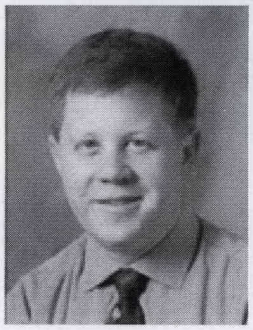
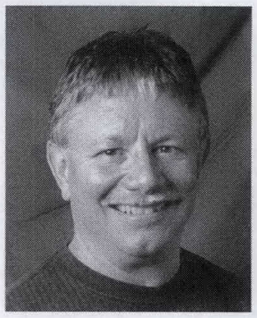


Brian E. Fischer
General Dynamics Advanced
Information Systems
Michigan Research and
Development Center
1200 Joe Hall Drive,
Ypsilanti, MI 48197, USA
Tel: +1 (734) 480-5125
Fax: +1 (734) 480-5328
Email: Brian.Fischer@gd-ais.com



Ivan J. LaHaie
General Dynamics Advanced
Information Systems
Michigan Research and
Development Center
1200 Joe Hall Drive,
Ypsilanti, MI 48197, USA
Tel: +1 (734) 480-5207
Fax: +1 (734) 480-5328
Email: Ivan.LaHaie@gd-ais.com

A Novel Method for High-Power Thermal Vacuum Testing of Satellite Payloads Using Pickup Horns

***Sudhakar K. Rao*[1], *Clency Lee-Yow*[2], *and Philip Venezia*[2]**

[1]Lockheed Martin Commercial Space Systems
100 Campus Drive, Newtown, PA 18940, USA
E-mail: sudhakar.rao@lmco.com

[2]Custom Microwave Incorporated
24 Boston Court, Longmont, CO 80501, USA

Abstract

This paper presents the development of a novel method for high-power thermal vacuum (TVAC) testing of satellite payloads using pickup horns (PUH). It describes the design, manufacture, and qualification results for a Ku-band pickup horn, followed by high-power thermal vacuum test results of a Ku-band satellite for fixed satellite service. Based on the successful demonstration of this method, a generic pickup horn (GPUH) – with improved performance over a large bandwidth, covering 7.0 GHz to 21.0 GHz – was developed for testing of X-band, Ku-band, and Ka-band satellite payloads. Detailed design and qualification aspects of the generic pickup horn are addressed, including measured results. This method has been successfully employed for high-power thermal vacuum testing of three different satellites at Lockheed Martin Commercial Space Systems (LMCSS), and is the planned testing method for all future payloads.

Keywords: Satellite antennas; thermal factors; thermal variables measurement; space vehicle power systems; high power thermal vacuum test; horn antennas; pickup horn

1. Introduction

High-power thermal vacuum (HPTVAC) tests need to be performed for all satellites after the payload is integrated with the spacecraft structure, and after the integrated satellite goes through the initial qualification tests at ambient temperature. These tests are conducted in order to insure the integrity of the payload and spacecraft in vacuum and with high power. They are performed, prior to launch, in large thermal vacuum chambers, simulating the space environment. The purpose of the high-power thermal vacuum test is two-fold. The first purpose is to validate the thermal performance of the spacecraft in vacuum with all downlink channels powered up. The second purpose is to test the payload performance of all transponder channels. Previous high-power thermal vacuum testing methods used by satellite manufacturers include (a) the absorber-box method and (b) the waveguide-plumbing method, which are described below.

The absorber-box method employs a large box surrounding the flight horn, which is placed inside the thermal vacuum chamber. The box contains high-power loads that are cooled through either water pipes or through liquid nitrogen (LN_2). Since the box is very large, it allows high-power thermal vacuum testing of only one antenna payload at a time. There are typically three to six downlink antennas on a satellite, and this method requires breaking the vacuum after each antenna payload test has been completed. It also requires a very long schedule of six to eight weeks to complete high-power thermal vacuum testing of a satellite. Another disadvantage of this method is that the RF leakage into sensitive receivers of the payload is difficult to control, due to the large size of the absorber box.

The second method, using waveguide-plumbing, involves demating of the flight horn and connecting the waveguide STE (special test equipment) to the flight waveguide. The waveguide special test equipment is then plumbed through a series of several long waveguide sections and bends from the thermal vacuum chamber to outside, using an RF-transparent high-power window. This has to be repeated for each antenna. The RF power is transported through the waveguide plumbing and RF window to outside the thermal vacuum chamber, where it is cooled externally. This method has the drawbacks of not being able to test the complete payload, due to the absence of the flight horns; poor return loss, due to waveguide plumbing; sensitivity to polarization; and it has the possibility of catastrophic damage to the satellite in a case where the RF window breaks down.

The new method, using pickup horns (PUH), overcomes the limitations of the previous methods, and is relatively inexpensive and faster. The pickup horn is placed in close proximity to the flight horn. The pickup horn is designed to absorb all of the RF power from the payload channels, with minimal RF leakage outside the unit. The absorbed power heats the pickup horn, and the heat is quickly transferred through the sidewalls, where it is cooled through a coolant that flows through the two sidewalls. The main advantages of this method compared to conventional methods are:

- No RF power goes outside the thermal vacuum chamber through the critical RF window;
- The method does not require complicated RF plumbing;
- The method does not require breaking the vacuum to test multiple payloads on the spacecraft;
- The method is significantly faster and cheaper compared to conventional methods;
- The method is less sensitive to alignment, polarization, and bandwidth; and
- There is lower risk of multipaction power breakdown.

This paper presents the design, manufacture, and qualification testing of a novel Ku-band pickup horn, which has recently been successfully used for high-power thermal vacuum testing of two Ku-band satellites. The qualification results of the return-loss response, the thermal response, and RF leakage of the pickup horn, measured with the flight horns, are presented. Based on the successful demonstration of this method, a generic pickup horn (GPUH) has been developed, with improved performance, higher power handling, a bandwidth larger than three octaves, and that is insensitive to polarization. The generic pickup horn design is very generic, and can be used for X-band, Ku-band, and Ka-band frequencies with LP, HP, RHCP, LHCP, or any other polarization. The generic pickup horn has been recently used on another satellite program with great success, and is base-lined for high-power thermal vacuum testing of all future satellite programs at Lockheed Martin (LMCSS). The pickup horn and generic pickup horn were jointly developed by LMCSS and Custom Microwave Inc. Lockheed Martin has two patents pending on this technology [1, 2].

2. Pickup Horn Method for HPTVAC Testing

The pickup horn (PUH) method for high-power testing of satellite payloads in a thermal vacuum chamber is illustrated in Figure 1. The spacecraft, integrated with the payload, is rolled over onto a dolly into the thermal vacuum chamber, with all of the deployed reflectors in the stowed position. One pickup horn per antenna feed is used, and there are typically three to six feed horns on a payload. Each flight horn illuminates a reflector the surface of which is shaped to meet the coverage region of a geographical region, as seen by the geostationary satellite. The pickup horn is

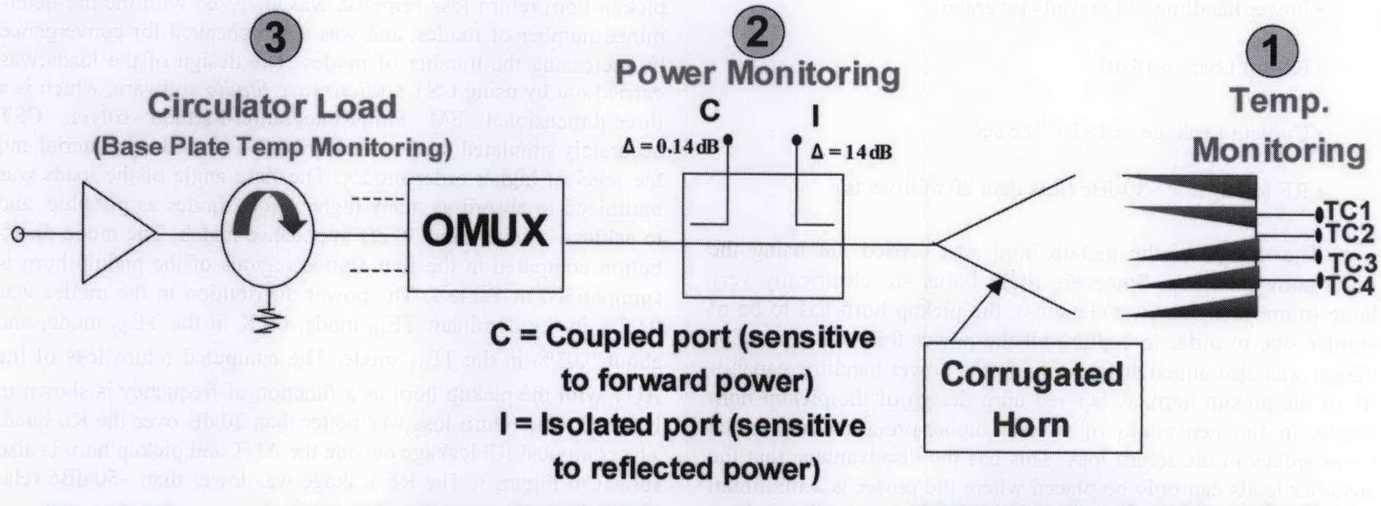


Figure 1. The concept of the pickup horn method for high-power thermal vacuum (HPTVAC) testing of satellite payloads.

placed in close proximity to the flight horn, with no physical contact between them. All payload channels are combined through an output multiplexer (OMUX). The combined power is radiated through a flight horn, which is typically a corrugated horn with low cross-polar levels. A dual-directional test coupler is used in between the output multiplexer and the flight horn, for power monitoring and payload testing on the ground. The test coupler has a coupled port that is sensitive to forward power, and an isolated port that is sensitive to reflected power. The ratio between the two powers (after calibration for the directivity of the coupler, cables, and connectors) gives the channel return loss. The measured phase response of the channel as a function of frequency gives the group delay. The pickup horn shown on the right side of Figure 1 absorbs all the power coming through the feed horn, with minimal reflections going back to the horn. Thermocouples, installed in the pickup horn, enable close monitoring of the temperature at various parts of the pickup horn, as the chamber is cycled thermally through cold and hot plateaus. The safety features include continuous monitoring of temperature at the pickup horn loads, power through the test-coupler ports, and temperature at the base-plate of the circulator loads as the payload is thermally cycled in the vacuum chamber. If either a temperature or power level exceeds the allowable limits, the payload power is automatically shut off for the safety of the spacecraft. Figure 2 shows the system block diagram for the high-power thermal vacuum testing of a typical flight payload, including the horns, and using the pickup horn method. The safety control features are the audible alarms, temperature monitoring, and power turn-off through frequency synthesizers. The payload safety is therefore not compromised, even in the case of catastrophic failure, due to the test setup.

The key design objectives for the pickup horn are (a) to absorb all of the RF power from various channels of the payload transmitted through the feed horn; (b) to match the return loss of the pickup horn with the feed horn, causing minimal reflections going back to the payload; (c) thermal control of the pickup horn through an external cooling system; (d) minimal material outgassing due to the pickup horn; (e) no leakage of the coolant that flows through the pickup horn; and (f) to minimize the RF power leakage into the chamber. Typical specifications for the Ku-band pickup horn are:

- Frequency band: 10.70 GHz to 12.75 GHz (18% bandwidth)

- Polarization: linear (VP or HP)

- Power handling: 2000 watts (average)

- Return Loss: >18 dB

- Coolant Leakage: $<1\times10^{-6}$ cc/sec

- RF leakage: <-50 dBc (less than 20 milliwatts)

The design of the pickup horn was carried out using the flight-horn geometry. Since the flight horns are electrically very large (more than four wavelengths), the pickup horn has to be of similar size in order to capture all the power from the horn. The design was also aimed at maximizing the power-handling capability of the pickup horn. A tapered horn design of the pickup horn results in the generation of several higher-order modes, which cause spikes in the return loss. This has the disadvantage that the absorber loads can only be placed where the power is a minimum at the walls of the horn. A partitioned design for the pickup horn that avoids any flare-angle taper was selected for two reasons. First, the partitioned design enabled incorporation of several distributed loads at locations where the power was maximum, and allowed increasing the power-handling capability of the pickup horn. Second, by dividing a single large aperture into several smaller apertures, the higher-order modes were well controlled, thereby avoiding risk due to resonances or spikes caused by trapped modes. The aperture was divided into N slotted regions, each being separated with thin metallic walls. The slots were overmoded, in order to make the pickup horn less sensitive to polarization. Each of the slotted regions was designed with absorber loads that were well matched, with better than 30 dB return loss.

The RF design of the pickup horn was carried out by analyzing the scattering parameters of the combined feed assembly, consisting of the flight horn and the pickup horn. The slots were designed to produce a Gaussian aperture distribution for the corrugated horn, with larger slots in the middle and smaller slots at the edges, with a power ratio of 4:1 between them. The basic modes in the slotted regions of the pickup horn were the TE_{10}, TE_{30}, and TE_{11}/TM_{11} modes. The design parameters were the spacing between the horn and the pickup horn, the sizes of the slots, the length of the pickup horn, and the design of the loads. About 40% of the power was absorbed in each of the larger slots in the middle, while 10% of the power was absorbed in the smaller edge slots.

The detailed design of the pickup horn was performed through RF analysis of the combined structure of the antenna under test (AUT) and the pickup horn. The combined structure was then analyzed using commercially available software that uses mode-matching and a finite-element solver: *Microwave Wizard* by Mician [3]. This software allows the user to define the number of modes in the cascade modal analysis. As a general rule, using a large number of modes yields better accuracy of the results, but the number is often limited by the computer's memory. In this particular case, where the AUT and the pickup horn were electrically large, the structure's physical symmetry was used as an advantage by avoiding the asymmetrical modes wherever possible. This method worked well for the AUT, because it could make use of electric and magnetic transverse symmetries, as well as radial symmetry. However, when simulating the AUT with the pickup horn, the overall structure was no longer radially symmetrical, and was symmetric in one transverse dimension. Only a magnetic symmetry plane could be incorporated for the pickup horn. First, the AUT was analyzed using radial and transverse symmetries. The number of modes was gradually increased until the return loss response achieved "convergence." Then, the combined AUT and pickup-horn return loss response was analyzed with the pre-determined number of modes, and was again checked for convergence by increasing the number of modes. The design of the loads was carried out by using CST's *Microwave Studio* software, which is a three-dimensional EM Finite-Integration-Method solver. CST accurately simulated the power distribution in the load material and the level of higher-order modes. The flare angle of the loads was optimized to absorb as many higher-order modes as possible, and to achieve a better than 30 dB impedance match. The mode distribution computed in the four slotted regions of the pickup horn is summarized in Table 1. The power distribution in the modes was 92.7% in the dominant TE_{10} mode, 6.1% in the TE_{30} mode, and about 0.03% in the TE_{11} mode. The computed return loss of the AUT with the pickup horn as a function of frequency is shown in Figure 3. The return loss was better than 20 dB over the Ku band. The computed RF leakage outside the AUT and pickup horn is also shown in Figure 3. The RF leakage was lower than –50 dBc relative to the input power.

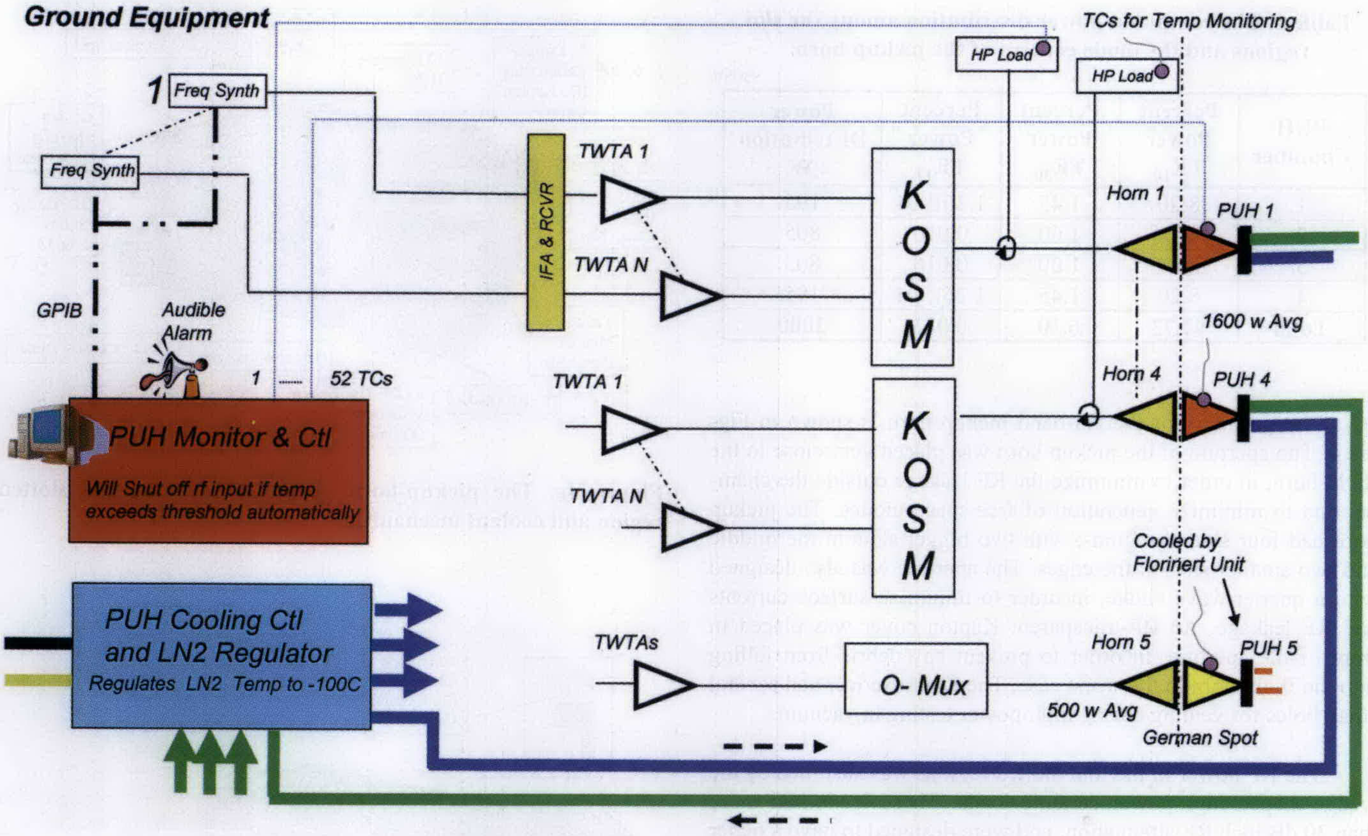


Figure 2. A system block diagram of HPTVAC testing with pickup horns, showing the safety features.

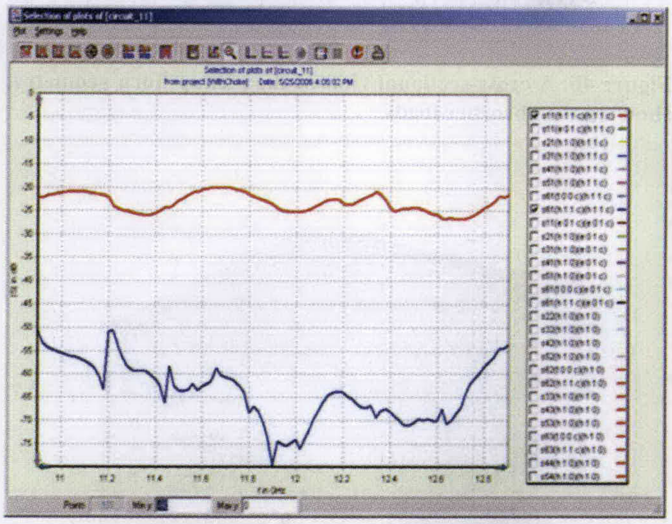


Figure 3. The computed return loss (red curve) and RF leakage (blue curve) of the pickup horn with a corrugated horn over the Ku-band transmitting frequencies.

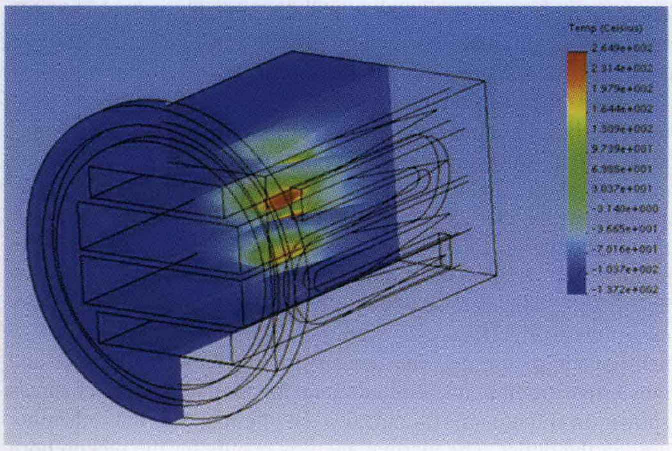


Figure 5a. A thermal-analysis plot, showing the maximum temperatures at various locations of the pickup horn with 2000 W RF power and with LN2/GN2 coolant

Table 1. The computed power distribution among the slot regions and the mode content of the pickup horn.

PUH Chamber	Percent Power TE_{10}	Percent Power TE_{30}	Percent Power TE_{11}	Power Distribution W
1	8.20	1.45	1.26E-04	195
2	38.16	1.60	0.016	805
3	38.16	1.60	0.016	805
4	8.20	1.45	1.26E-04	195
Total	**92.72**	**6.10**	**0.032**	**2000**

The geometry of the Ku-band pickup horn is shown in Figure 4. The aperture of the pickup horn was placed very close to the flight horn, in order to minimize the RF leakage outside the chamber and to minimize generation of free-space modes. The pickup horn had four slotted regions, with two bigger slots in the middle and two smaller slots at the edges. The aperture was also designed with a quarter-wave choke, in order to minimize surface currents and RF leakage. An RF-transparent Kapton cover was placed in front of the aperture, in order to prevent any debris from falling into the flight horn in the worst case. The Kapton cover had several small holes for venting during high-power testing in vacuum.

The RF power in the four slotted regions was absorbed by the wedge-shaped high-power ceramic loads. These loads had more than 30 dB/inch RF attenuation, and were designed to have a better than 30 dB match. The absorber loads were shorted at the other end with a common metallic wall, and were held in place with screws. The loads had small channel cuts on the bonded side, in order to place thermocouples (TCs) to monitor the temperature during high-power thermal vacuum testing of the payload. These thermocouples served as part of the safety system, which turned off the RF power in case any of the thermocouples read temperatures that were outside the limits set by prior qualification tests. The RF loads in the slotted regions were bonded to the metallic walls by using very thin silver-filled silicone adhesive. The adhesive transferred the heat from the loads to the side metallic walls very efficiently, where it was cooled through two reservoir channels that allow flow of the coolant. The side walls of the pickup horn had serpentine channels on each of the two sides for efficient heat transfer through either GN2/LN2 or Fluorinert coolant, which transfers the heat from the pickup horn to outside the thermal vacuum chamber. The two serpentine channels were closed using stainless-steel covers over them, with knife-edge grooves that sank into the copper body and prevented any leakage of the coolant. In addition, the stainless-steel side cover plates were attached to the pickup horn using screws with bevel washers, which prevented any loss in pre-load. All screws were tightened with a minimum of 15 inch-pounds of torque. The coolant passed through the inlet and transferred the heat it collected from the two serpentine channels (shown in Figure 4c) to outside the thermal vacuum chamber through the outlet. The thermal analysis results for the pickup horn are shown in Figure 5, with an input power of 2000 watts and with LN2/GN2 coolant. The large slots saw a maximum power of 800 watts each, while the small slots saw a maximum power of 200 watts each. The maximum temperature was at the large load, and was 265°C. The maximum temperature at the adhesive was 122°C, and the minimum temperature was at the flange, and was −125° C. These were well within the temperature limits for the ceramic loads and the silicone adhesive. The distributed load design for the pickup horn, as shown in Figure 5b, worked well for the high-power applications. A coolant-leakage test was performed

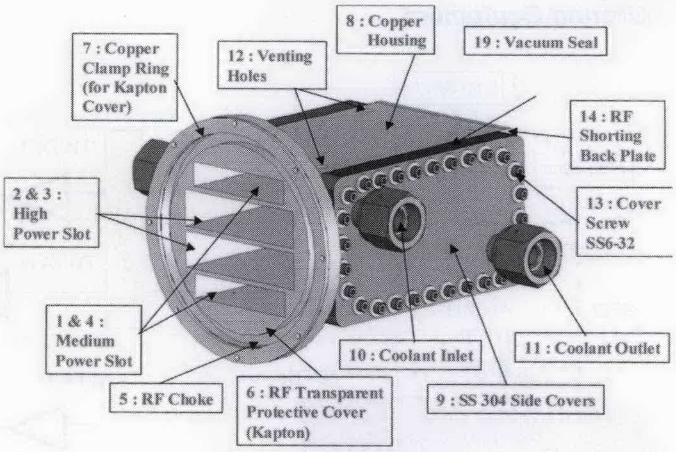


Figure 4a. The pickup-horn geometry, showing the slotted region and coolant mechanism.

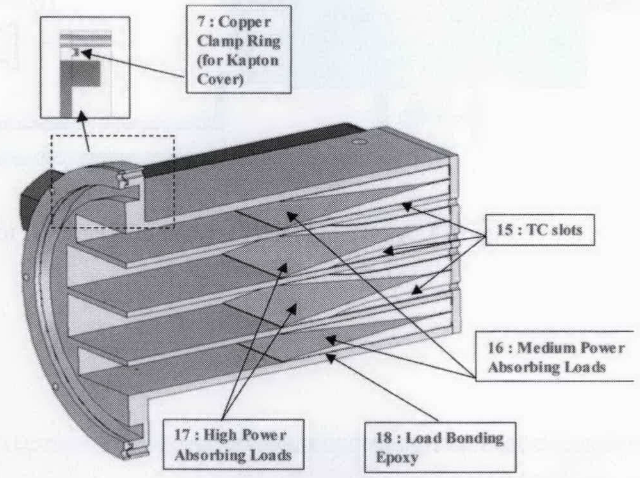


Figure 4b. A cross-sectional view of the pickup-horn geometry, showing the absorber loads.

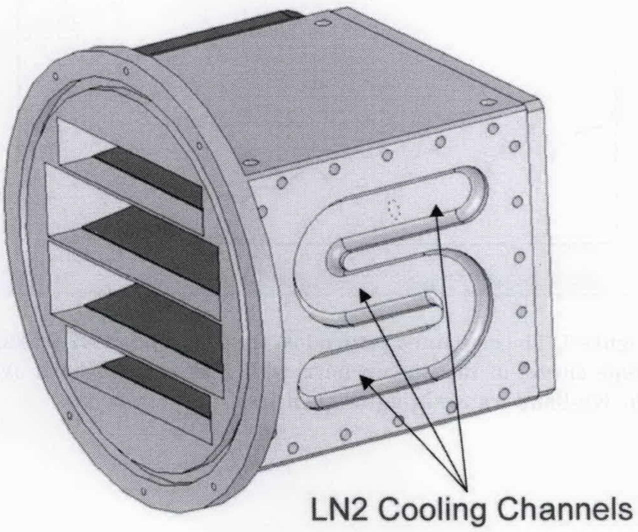


Figure 4c. A side view of pickup-horn geometry, showing the coolant channels.

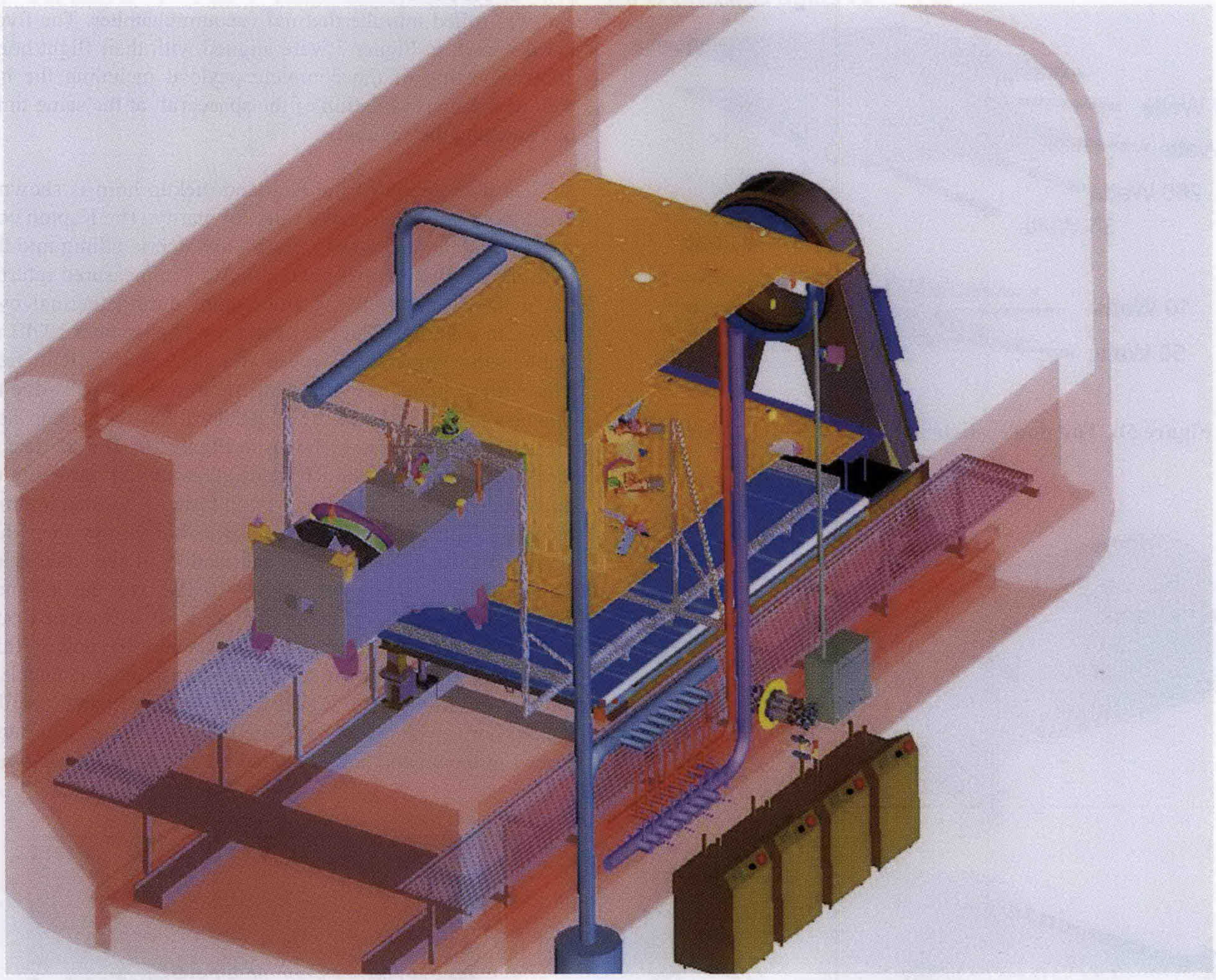


Figure 7. Pickup horns integrated with the flight horns in the TVAC chamber.

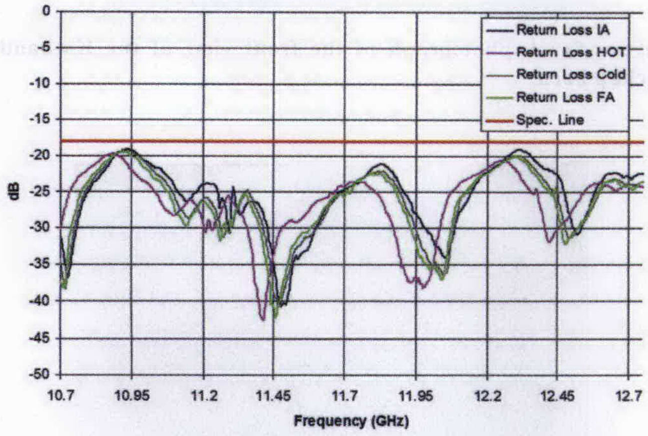


Figure 9. The measured return loss of the pickup horn with the flight horn during thermal cycling.

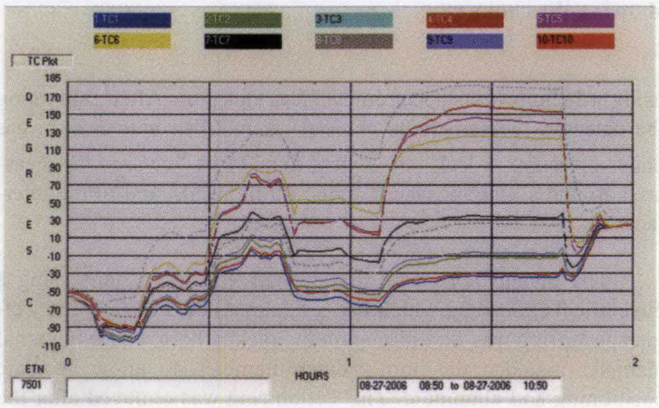


Figure 11. Temperature profiles of the pickup horn with the flight horn that were monitored through various thermocouples at different RF power levels of the payload (the maximum average power was 2000 W).

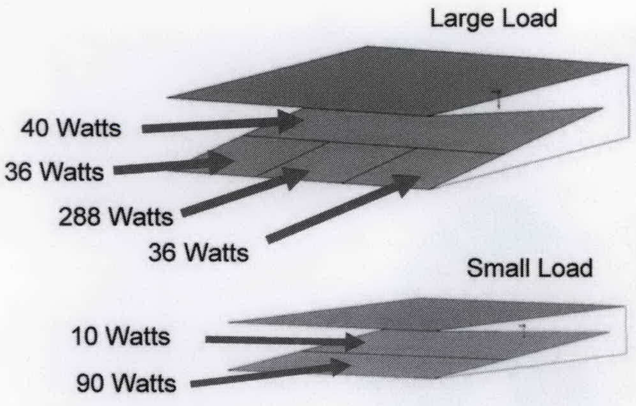


Figure 5b. The power distributions in the RF loads.

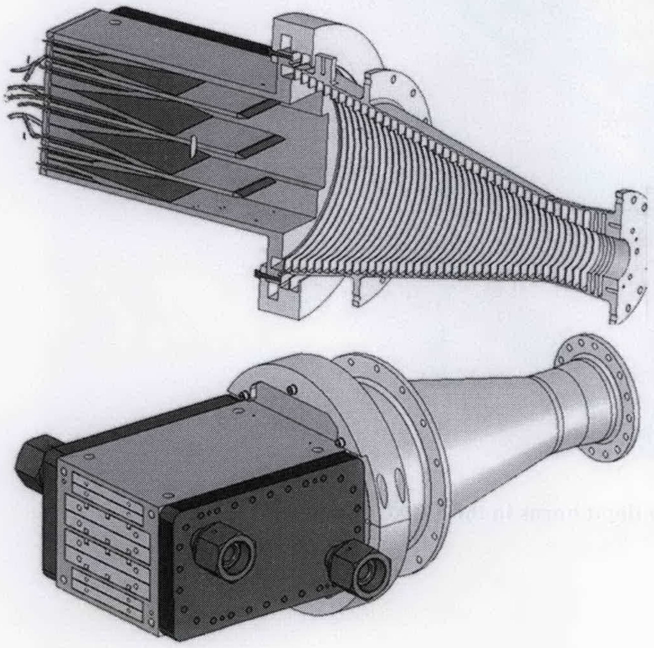


Figure 6. The pickup horn alignment with the flight horn, showing the choke ring.

using a helium mass-spectrometer leak detector. After calibrating the detector, the serpentine channels were filled with helium gas under pressure. A leak rate of less than 1×10^{-6} cc/sec was measured around all the interfaces, bolts, fitting welds, and fitting interfaces.

The pickup horn was aligned with the flight horn using a dielectric Teflon ring, which had a thickness of 0.100 in. The Teflon spacer ring was first placed on the pickup horn, and its internal diameter matched the horn's outer diameter, to allow accurate positioning and alignment. The Teflon ring was removed after the alignment was completed. A detachable choke-ring was then attached around the pickup-horn flange. The purpose of the choke ring was to minimize the RF leakage going into the thermal vacuum chamber and sensitive parts of the payload. The choke ring suppressed the leakage by about 10 dB. Figure 6 shows the alignment of the pickup horn with the flight horn. The use of pickup horns for high-power testing of a spacecraft is illustrated in Figure 7. The payload was integrated with the spacecraft. This assembly was mounted on an L-shaped dolly in the horizontal position, and was rolled into the thermal vacuum chamber. The five pickup horns shown in Figure 7 were aligned with their flight horns. This allowed testing of the complete payload including the horns, as well as thermal validation of the spacecraft at the same time, without breaking the vacuum.

A photograph of the Ku-band pickup horn is shown in Figure 8 without the RF choke ring, for clarity. The Kapton cover was RF transparent, and was to protect any debris falling into the flight horn during the thermal vacuum test. The measured return loss of the pickup horn with the flight horn during thermal cycling is shown in Figure 9. The return loss was better than 19 dB and was stable with temperature, except for the slight shift in frequency. This shift in frequency with temperature was typically due to minor dimensional changes of the flight horn and the pickup horn. The measured RF leakage is shown in Figure 10. The RF leakage was measured by probing the RF fields all around the structure using an open-ended waveguide, and monitoring the maximum power received. The RF leakage was about 4 dB lower than the levels shown in Figure 10 with the subtraction of the waveguide gain. The measured leakage was below –50 dBc over the designed band. The thermal validation of the pickup horn was carried out in the thermal vacuum chamber with 2000 watts of RF power (this represented the average power of all the transponder channels), going through the flight horn. Figure 11 shows the thermal profile of the pickup horn, which was monitored through several thermocouples placed in the pickup horn's slotted region, as the power was gradu-

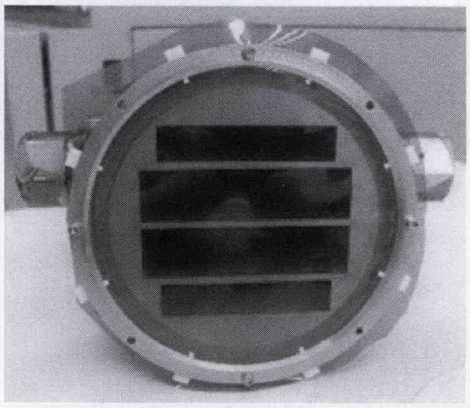


Figure 8a. A photograph of the front view of the Ku-band pickup horn.

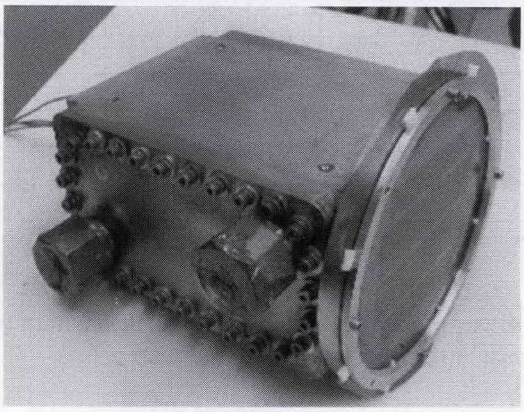


Figure 8b. A photograph of the side view of the Ku-band pickup horn.

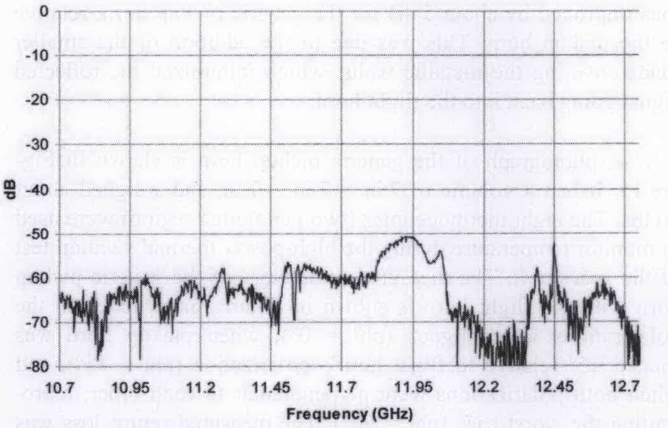


Figure 10. The measured RF leakage (in dBc) of the pickup horn with the flight horn.

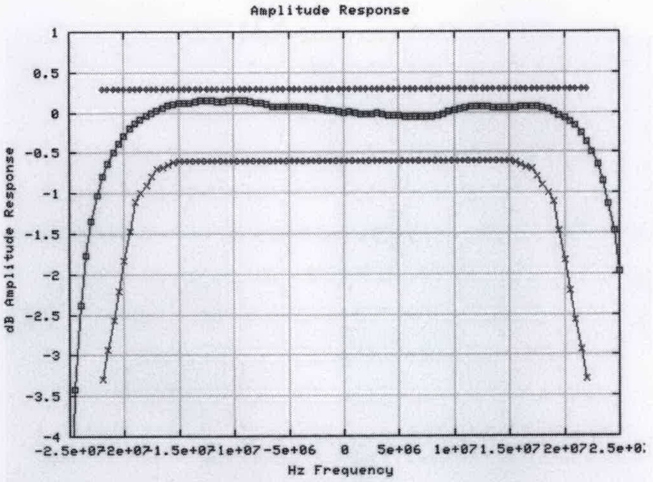


Figure 12. The typical channel response of the Ku-band payload, measured using the pickup horn method.

ally increased during the payload test. The hot and cold temperatures were within the allowable range of +260°C to –120°C. The channel response monitored through the pickup horn is shown in Figure 12. The channel amplitude response was well within the two red curves, representing ±0.4 dB maximum variation. The group-delay specification was also met, along with the amplitude-ripple requirement for all the payload channels. This indicated that the pickup-horn method of high-power thermal vacuum testing could be used to test the final payload performance, as well as for simultaneous thermal validation of the payload.

3. Development of the Generic Pickup Horn (GPUH)

Based on the successful high-power thermal vacuum testing of two satellite payloads using the pickup horn, a generic pickup horn was developed jointly by Lockheed Martin and Custom Microwave Inc. The objectives of the generic pickup horn were (a) a much wider bandwidth capability, so that it could be used for testing of X-band, Ku-band, and Ka-band satellites; (b) insensitivity to polarization, so that it could be used for vertical, horizontal, left-hand circular, and right-hand circular polarizations; and (c) a larger electrical size, so that it could be used for all satellite horns that are employed as feeds for both single reflectors and Gregorian reflectors that produce contoured beams through surface shaping of the reflector(s). In addition, the larger size of the generic pickup horn would have higher power-handling capability for the testing of future satellite payloads.

The geometry of the generic pickup horn is shown in Figure 13a, and a size comparison of the generic pickup horn relative to the pickup horn is illustrated in Figure 13b. The generic pickup horn was much larger than the pickup horn, and had a square opening of about 7 in × 7 in. Another design improvement for the generic pickup horn was that the thin metallic walls (exposed in the pickup horn) were covered with small loads, in order to improve the return loss, and also to make it less sensitive to polarization and alignment. All of the four slots had an identical size of 6.6 in × 1.575 in, and were loaded with ceramic loads. The number of vent holes was increased from eight to 32, for better venting in vacuum. The RF leakage was also improved, due to the larger size of the generic pickup horn, and due to the addition of absorber walls on the four detachable plates, which were attached to the aperture of the generic pickup horn and surrounded the flight horn. The design of the generic pickup horn was optimized by analyzing the return loss and RF-leakage response of the generic pickup horn with the flight horn, using *Microwave Wizard* software by Mician. The spacing between the two units was optimized analytically, and the power distribution among the modes and slots is given in Table 2. Each of the four slots was over-moded, in order to make the generic pickup horn less sensitive to polarization, and to increase

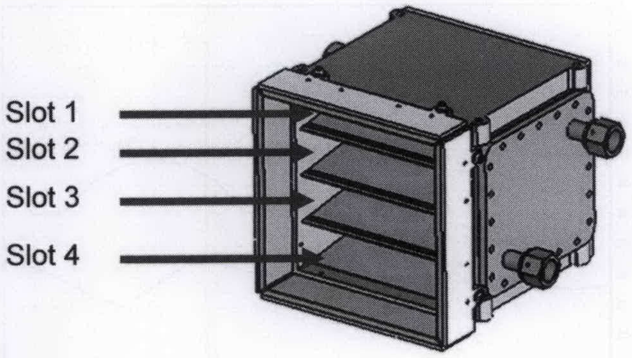


Figure 13a. The geometry of the generic pickup horn.

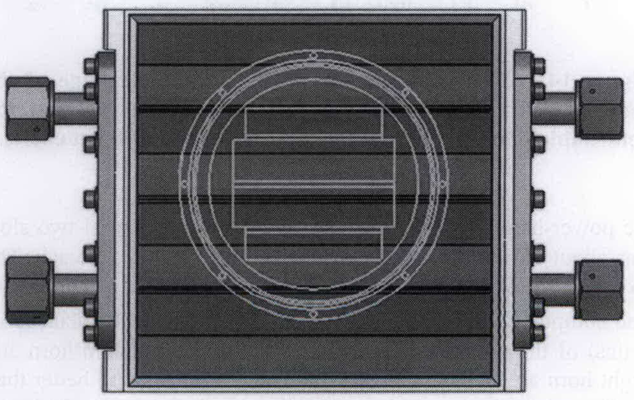


Figure 13b. A size comparison of the generic pickup horn and the pickup horn.

Table 2a. The computed power distribution among the slot regions and the mode content of the generic pickup horn: the HOM power distribution.

PUH Chamber	Percent Power				
	TE_{10}	TE_{30}	TE_{11}	TM_{11}	In Slot
1	1.58	0.05	1.58	0.03	3.24
2	37.15	5.62	0.32	3.02	46.11
3	37.15	5.62	0.32	3.02	46.11
4	1.58	0.05	1.58	0.03	3.24
Total	77.46	11.34	3.80	6.10	98.70

Table 2a. The computed power distribution among the slot regions and the mode content of the generic pickup horn, using a cosine-squared distribution.

Area	% Power
Chamber 1	5.77
Wall	1.36
Chamber 2	41.2
Wall	3.33
Chamber 3	41.2
Wall	1.36
Chamber 4	5.77
Total	99.99

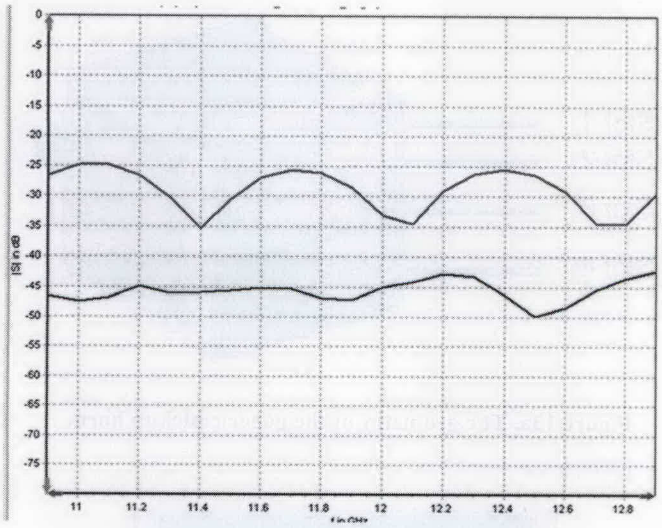


Figure 14. The computed return loss and RF leakage of the generic pickup horn with the corrugated horn (without the detachable plates) over the Ku-band transmitting frequencies.

the power-handling capability. The power in the central two slots was about 46% each, and the edge slots had about 3.3% each. The modes in the slotted region were the TE_{10}, TE_{30}, TE_{11}, and TM_{11}. The computed return loss and RF leakage (without the detachable plates) of the combined geometry of the generic pickup horn and flight horn are shown in Figure 14. The return loss was better than 25 dB over the Ku transmitting band, and leakage was better than –43 dBc. The detachable plates provided an additional improvement of about 10 dB for the RF leakage outside the structure. The return loss improved by about 5 dB for the generic pickup horn, relative to the pickup horn. This was due to the addition of the smaller loads covering the metallic walls, which minimized the reflected signal going back into the flight horn.

A photograph of the generic pickup horn is shown in Figure 15. It had a volume of 7 in × 7 in × 7 in, and weighed about 40 lbs. The eight thermocouples (two per slotted region) were used to monitor temperature during the high-power thermal vacuum test of the spacecraft. The measured return loss of the generic pickup horn with the flight horn is shown in Figure 16a, when both the polarizations were aligned (phi = 0°); when pickup horn was rotated 45° relative to flight horn's polarization (phi = 45°); and when both polarizations were perpendicular to each other, representing the worst case (phi = 90°). The measured return loss was better than 25 dB (as predicted) when the polarization of the generic pickup horn was aligned with the flight horn. The return loss deteriorated slightly, to 21.5 dB, when the generic pickup

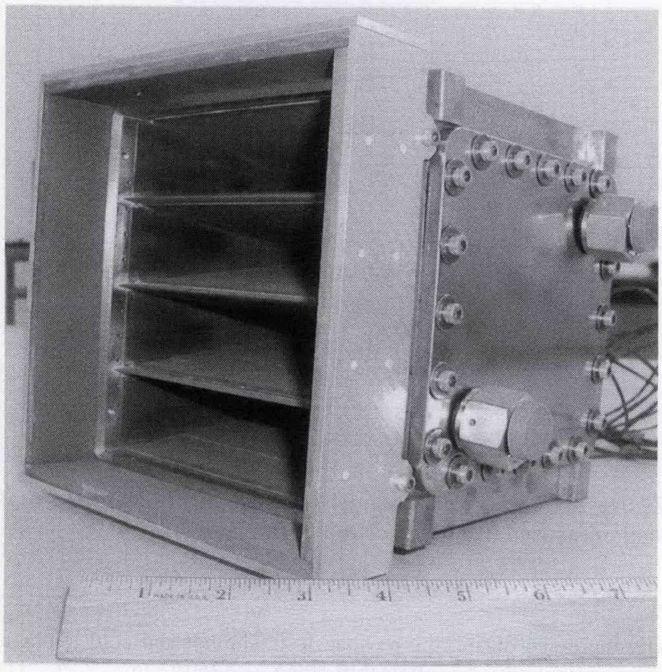


Figure 15. A photograph of the generic pickup horn.

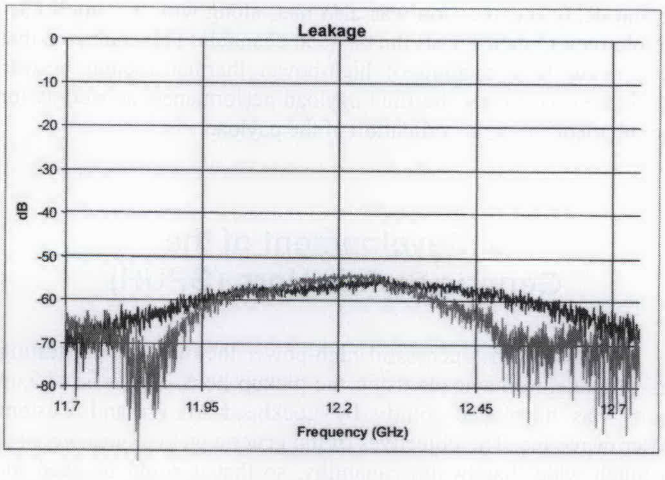


Figure 16b. The measured RF leakage of the generic pickup horn at two different worst-case locations.

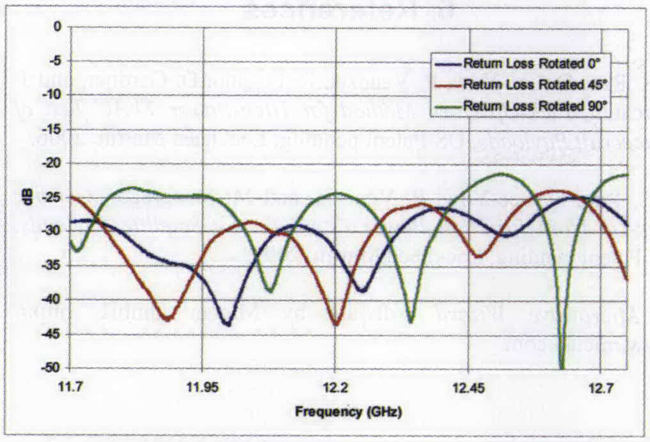


Figure 16a. The measured return loss of the generic pickup horn with the flight horn for different polarization orientations (phi = 0°, 45°, and 90°).

Figure 17. The thermal behavior of the generic pickup horn, monitored through thermocouples during a high-power thermal vacuum test.

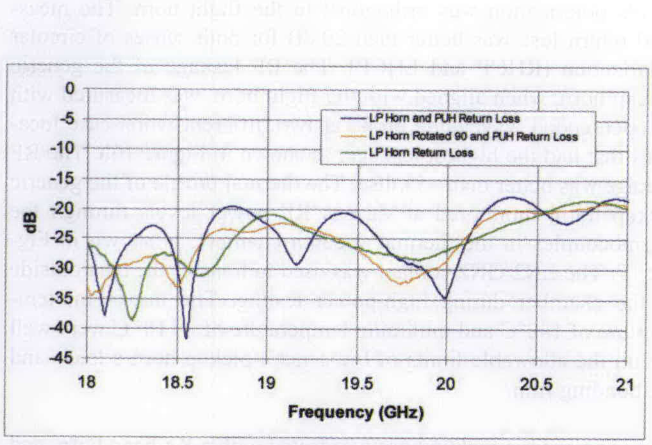


Figure 18. The measured return of the generic pickup horn at Ka-band frequencies for two polarization orientations (VP to VP and VP to HP).

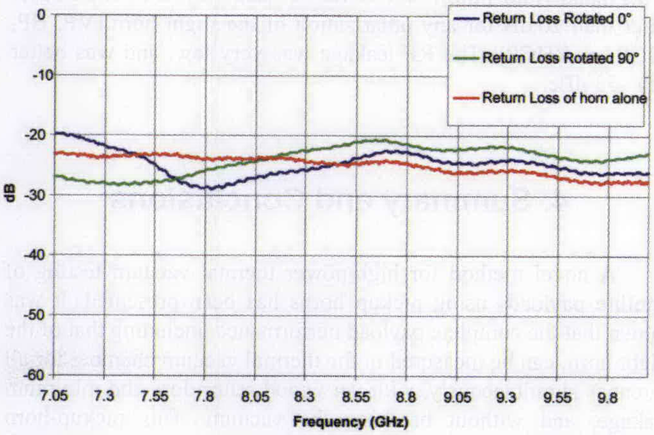


Figure 19. The measured return of the generic pickup horn at X-band frequencies for two polarization orientations (VP to VP and VP to HP).

horn's polarization was orthogonal to the flight horn. The measured return loss was better than 20 dB for both senses of circular polarization (RHCP and LHCP). The RF leakage of the generic pickup horn, when aligned with the flight horn, was measured with an open-ended waveguide probe at two different worst-case locations that had the highest leakage, as shown in Figure 16b. The RF leakage was better than –53 dBc. The thermal profile of the generic pickup horn, monitored at various RF power levels through the thermocouples in the thermal vacuum chamber, is shown in Figure 17. The LN2/GN2 coolant was used to transfer the heat outside of the chamber during high-power testing. The maximum temperature of 148°C and minimum temperature of –110° C were well within the allowable limits of the generic pickup horn's loads and the bonding film.

The generic pickup horn was tested with a Ka-band horn, and the return-loss response is shown in Figure 18. The return loss was better than 18 dB over the Ka-band transmitting frequencies. Figure 19 shows the measured return loss of the generic pickup horn with an X-band horn. The return loss was better than 20 dB over the 7.0 GHz to 10 GHz band. The generic pickup horn has been successfully used for high-power thermal vacuum testing of a Ku-band commercial satellite payload. The generic pickup horn was shown to have a very wide bandwidth, from 7.0 GHz to 21.0 GHz (a 3:1 bandwidth ratio), and could be used with a return loss of better than 20 dB for any polarization of the flight horn (VP, HP, LHCP, or RHCP). The RF leakage was very low, and was better than –53 dBc.

4. Summary and Conclusions

A novel method for high-power thermal vacuum testing of satellite payloads using pickup horns has been presented. It was shown that the complete payload performance, including that of the flight horn, can be measured in the thermal vacuum chamber for all antennas simultaneously, with very good return loss and minimum leakage, and without breaking the vacuum. This pickup-horn method reduces the high-power thermal vacuum testing time significantly, and is much cheaper than the other conventional methods. The generic pickup horn had a very large bandwidth, from 7.0 GHz to 21.0 GHz (a 3:1 bandwidth ratio). It can be used with feed horns illuminating a single reflector or with a dual-reflector antenna system, for high-power thermal vacuum testing of X-band, Ku-band, or Ka-band satellites. The generic pickup-horn design was insensitive to polarization, and can be used to test any linearly polarized or circularly polarized antenna system. The pickup-horn and generic pickup-horn methods have been successfully employed for payload testing of three recent satellites. They will be employed by Lockheed Martin for testing of all future payloads.

5. Acknowledgements

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6. References

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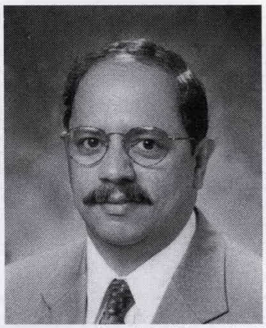
2. S. Rao, C. Lee-Yow, P. Venezia, and M. Macgregor, *Generic Pick-Up Horn for High Power TVAC Test of Satellite Payloads*, US Patent pending, Lockheed Martin, 2007.

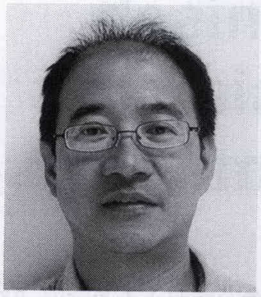
3. *Microwave Wizard* software by Mician GmbH, http://www.mician.com.

Introducing the Authors



Sudhakar K. Rao received MS and PhD degrees from the Indian Institute of Technology, in 1976 and 1980. He is currently working as Lockheed Martin's Corporate Senior Fellow in the payload engineering division at Lockheed Martin Commercial Space Systems, Newtown, PA. He has 33 years of experience in the design and development of communications payloads for both commercial and military satellites. Dr. Rao worked earlier at Boeing Satellite Systems, Hughes Aircraft Company, Spar Aerospace Limited, University of Manitoba, University of Trondheim, Electronics and Radar Development Establishment (Bangalore, India), and Electronic Corporation of India Limited (Hyderabad, India). He has 110 published technical papers and 30 US patent awards/filings. His work on modeling of satellite antenna patterns was adopted by the International Telecommunications Union in 1992 as an international standard.

Dr. Rao is an IEEE Fellow; a reviewer for IEEE and IEE journals; a member of the technical program committee for several IEEE, IEE, and European conferences; and has chaired various technical sessions in conferences and symposia. He received several awards in his career, which include LM Space Systems Company's Inventor of New Technology Awards in 2005 & 2007, LMCSS' Publication & Invention Awards in 2005 & 2006, Boeing's Technical Fellow award in 2001, Boeing's Special Invention Award in 2002, IEEE Benjamin Franklin Key award for innovations in 2006 from Region 2, and Lockheed Martin's Corporate Senior Fellow award in 2006. His biography is listed in Marquis *Who's Who in America*, *Who's Who in the World*, and Global Register's 2007 edition of *Who's Who in Executives & Professionals*.



Clency Lee-Yow was born in Port-Louis, Mauritius. He received the BSc and PhD degrees in Electrical & Electronic Engineering from Queen Mary College, University of London, in 1983 and 1987, respectively. From 1987 to 1988, he worked as a post-doctoral research assistant with the antenna group at Queen Mary College. From 1988 to 1994, he worked for Com Dev, Cambridge, Canada, where he designed and developed high-performance feeds for reflector antennas. From 1994 to 1995, he worked for Custom Microwave Inc. (CMI) as a project manager. He became Vice President of CMI in 1996, and took over as President in 1999, the position he currently holds. At CMI, he developed several high-performance, tuning-less, multi-functional, and multi-band feeds for reflector antennas from 1.0 GHz to 800 GHz. He has published several papers in technical conferences and journals, and has four US patents that are issued or pending.

Philip Venezia studied electrical engineering at the University of Colorado, Boulder, USA, from 1998 to 2002. He received the BS degree in Electrical Engineering (with honors) from the University of Colorado, Boulder, USA, in 2002.

He has been working with, Custom Microwave Inc., Longmont, CO, since 2004, where he is currently an RF design, development, and testing engineer. His current research interests include multi-frequency antenna feeds, and extremely-high-performance passive waveguide components in the 1.0 GHz to 800 GHz frequency range, for use in ground and space communications. He has published several papers in technical conferences and journals, and has three US patents that are pending.