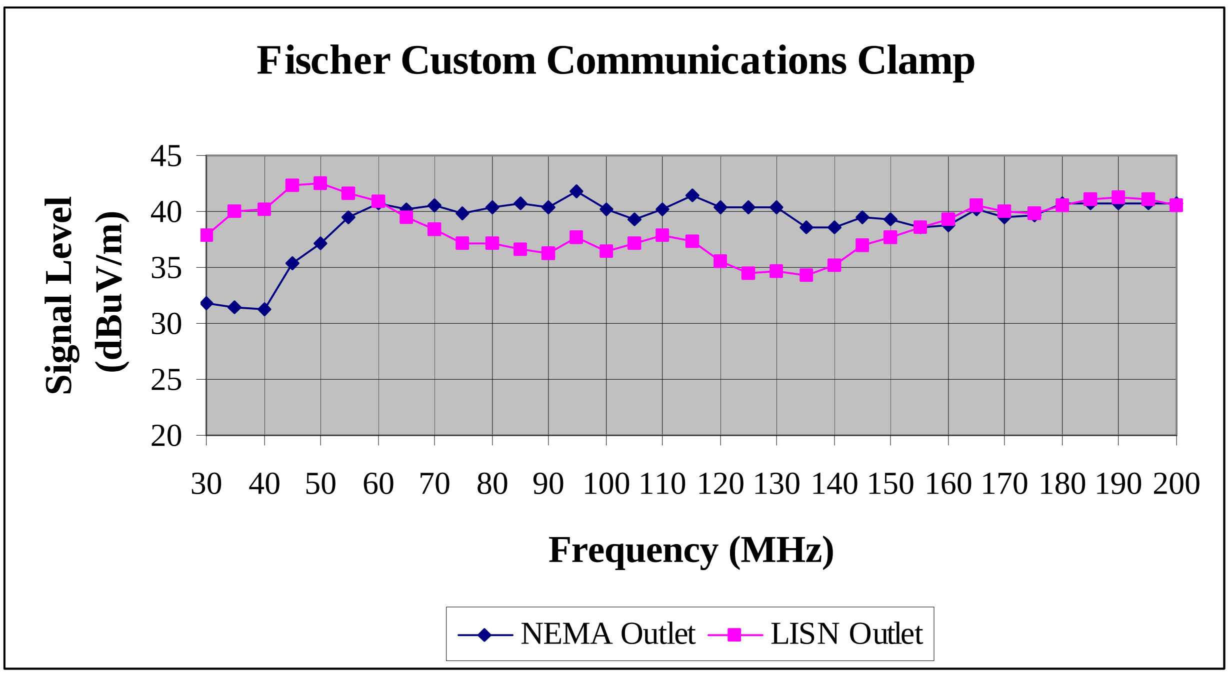


The following graphs show the effects of the different clamps separately, comparing the results obtained from the two power feeds in the chamber. Also shown is the difference between the two power feeds without a ferrite clamp on the power cord.


HP Chamber Results - No Ferrite
Signal Level (dBuV/m)
45
40
35
30
25
20
15
30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
Frequency (MHz)
NEMA Outlet
LISN Outlet


Schaffner INA 726
Signal Level (dBuV/m)
45
40
35
30
25
20
30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
Frequency (MHz)
NEMA Outlet
LISN Outlet

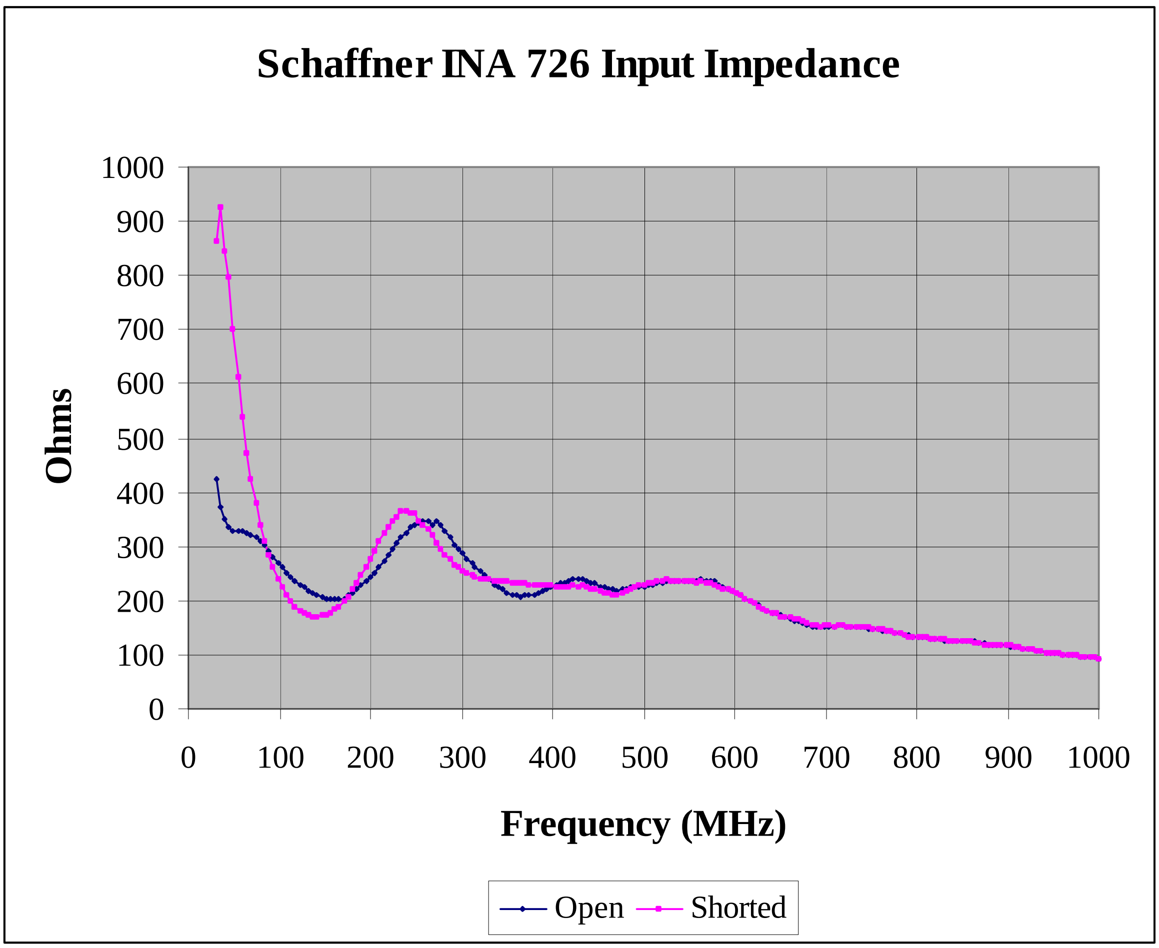


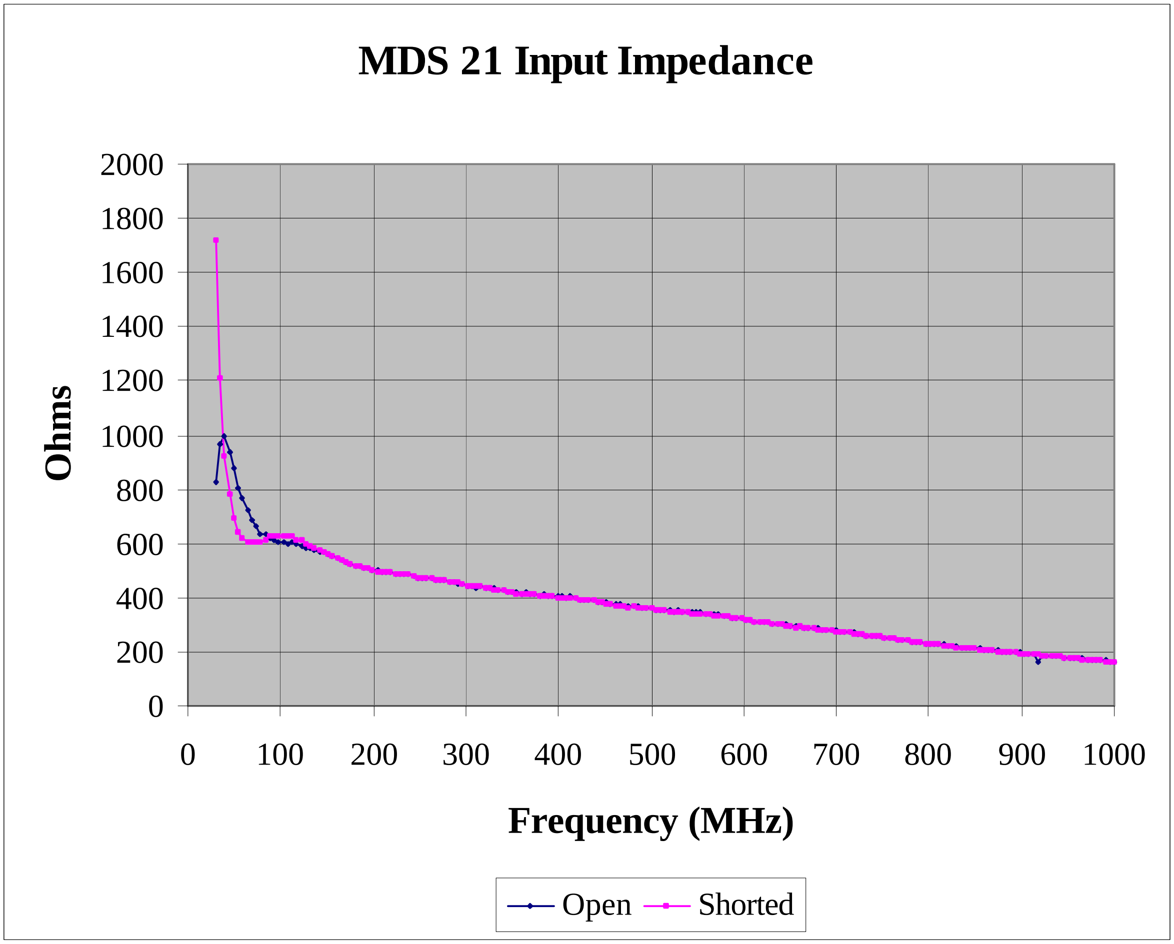


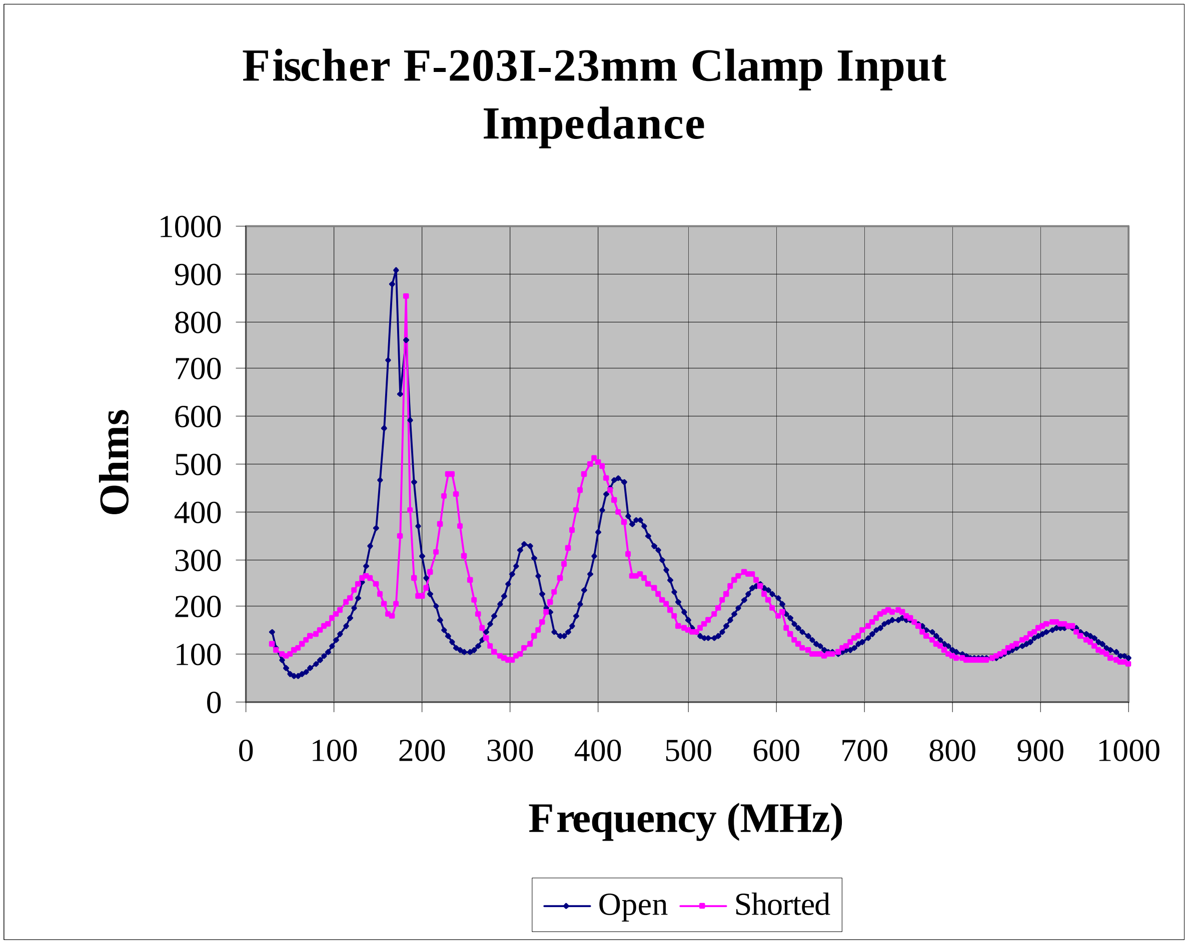
These graphs show that different ferrite clamps provide different results. The MDS 21 absorbing clamp provides the best decoupling of the power feed impedance from the measurement results with the Schaffner INA 726 in a close second. The Fischer Custom Communications F-203I-23mm EM clamp is far less effective in this role.

VIII. Ferrite Clamp Information

The ferrite clamp used for the inter-laboratory comparisons was a Schaffner INA 726 decoupling clamp. In addition, a MDS 21 absorbing clamp and a Fisher Custom Communications F-203I-23mm EM clamp were investigated. CISPR/G/143/CDV calls for using clamps which provide at least 15 dB of loss in a 50 ohm system. The impedance of this clamp was measured as a function of frequency with a network analyzer and a test jig similar to the EM Clamp calibration fixture called out in IEC 61000-4-6. The clamp was tested with the wire through the center of the clamp open circuited and shorted to the reference. The network analyzer was set to read the magnitude of the impedance of the load at the end of a coaxial cable. The following graphs show the input impedance of the three clamps as measured by the network analyzer at the EUT end of the clamp. Two measurements are depicted, one with a "short" and one with an "open" at the far end of the clamp.




MDS 21 Input Impedance
Ohms
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
100
200
300
400
500
600
700
800
900
1000
Frequency (MHz)
Open
Shorted



The first graph shows that the impedance of the INA 726 clamp is relatively independent of the load impedance at frequencies much above 300 MHz. Below about 300 MHz the load has an impact on the overall impedance "seen" by the network analyzer. The variation above 76 MHz, the frequency where the two plots make their first crossing, however is very small. The second graph shows that the same is true for the MDS 21 absorbing clamp at frequencies above 100 MHz. Finally, the third graph shows that the Fisher F-203I-23mm clamp, on the other hand, is heavily impacted by the load impedance (open or short circuit) at frequencies below about 600 MHz.

The insertion loss of all three clamps was measured over the frequency range of 30 to 1000 MHz by measuring the loss when the clamp, in an IEC 61000-4-6 EM clamp calibration fixture, was inserted into the transmission line. The Schaffner INA 726 isolation clamp and the MDS 21 absorbing clamp both provided more than the required 15 dB of loss while the Fischer Custom Communications F-203I-23mm clamp just provided that number around 250 MHz (and had better performance at most other frequencies). If this were the only measurement made, all three clamps would be judged adequate for the purpose proposed in CISPR/G/143/CDV.

IX. Conclusions

Two conclusions may be reached from the data taken in this round of testing:

- The data taken at the 3 facilities shows that the use of ferrite clamps on cables leaving the turntable (in this case, power cords) can significantly improve repeatability between laboratories.
- The data also shows, however, that the characteristics of the ferrite clamps must be controlled more completely than simply specifying an insertion loss figure in a 50 ohm system. The absolute input impedance of the clamp must also be specified. Failure to do this can result in differences between laboratories due to differing characteristics of the ferrite clamps.

X. Recommendation

The U.S. should cast a NO vote on the FDIS resulting from CISPR/G/143/CDV with the justification being that the current proposal does not adequately characterize the ferrite clamp to be used. The proposal does offer an improvement in repeatability between laboratories, but the residual errors due to differences in ferrite clamps which meet the requirement in the proposal could be further improved by a more complete definition of the clamp characteristics.