Busek BHT-1500 External vs Center Cathode EMC Study

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Abstract: Radiated emissions from the Busek BHT-1500 Hall thruster were measured from 10 kHz to 40 GHz. This thruster was operated with its cathode conventionally mounted outside the discharge and at the center of the thruster. Comparison were made of horizontal and vertical polarized emissions for both cathode positions, 1.5 and 1.8 kW power levels, and discharge potentials of 300V and 400V. At frequencies below 1 MHz, the center-mounted cathode emissions were 10 dB below those of the externally mounted cathode. Placement of the cathode at the center of the thruster increased the emission over the externally mounted cathode by as much as 15 dB in the 100 MHz to 300 MHz band with a discharge potential of 400 V. The vertically polarized emission is less by 10-15 dB in the 500 MHz to 1000 MHz band with the center cathode position. The L-band (1-2 GHz) emission did not change significantly when the cathode was moved from the external to the center position. Finally, S-band vertically polarized emission was 10 dB higher with the center cathode position for 300V discharge potential. There were no significant emissions at frequencies above 20 GHz.

Nomenclature

dBμV/m	=	*20log(E/μV/m); 120 dBμV/m = 1V/m*
EMC	=	electromagnetic compatibility
C-band	=	4 – 8 GHz
L-band	=	1 – 2 GHz
S-band	=	2 – 4 GHz

I. Introduction

Numerous studies on the character and origin of the electromagnetic emission from Hall Current Thrusters (HCTs) have been made. The low frequency emissions (< 100 MHz) are strong and have been measured for various thrusters.[1-4] Most of these low frequency emissions are associated with anode current oscillations and plasma modes; a quantitative study of their origin is available.[5] Significant emission from higher frequencies (0.5 – 8 GHz) is pulsed and has been associated with the cathode plume or possibly the cathode plume-main plume interaction.[3,6-8] Emission at frequencies greater than 8 GHz is largely absent but emission above 18 GHz has been observed and is

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likely plasma frequency oscillations at the exit of the cathode where the electron density is high enough to generate oscillation at these frequencies.[1]

Even though the emission is greatest at frequencies below 100 MHz, this low frequency emission is seldom a concern for communication satellites whose transponders operate above 1 GHz. The emission above 1 GHz, however, has the potential of degrading the sensitivity of on-board receivers, especially if connected to omni-directional (low gain) antennas. This situation will become more common as operators choose an all-electric bus, thus requiring long periods of electric propulsion operation during orbit-raising from LEO to GEO.

The origin of the L-band emission (1- 2- GHz) is localized to regions in front of the cathode[8]; this emission increases if the flow to the cathode is reduced to a xenon "starved" condition. The origin of the S-, and C-band emission more diffuse[8] and is a strong function of the thruster magnetic field.[9] These observations lead one to speculate that the emission from a HCT may be sensitive to the position of the cathode.

Recent electromagnetic compatibility (EMC) measurements of the Busek BHT-1500 HCT presented the opportunity to test this hypothesis. This thruster is designed to operate with a cathode placed conventionally outside the thruster body or in the center of the body of the thruster. Performance and plume of this thruster are available.[10] The measurements were made for four operating mode of the BHT-1500 using MIL-STD 461 standards for radiated emission from 10 kHz – 18 GHz (RE102) and 18 – 40 GHz (RE103).

II. Measurements

The measurements were made at The Aerospace Corporation Electric Propulsion EMC Facility. Because the characteristics of this facility are well documented[11] only a brief description is presented here. The EMC facility is shown in Figure 1. The small (0.9 m diam. and 1.5 m long) all-dielectric vacuum tank houses the thruster. This completely nonmetallic and non-carbon tank is constructed of S2 glass that has a relatively low dielectric constant and is largely transparent to electromagnetic radiation. This fiberglass tank mates to a stainless steel vacuum chamber, which is pumped with four cryotubs and six reentrant cryopumps. A high-power thruster placed in this chamber is usually mounted on a water-cooled plate to control its temperature. A more complete description of the characteristics of the dielectric tank is available.[12]

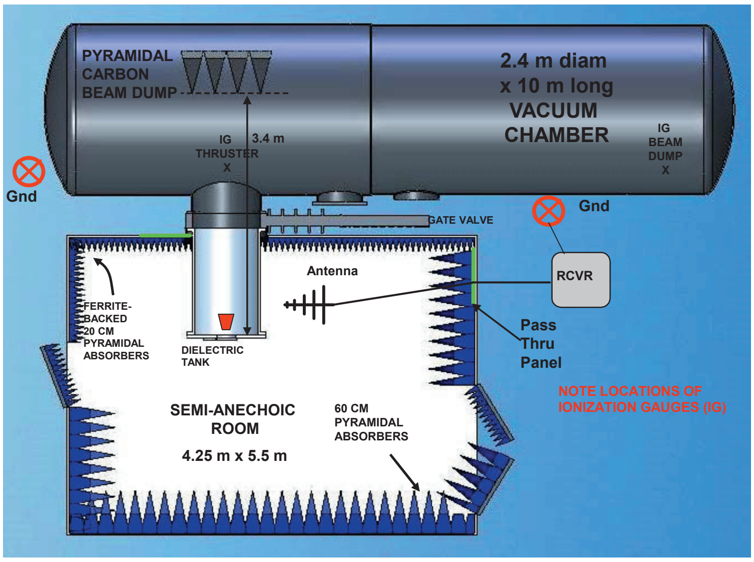

Figure 1. Facility used to make EMC measurements on the BHT-1500 thruster.

A 5.5m x 4.25m x 3m semi-anechoic room surrounds the dielectric tank to shield the thruster from the ambient electromagnetic environment. It provides >100 dB shielding from 14 kHz - 18 GHz and is designed to be MIL-STD 285 and NSA 65-5 compliant. The plume of the thruster exhausts into the main vacuum tank, terminating on a beam dump comprising a series of 0.6-m-high aluminum pyramids covered with grafoil to reduce sputtering by the high-energy xenon ions and reduce scattering of electromagnetic radiation from the thruster by the main tank at higher frequencies.

Analyzers, receivers, and custom-built time-domain instruments record the radiation emanating from the thruster. Below 18 GHz, the instruments connect sequentially to a series of antennas through a panel in the semi-anechoic room using a two-section semi-rigid cable with known attenuation. Above 18 GHz, a smaller receiver situated in the anechoic room connects sequentially through one of two short cables to a series of low-noise amplifiers (LNAs) mated directly to octave horns.

As noted above, the Busek Hall Thruster (BHT-1500) can be operated with its cathode positioned at center of the annular or more conventionally mounted outside the annular discharge. It is designed to operate at powers between 1.0 and 2.5 kW. For these measurements, the thruster was operated in four modes: 1.5 kW at 300V and 400V discharge voltages and 1.8 kW at 300V and 400V discharge voltages. MIL-STD RE02 measurement (10 kHz – 18 GHz) were made for these operating modes for both cathode configurations. The RE03 measurements (18 GHz – 40 GHz) were made for all four thruster modes for the center cathode configuration only. The scan rates for these frequencies were those specified as the fastest permitted by MIL-STD 462; however, slowing the scan rate by a factor of 2 showed no difference in the emission levels indicating that the faster rate was adequate to capture the worst case emission levels.

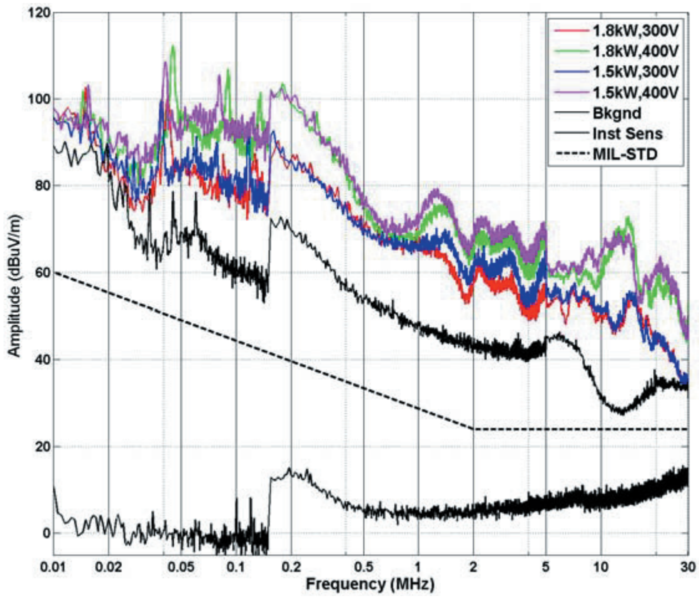

Figure 2. Vertical polarization emission from BHT-1500 thruster from 10 kHz - 30 MHz for all four modes using a **center cathode**. The instrument sensitivity and background radiation are indicated with black curves. The MIL-STD 461 is marked with a dashed line. Abrupt increase at 150 kHz is due to a 10X increase in

III. Results

We present the data in this section in order of increasing frequency. Emission from the lowest frequency interval was taken with a vertical rod antenna that can only register vertical polarization. These data are presented in Figures 2 and 3. Figure 2 displays the center cathode vertical polarization emission from 10 kHz - 30 MHz and Figure 3 displays the same for the external cathode. The observant reader will note that the emission is approximately 10 dB higher for the external cathode below 1 MHz but both spectra are similar in magnitude between 1 MHz and 30 MHz.

The emission between 30 MHz and 18 GHz is shown in Figure 4 for all modes and both polarizations. The difference between the emissions for the center and external cathode is highlighted for the horizontal polarization in Figure 5. These plots show that greatest difference in emission between the two cathode positions is in the 100 - 300 MHz frequency interval for an anode potential of 400 V; the emission using center cathode position having as much as 15 dB greater magnitude. Interestingly, the L-band emission (1 -2 GHz) that has been identified with the cathode shows little sensitivity to the change in position.

Corresponding plots for the vertical polarization emission given in Figure 6 show similar differences with an interesting exception. The S-band emission (2–4 GHz) is about 10 dB higher for the center cathode position than the external position for a discharge voltage of 300 V. Curiously, there is no significant difference for the 400 V discharge potential for the two cathode potentials, although Figure 4 shows that the emission for the 400 V discharge potential is greater than that of the 300 V emission.

Finally, we note from Figure 4 that there is no emission above the background in the C-Band, which is often observed in other Hall thrusters [2].

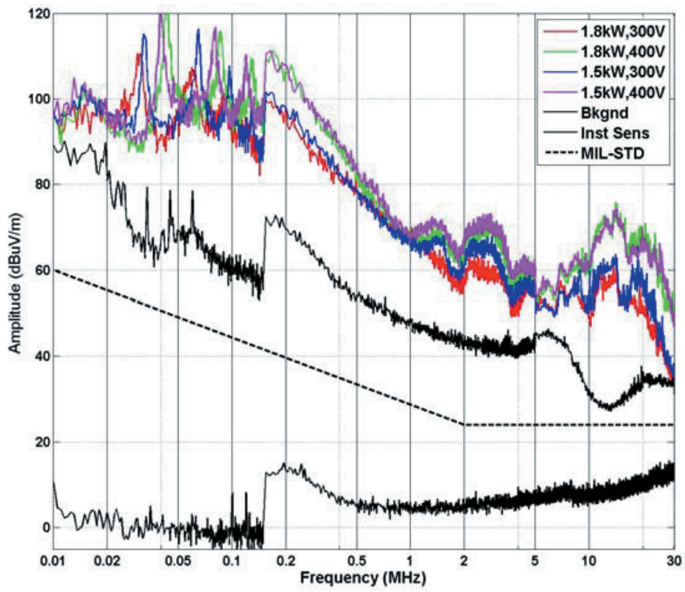

Figure 3. Vertical polarization emission from BHT-1500 from 10 kHz - 30 MHz for all four modes using an **external cathode**.

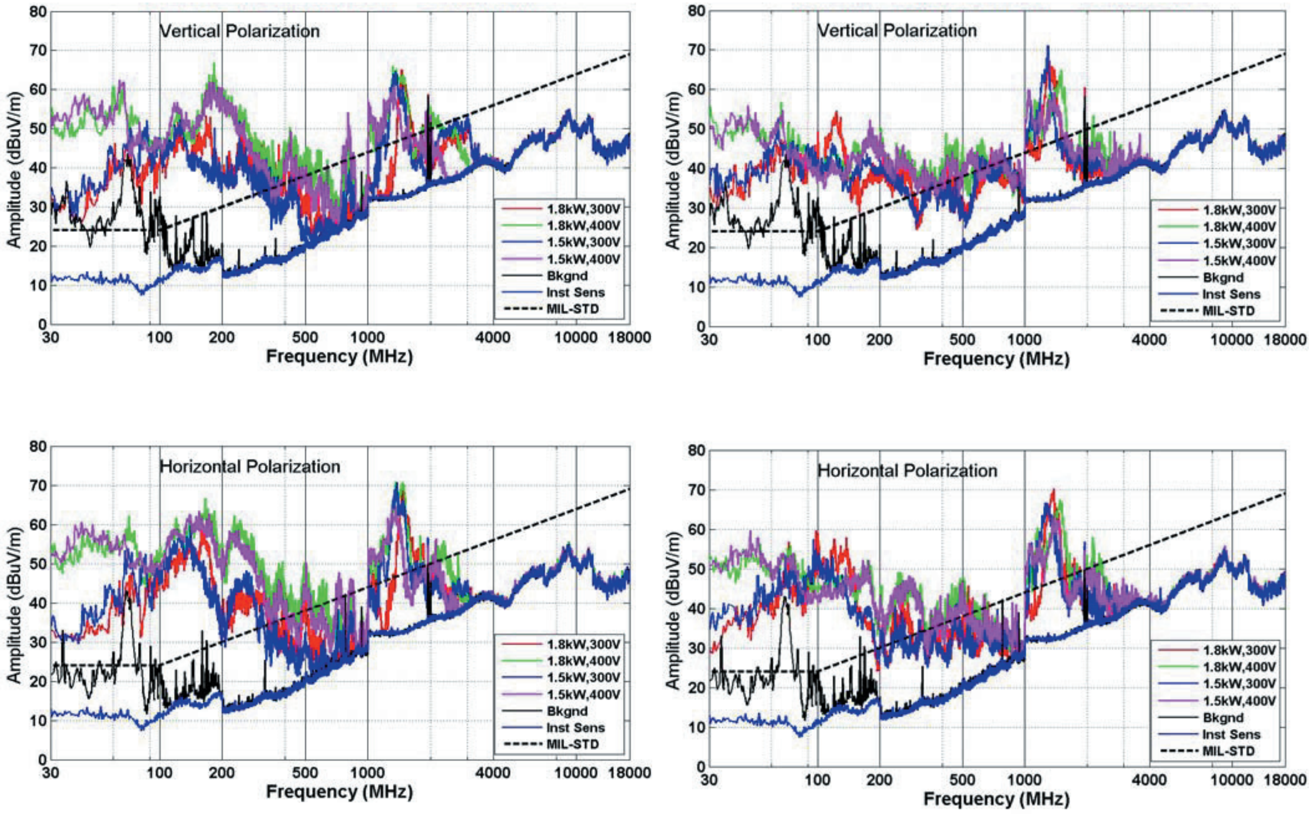

Figure 4. Vertical (above) and horizontal (below) polarization emission from BHT-1500 from 30 MHz - 18 GHz for all four modes using a center (left) and an external (right) cathode.

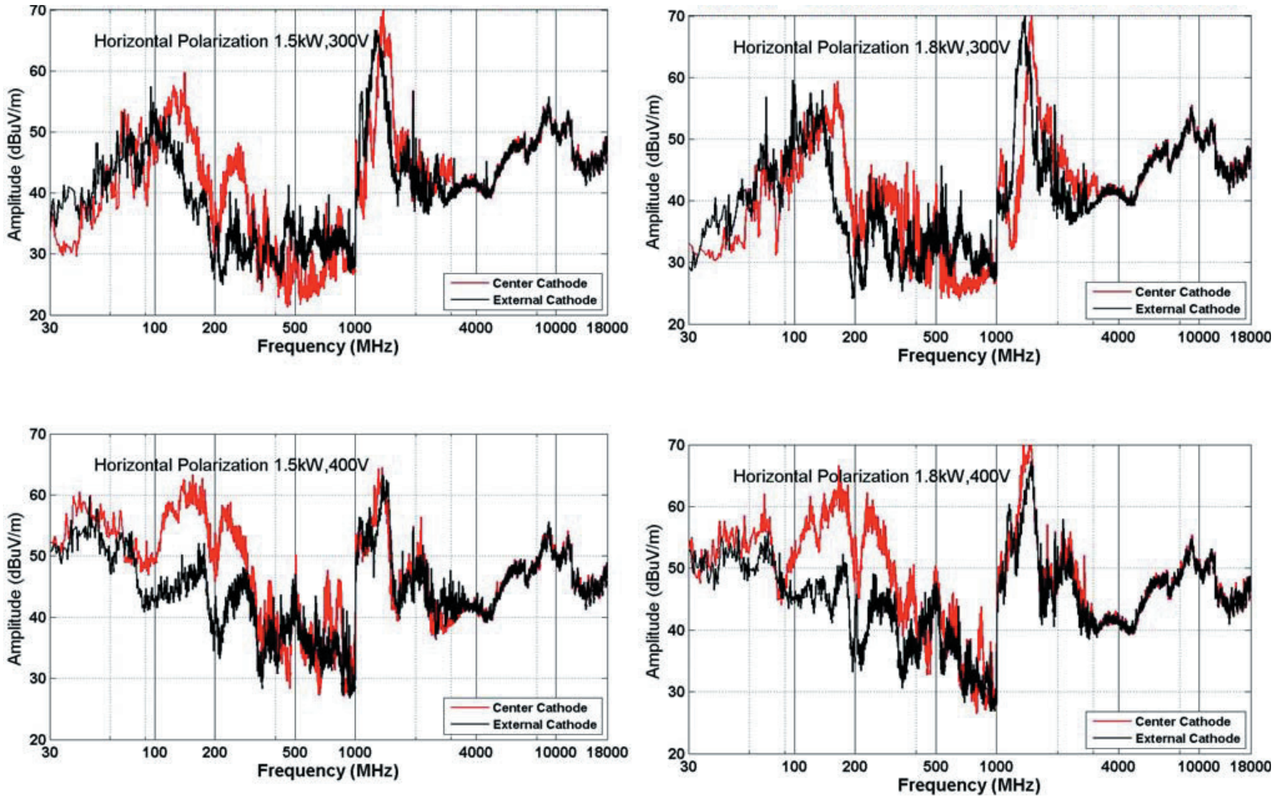

Figure 5. Center verses external cathode comparison, 300V and 400V, 30 MHz-18 GHz, horizontal polarization.

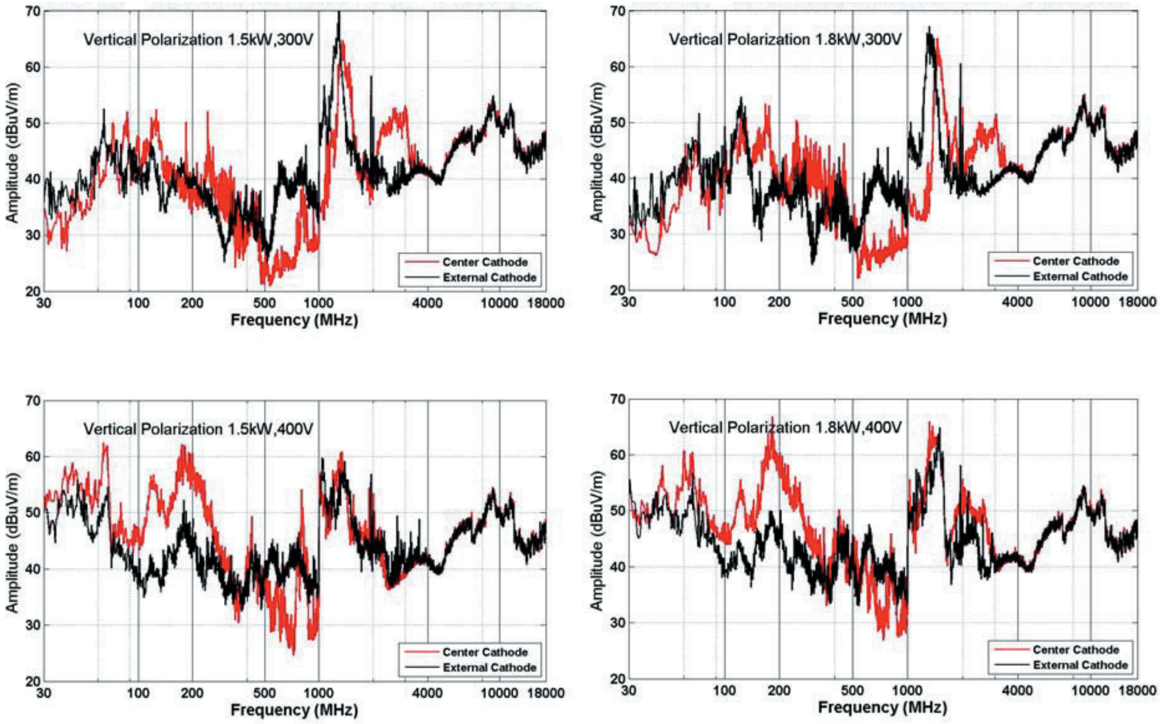

Figure 6. Center verses external cathode comparison, 300V and 400V, 30 MHz-18 GHz, vertical polarization.

For completeness, the emission from BHT-1500 thruster for the center cathode position from 18 – 40 GHz for all powers and both polarizations is shown in Figure 7. The only significant emission above the instrument sensitivity is at the higher power, higher discharge voltage in the horizontal polarization between 18 and 20 GHz. This radiation has been seen before [1] and is likely due to electron plasma oscillations.

In summary, at frequencies corresponding to the plasma mode oscillations of the Hall thruster (< 1 MHz), placing the cathode at the center reduces the emission from these oscillations by approximately 10 dB. However, placement of the cathodes at the center of the thruster increases the emission by as much as 15 dB in the 100 – 300 MHz band when the thruster is operated with a discharge potential of 400 V. The vertically polarized emission is decreased by10-15 dB from 500 to 1000 MHz with the center cathode placement. Interestingly, the L-band emission that previous studies have linked to the cathode shows little variation when the cathode is moved from the external to the center position. Finally, S-band vertically polarized emission is 10dB higher for the center mounted cathode when the thruster is operated with a 300V discharge potential. There was no significant emission from the thruster above 20 GHz. In general, the emission profiles from the BHT-1500 thruster were similar of other Hall thrusters for either cathode position.

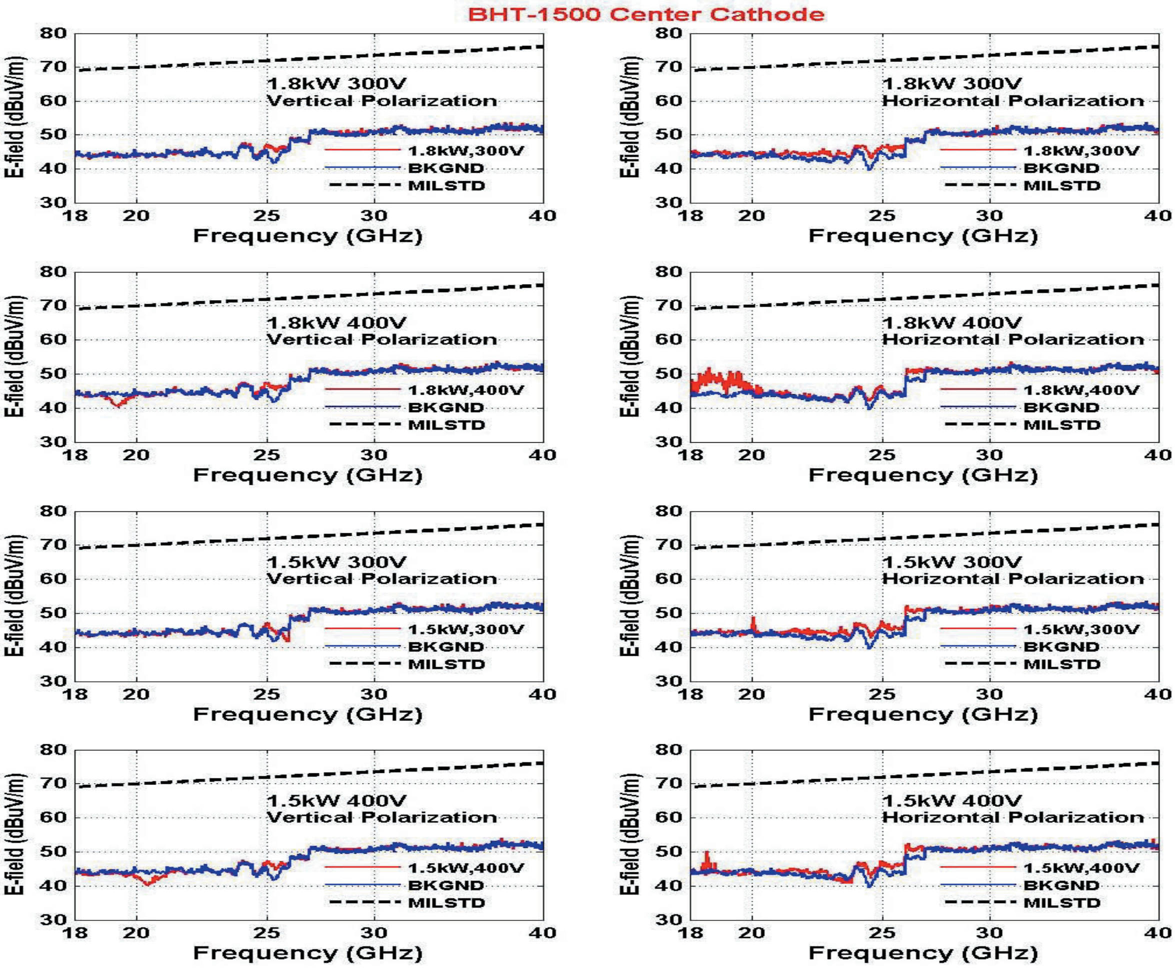

Figure 7. Emission from BHT-1500 thruster with the center cathode position from 18 – 40 GHz

Acknowledgments

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